ICI2026

12TH INTERNATIONAL CONFERENCE ON ISOTOPES

Florence, 15-19 February 2026

Book of Abstracts

UNIVERSITÀ DEGLI STUDI DI MILANO

INFN

WORLD COUNCIL ON ISOTOPES WCI

Book of Abstracts

12th International Conference on Isotopes (12ICI)
Florence, Italy | 15–19 February 2026

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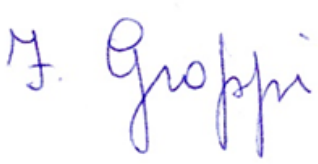
Message from the Conference Chair

Dear Colleague,
It is a great pleasure to welcome you as a fully registered delegate to the 12th International Conference on Isotopes (12ICI), which will be held in Florence, Italy, from February 15 to 19, 2026, in partnership with the University of Milano and the National Institute for Nuclear Physics (INFN).
The ICI conference series, established in 1995 and organized under the auspices of the World Council on Isotopes (WCI), aims to promote the beneficial uses of isotopes and highlight their vital role across a wide spectrum of disciplines, including nuclear science, medicine, environmental protection, and industry. Over the years, these conferences have fostered a unique interdisciplinary platform, bringing together isotope producers, researchers, and end-users from around the world.
Building on this tradition, 12ICI will offer a comprehensive program covering applications of isotopes in medicine, industry, agriculture, national security, nuclear chemistry, radiochemistry, nanoparticles, health physics, and more. The conference will provide an invaluable opportunity for networking, collaboration, and knowledge exchange among scientists, industry experts, and policy makers.
A special focus will be dedicated to young researchers and students, offering them a stage to present their work, engage with leading experts, and actively participate in shaping the future of isotope science. Awards for Best Oral Presentation and Best Poster in the young researchers' category will be granted at the closing session.
We are also pleased to announce that selected contributions will be published in a Special Issue of the Journal of Radioanalytical and Nuclear Chemistry (JRNC).
We look forward to welcoming you in Florence for what promises to be an exciting and fruitful scientific event.
Warm regards,

Prof. Flavia Groppi
Chair of the 12th International Conference on Isotopes



Message from the WCI President

Dear Colleagues and Friends,
It is with great excitement and anticipation that I welcome you to the 12th International Conference on Isotopes (12ICI), which will be held in the magnificent city of Florence, Italy, this coming February. This conference represents a remarkable opportunity to gather leading experts and scientists from around the world to share knowledge, foster collaborations, and explore the role of isotopes, radionuclides, and nuclear radiation in advancing science, medicine, and environmental protection.
I encourage all participants to not only engage in the stimulating discussions and groundbreaking ideas that this conference promises, but also to take the time to immerse themselves in the beauty and history of Florence. As one of the most iconic cities in the world, Florence offers a unique blend of cultural heritage, art, and architecture. From the renowned Uffizi Gallery to the awe-inspiring Duomo, Florence is sure to provide a rich and inspiring backdrop for both your professional and personal experiences.
We are deeply grateful to our gracious hosts in Italy, whose commitment and support have made this event possible. Italy's leadership in scientific research and its vibrant cultural heritage make it the perfect location for this important gathering.
As we look forward to this exciting event, I wish for a successful, fruitful, and inspiring conference. May it be an opportunity for scientific advancement, personal growth, and, of course, an unforgettable experience in the heart of one of Europe's most beautiful cities.
Thank you, and we look forward to welcoming you in Florence!
Warm regards,

Paul T. Dickman
President
World Council on Isotopes (WCI)

Welcome

12th International Conference on Isotopes (12ICI) brings together the international community working on the production and applications of isotopes across medicine, energy, environment, cultural heritage, industry and fundamental research. The conference continues the long-standing ICI series, established in 1995 under the auspices of the World Council on Isotopes (WCI), and provides a unique interdisciplinary forum for scientists, engineers, medical physicists, radiochemists, isotope producers and end users from all over the world.

The scientific programme includes plenary and keynote lectures, oral and poster sessions, panel discussions and special sessions dedicated to young researchers, women in isotope science, and education, public engagement and outreach. Particular emphasis is placed on applications of isotopes in nuclear medicine, radiopharmaceutical production, accelerator-based technologies, nuclear data, environmental studies, safeguards and metrology.

Dates: 15–19 February 2026
Venue: Grand Hotel Mediterraneo, Florence, Italy
Participants: Over 300 scientists from academia, research centres, international organizations and industry

Conference Chair: Prof. Flavia Groppi (University of Milan, INFN - MI)
Co-Chair: Dr. Gaia Pupillo (INFN - LNL)
Scientific Secretary: Dr. Michele Colucci (University of Milan, INFN - MI)

The conference is organized by the University of Milan in collaboration with the Istituto Nazionale di Fisica Nucleare (INFN) and the World Council on Isotopes (WCI), with the support and patronage of several national and international institutions.

Website: www.12ici.org

	Sunday, 15 February	Monday, 16 February				Tuesday, 17 February			
	Plenaria - Africa-Asia-Europa Room	Plenaria Africa Room	Plenaria Asia Room	Plenaria Europa Room	Pacifico Room	Plenaria Africa Room	Plenaria Asia Room	Plenaria Europa Room	Pacifico Room
08:00									
08:30		**Welcome Addresses**							
09:00						**Plenary Session**: "Advances in Isotopes Productions and Applications" - Tuesday			
09:30		**Institutional Keynote Speakers**							
10:00									
10:30		Group Photo				Coffee Break			
11:00		Coffee Break				Tue_S1_A **IPD**	Tue_S1_B **IPD**	Tue_S1_C **IAP**	Tue_S1_D **SQ**
11:30		**Plenary Session**: "Advances in Isotopes Productions and Applications" - Monday							
12:00									
12:30		Sponsor Session							
13:00		Lunch Break				Lunch Break			
13:30									
14:00									
14:30						Tue_S2_A **YS - IPD**	Mon_S2_B **IPD**	Tue_S2_C **IAP**	Tue_S2_D **SQ**
15:00		Mon_S2_A **IPD**	Mon_S2_B **IPD**	Mon_S2_C **YS - IAP**	Mon_S2_D **ENDEC**				
15:30									
16:00	**Conference Check-in**								
16:30		Coffee Break				Coffee Break			
17:00		Mon_S3_A **IPD**	Mon_S3_B **IPD**	Mon_S3_C **YS - IAP**	Mon_S3_D **ENDEC**	Tue_S3_A **YS - IPD**	Mon_S3_B **IPD**	Tue_S3_C **IAP**	Tue_S3_D **SQ**
17:30									
18:00	**Opening Ceremony**								
18:30									
19:00	**Welcome Cocktail**								
19:30									
20:00									

IPD - Isotopes Production and Devices
IAP - Isotope Applications
IE - Isotopes in the Environment
PEU - Policy, Economics and Global Impact of Isotopes Production and Use
ENDEC - Enegy and Decommissioning
SQ - Security, Safery and Quality Assurance
EDU - Education
YS - Young Scientists Session

	Wednesday, 18 February				Thursday, 19 february				Friday, 20 February
	Plenaria Africa Room	Plenaria Asia Room	Plenaria Europa	Pacifico Room	Plenaria Africa Room	Plenaria Asia Room	Plenaria Europa	Pacifico Room	
08:00	**Panel** - Policy, Economics, and Global Impact of Isotope Production and Use								EXTRA TOUR to INFN Legnaro National Laboratory - LNL in Legnaro (PD)
08:30									
09:00	**President Forum** - The Isotope Eco-System and Building Resiliency				Wed_S3_A **IPD**	Wed_S3_B **IPD**	Wed_S3_C **IAP**	Wed_S3_D **EDU**	
09:30									
10:00					Coffee Break				
10:30	Coffee Break				**Marie Curie Session**				
11:00	Wed_S1_A **IPD**	Wed_S1_B **IE**	Wed_S1_C **IAP**	Wed_S1_D **EDU**					
11:30									
12:00					**Closing Ceremony**				
12:30									
13:00	Lunch Break				Lunch Break				
13:30									
14:00									
14:30	Wed_S1_A **IPD**	Wed_S2_B **IE**	Wed_S2_C **IAP**	Wed_S2_D **YS - SQ/EDU**	Technical tour at the LABEC - Laboratory of Nuclear Techniques INFN				
15:00									
15:30									
16:00									
16:30	Coffee Break								
17:00	Wed_S3_A **IPD**	Wed_S3_B **IPD**	Wed_S3_C **PEU**	Wed_S3_D **YS - ENDEC/IE**					
17:30									
18:00									
18:30									
19:00	Bus transfer to Gala Dinner location								
19:30									
20:00	**Gala Dinner - "La Loggia"**								
21:00									
22:00									

IPD - Isotopes Production and Devices
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YS - Young Scientists Session

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Oral Abstracts

ISOTOPES AND ELEMENTS FOR PAST AND FUTURE

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Introduction

When approaching to the study of cultural heritage, typical questions to be addressed are related to "when, what and how". Without forgetting the fundamental expertise and action of historians, restorers and human scientists, applied nuclear physics can give us a valuable support in answering those questions. In such a framework, radiocarbon probably is the most well known tool to handle the question of when and sometimes, even though in an undirected way, that of how.

Description of the Work or Project

The measurement of the residual 14C concentration in organic materials and in some specific inorganic systems allow us to estimate the age of materials. In the past years, many efforts have been put in optimizing the attainable precision and accuracy of the method. However, many challenges are still present, e.g. which is the smallest mass that can be processed? How can we treat very complex materials to cope with any possible sources of contamination? If we can improve the experimental uncertainty in the measurement of the radiocarbon concentration, how can we combine this important improvement with the inevitable variations of the concentration of this isotope in atmosphere? On the other hand, the study of isotopes and elements applying ion beam techniques can help us to address the questions of what and how. Also in this case, even though these techniques are well established in their fundamental principles, new challenges are related for instance to the competition of easy and portable new systems, as, for example, the X-ray fluorescence (XRF) ones.

Conclusions

In this presentation, the aforementioned key points will be discussed with a particular attention to the experience of LABEC, the Laboratory of nuclear techniques for the Environment and the Cultural Heritage, of the National Institute of Nuclear Physics, jointly managed with the Department of Physics of the University of Florence.

NEW TRENDS IN PRODUCTION OF NOVEL MEDICAL RADIONUCLIDES

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Introduction

The production technology of reactor- and cyclotron-based radionuclides, routinely used in patient care, encompassing about 60 million cases worldwide per year, is generally well established. However, to meet demands of some new emerging medical applications, such as bimodal imaging, theranostic approach or radioimmunotherapy, novel radionuclides with versatile labelling chemistry are needed. In great demand are presently longer-lived non-standard positron emitters for diagnosis and low-energy highly-ionising β^-- and α-particle emitters for therapy.

Description of the Program

This talk gives an overview of new research trends in production of novel medically interesting radionuclides using the existing and some emerging technical facilities.

(i) *Research reactors*. Continuous radiochemical work, occasionally combined with mass separation, is in progress to produce several therapeutic radionuclides with high specific activity (e.g. ^{47}Sc, ^{153}Sm, ^{161}Tb, etc.).

(ii) *Small medical cyclotrons (E<20 MeV)*. Extensive new installations are taking place worldwide for production of standard radionuclides (e.g. ^{11}C and ^{18}F) for use in patient-care related positron emission tomography (PET). Furthermore, in view of increasing significance of non-standard positron emitters (e.g. ^{64}Cu, ^{68}Ga, ^{86}Y, ^{89}Zr), strong efforts are underway towards developing sophisticated solid, gaseous and solution targets at those machines for clinical scale production of those novel radionuclides.

(iii) *Medium*-sized cyclotrons. High-intensity α-particle beams are being developed, and work on targetry and radiochemical processing is in progress to produce large quantities of ^{211}At for α-therapy, and high-spin isomers ^{117m}Sn and ^{193m}Pt for Auger therapy.

(iv) *Intermediate energy cyclotrons/accelerators*. Use of (p,x) reactions is being intensified to produce several radionuclides (e.g. ^{47}Sc, ^{67}Cu, ^{73}Se, ^{134}Cs, ^{225}Ac, etc.); also (p,spall) process in combination with on-line mass separation is occasionally used (e.g. ^{152}Tb). Another approach is to generate p(Be) or d(Be) fast neutrons and use them to induce (n,2n) or (n,xp) reactions to produce therapeutic radionuclides (e.g. ^{225}Ac, ^{67}Cu, etc.)

(v) *LINACs*. High-intensity electron beams are being developed to generate
   a) high-flux low-energy neutrons to deliver an (n,γ) activation product (e.g. ^{99}Mo);
   b) high energy photons to induce (γ,n) reaction products, e.g. (^{99}Mo and ^{225}Ra→^{225}Ac), or (γ,p) reaction products (e.g. ^{47}Sc, ^{67}Cu).

Wherever possible, an overall appraisal of recent advances will be given.

Conclusions

Besides routine production of radionuclides for patient care, strong efforts are presently being harnessed in diverse directions to obtain important novel radionuclides in quantities and qualities needed for clinical applications. Some of the tasks involved are very challenging, but several new projected routes appear to be promising. On the other hand, it is a dynamic field and the research directions may vary with changing clinical demands.

Cross section measurements and production of ^{165}Tm via the ^{165}Ho(a,4n) reaction: generator of a pure Auger electron emitter, ^{165}Er.

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Introduction

For the treatment of micrometastatic or disseminated cancers, radiopharmaceuticals with high Linear Energy Transfert (LET) radiations, such as Auger Electron emitters (AEs), show potential in preclinical studies [Kassis, 2003]. Fundamental radiation biology studies on effects of AEs require a pure AE-emitting radionuclide, with minimal associated medium/high energy electron or photon emissions. To this end, ^{165}Er is a promising radionuclide. It emits 7 AEs per decay [ICRP 107] with only associated X-rays emission. There are several possible production routes among which one of the most promising routes is the indirect production through ^{165}Ho(α,4n)^{165}Tm reaction that allows to make a ^{165}Tm/^{165}Er generator ($T_{1/2}$ = 30.06 h/10.36 h). Moreover, the naturally monoisotopic target allows to limit co-productions by adapting beam energy. From that, it makes possible to reach better Molar Activity (MA) mandatory for dosimetry studies.

Description of the Work or Project

In a project including also aspects of chemical separations and radiolabeling tests, a focus on productions with the ^{165}Ho(α,x) reactions using a 68 MeV alpha beam from the GIP ARRONAX C70 XP cyclotron will be presented. Firstly, cross-sections measurements were performed using the stacked foil technique to consolidate the shape of the excitation function, which could show some discrepancies between existing values. Beam intensity has been obtained using an instrumented Faraday cup. Absolute cross-sections were also measured for the monitor reactions ^{nat}Al(α,x)^{22}Na,^{24}Na. These values acquired between 38 and 67 MeV allow us to establish theoretical estimations of MA values under thick-target irradiation conditions. In a second phase, thick target (50 µm) production were carried out.

Conclusions

The cross-section measurements performed for the ^{165}Ho(a,xn) reactions are in agreement with recent cross-section data. The maximum production cross-section of ^{165}Tm is around 1200 mb at 50 MeV. Thick target (50 µm) productions were carried out at an incident energy of 58 MeV, limiting the production of ^{166}Tm and enhancing the ^{166}Er/^{165}Er ratio. The ^{165}Tm activities produced for 14 µA.h are 93 MBq. A theoretical calculation based on these measured cross-section values gives a production of 125 MBq. This difference of 25% can be explained by the overestimation of the current measurement of our high-intensity irradiation device and by the losses of the recoil nuclei. Without considering the efficiency of chemical separation, the radiological purity of ^{165}Er would be 100%. After a chemical separation to isolate the thulium completed End Of Beam (EOB) plus 2h and an 8h ^{165}Tm/^{165}Er generator cycle, the calculated MA is minimum for the 1st elution (EOB+10h) with 1.9 10^3 MBq/nmol for 50 MeV and 2.4 10^3 MBq/nmol for 56 MeV.

[Kassis, 2003] "Cancer therapy with Auger Electrons: Are We Almost There?" J. of Nuclear Medicine 2003;44(9):1479-1481.

TOWARDS OPTIMIZED ^{133}La AND ^{135}La PRODUCTION THROUGH CROSS-SECTION MEASUREMENTS FROM BARIUM TARGETS

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Introduction

Theranostics in nuclear medicine involves the use of radionuclides for both diagnostic and therapeutic applications by labeling molecular targeting vectors. These radionuclides, known as theranostics pairs, ideally have similar chemical properties and often belong to the same element. A promising pair is ^{133}La/^{135}La[1]. The β^+-emitter ^{133}La [$t_{1/2}$ = 3.9 h] is suitable for PET imaging, whereas ^{135}La [$t_{1/2}$ = 18.95 h] shows potential for Auger Electron Therapy (AET). Their production can be achieved through the nuclear reactions ^{134}Ba(p,2n)^{133}La and ^{135}Ba(p,n)^{135}La by low-energy proton irradiation of barium targets. A precise knowledge of the nuclear reaction cross sections leading to lanthanum radioisotopes is therefore essential to optimize irradiation parameters and maximize radionuclidic purity and production yield.

Materials and Methods

At the Bern medical cyclotron (IBA Cyclone HC 18/18, 18 MeV, max 150 μA)[2], several cross sections for theranostic radionuclides have been measured[3]. For lanthanum isotope production, we irradiated natural Ba, enriched ^{134}Ba, and enriched ^{135}Ba targets. This approach allowed us to disentangle the contributions of different nuclear reactions. The resulting experimental data were used to evaluate the selected production routes and to define optimal irradiation parameters. Production strategies were analyzed for two facilities: (i) a medical cyclotron such as the Bern unit and (ii) the future CHeFS accelerator complex, proposed by the Tera-Care Foundation[4], consisting of a 15 MeV high-current linac (CHeF-1, up to 10 mA extracted proton current) and a synchrotron (CHeF-2) designed for hadron therapy. This comparison is particularly relevant for ^{133}La, where the higher energy of the cyclotron is weighed against the significantly larger beam current of the linac. In the cyclotron case, solid target irradiation tests have also been performed to validate the production feasibility.

Conclusions

Preliminary cross-section results for ^{133}La and ^{135}La production from barium targets have been obtained, and some of the investigated reactions have been measured for the first time. These data enabled the determination of optimal irradiation parameters for both cyclotron- and linac-based facilities. First production tests at the Bern medical cyclotron confirmed the potential of solid target irradiation for ^{133}La and ^{135}La, while the high currents foreseen at CHeFS could provide unprecedented production yields. This study contributes to the ongoing development of reliable production routes for lanthanum isotopes and supports the broader effort toward establishing an efficient supply chain of theranostic radionuclides.

References

[1] Nelson et al, 2020. *Scientific Reports 10*, 22203. doi:10.1038/s41598-020-79198-x
[2] Braccini, 2013. *AIP Conf Proc 1525*, 144-150. doi:10.1063/1.4802308
[3] Dellepiane et al, 2023. *J Phys: Conf Ser 2586*. doi:10.1088/1742-6596/2586/1/012116
[4] Tera-Care Foundation, Geneva, Switzerland: https://tera-care.ch/

PRODUCTION OF TECHNETIUM RADIOISOTOPE BY ALPHA-PARTICLE BEAM IRRADIATION OF 93 NIOBIUM UP TO 50 MEV

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Introduction

The long-lived technetium isotopes ^{96g}Tc ($T_{1/2}$ = 4.3 d) and ^{95g}Tc ($T_{1/2}$ = 20.0 h) have been suggested as possible substitutes for the commonly applied short-lived medical radionuclide ^{99m}Tc ($T_{1/2}$ = 6.0 h) [1], which functions as a γ-ray source in single-photon emission computed tomography (SPECT) diagnostics. Radionuclides of technetium with mass numbers A ≤ 97 can be obtained through α-induced nuclear reactions on the target of the monoisotopic element niobium (^{93}Nb 100%). Nevertheless, published experimental cross sections results for the ^{93}Nb(α,x) channels remain inconsistent, highlighting the need for further reliable measurements. In this study, natural niobium foils were irradiated with a 50-MeV alpha-particle beam to determine the production cross sections of Tc radioisotopes and other by-products, including Mo, Nb, Zr and Y.

Description of the Work or Project

We performed an experiment to measure the cross sections of the ^{93}Nb(α,x) nuclear reactions using the AVF cyclotron at the RIKEN Radioactive Isotope Beam Factory. The stacked-foil activation technique combined with off-line high-resolution gamma-ray spectrometry was employed for the measurements. The stacked-foil target consisted of ^{93}Nb foils as the main target and ^{nat}Ti foils for monitor reactions. The incident alpha-beam energy was determined by the time-of-flight method, while its average intensity was quantified from the collected charge using a Faraday-cup-like target holder.

Conclusions

We determined the production cross sections of ^{96g,95m,95g,94g,93m,93g}Tc, ^{93m}Mo, ^{95m,95g,92m,91m,90}Nb, ^{89g}Zr and ^{88,87g}Y from ^{93}Nb(α,x) nuclear reactions up to 50 MeV. Based on these measured cross sections, the corresponding thick-target yields of some of the listed radionuclides were evaluated. The obtained cross section data are expected to contribute to the production of technetium radioisotopes and to the refinement of nuclear reaction models.

References

1. Hayakawa, T., Y. Hatsukawa, and T. Tanimori, ^{95g}Tc and ^{96g}Tc as alternatives to medical radioisotope ^{99m}Tc. *Heliyon*, 2018. ***4(1)***:p. e00497. https://doi.org/10.1016/j.heliyon.2017.e00497

INVESTIGATE QUANTITATIVE BREMSSTRAHLUNG IMAGING BY 166HO

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Introduction

Bremsstrahlung imaging (BSI) has gained increasing attention driven by the use of β^- emitters in radiometabolic therapy. In this context, quantitative measurement of the spatial–temporal biodistribution of the radioisotope can account for patient-specific variability in pharmaceutical metabolism and uptake, enabling more accurate and personalized treatment. However, the continuous energy spectrum of bremsstrahlung photons and the low production yield of bremsstrahlung ɣ from β^- emitters pose significant challenges to the quantitative implementation of BSI in clinical practice. The present work extends our previous investigation of critical aspects of BSI on almost pure ^{90}Y β^- emitter [1], to the hybrid ^{166}Ho.

Description of the Work

The monochromatic ɣ from the ^{166}Ho represent a reference signal for the more tricky-to-quantify BS radiation. Hybrid ɣ-β radio-emitters represent a valuable option for development, calibration and characterization of BSI devices, especially when supported by adequate simulations. The proposed study makes use of a portable, custom, and highly configurable detector system developed for small-animal imaging with ɣ-emitting radionuclides [2]. The experimental setup includes small PMMA phantom disks with cylindrical inserts containing ^{166}Ho of known activity diluted in distilled water, as well as radiator plates made of different materials (Pb, PMMA, and Cd) and thicknesses, interposed between the phantoms and the detector entrance window.

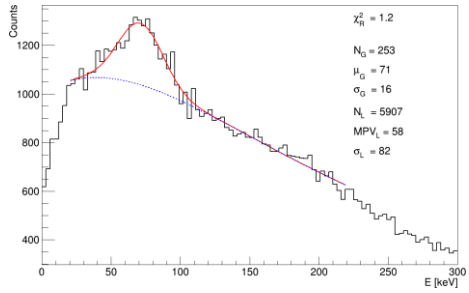

Figure: measured ɣ energy spectrum; three energy regions are considered: low <50 keV dominated by radiated ɣ's, mid 60-90 keV with about 20% of monochromatic ɣ, high >100 keV with continuum radiated ɣ's only. The dotted blue Landau function fits the continuum, while the red Gaussian curve on top of the Landau fits the monochromatic peak of the ^{166}Ho

Conclusions

Different configurations of phantoms and radiators plates were investigated and compared with Montecarlo simulations. Combinations of energy windows were applied during image reconstruction to reduce dependence on detector-specific characteristics and improve image quality. Results will be reported at the conference.

References

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[2] F. Garibaldi et al. (2020) "Development of a high-resolution and high-efficiency single-photon detector for studying cardiovascular diseases in mice", Eur. Phys. J. Plus 135:141 https://doi.org/10.1140/epjp/s13360-020-00102-7

EXCITATION FUNCTION MEASUREMENTS FOR RADIOISOTOPE PRODUCTION AT RIKEN

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Introduction

Radioisotopes are used in nuclear medicine for both diagnostic and therapeutic purposes. Charged-particle-induced reactions are commonly employed to produce these radioisotopes. Since each radioisotope can be generated through various combinations of projectiles and targets, accurate cross-section data are essential for identifying the most suitable reactions with minimal byproducts and high cost-effectiveness. Therefore, we systematically conduct excitation function measurements at RIKEN, Japan. We present a brief overview of our research activities.

Description of the Work or Project

Excitation function measurements are carried out using the AVF cyclotron at RIKEN, Japan. Well-established experimental methods are employed, including the stacked-foil activation technique and high-resolution γ-ray spectrometry. The primary projectiles used are protons, deuterons, and α-particles, with a recent extension to ^{7}Li.

In most cases, targets consist of pure metal foils. The foils are cut into sizes of 10 × 10 mm or 8 × 8 mm to fit target holders, which also serve as Faraday cups. The main target and monitor foils are arranged in the holders as stacked targets.

The stacked targets are irradiated with charged particles accelerated by the AVF cyclotron. The beam energies are 30 MeV for protons, 24 MeV for deuterons, 29 and 50 MeV for α-particles, and 70 MeV for ^{7}Li. Beam energies are determined using the time-of-flight method. Total beam charges are measured with the Faraday cups, and average beam intensities are calculated from the total charge and irradiation time.

After the end of bombardment, the irradiated foils are separated. γ rays emitted from the foils are measured without chemical separation using high-purity germanium detectors. The detector efficiency is calibrated using two types of point sources: a multiple γ-ray source (^{57,60}Co, ^{85}Sr, ^{88}Y, ^{109}Cd, ^{113}Sn, ^{137}Cs, ^{139}Ce, ^{203}Hg, and ^{241}Am) and a single ^{152}Eu source.

In 2025, we conducted 15 experiments through international collaborations with researchers in ATOMKI, Hungary and National University of Mongolia, Mongolia. These included deuteron-induced reactions on Sr; α-particle-induced reactions on Mg, Fe, Nb, Rh, Ce, Ho, and Au; and ^{7}Li-induced reactions on Al, V, Fe, Zr, and Ag.

Conclusions

We conduct excitation function measurements to investigate nuclear reactions for medical radioisotope productions. The measured data are analyzed, and the results are published in peer-reviewed scientific journals. These results are expected to advance applications in nuclear medicine.

RADIOISOTOPE RESEARCH AT THE BIRMINGHAM ACCELERATOR FACILITIES

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The University of Birmingham has operated several cyclotrons since the 1940s and the current machine, a Scanditronix MC40, is the workhorse of a vibrant and diverse research programme. In December 2023, a new High Flux Accelerator-Driven Neutron Facility (HF-ADNeF) was commissioned, capable of producing 1e13 neutrons/s [1].

The Cyclotron Facility has long been exploited for research into radioisotopes for a large variety of applications — as well as producing imaging isotopes daily for the National Health Service — but over the last two years this research has ramped up with studies focused on novel medical radionuclides such as iodine-124, astatine-211, actinium-225 and many more. With the addition of high-flux neutron beams, previously out-of-reach neutron-rich isotopes can also be produced.

An overview of radioisotope work at Birmingham will be given.

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RADIONUCLIDE PRODUCTION AT THE UNIVERSITY OF WISCONSIN – MADISON

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Introduction

The University of Wisconsin – Madison Cyclotron Research Group has been pursuing radioactive isotope science for over four decades, first using a CTI RDS 112 prototype cyclotron installed in 1984 and, since 2008, using a GE PETtrace cyclotron. In addition to its own portfolio of extramurally funded basic science, the group provides radioactive material synthons, syntheses, and services to a disseminated user base within its home institution and to an international network of colleagues and collaborators. A selection of experiences from this history will be described, emphasizing scaled radionuclide production to support clinical trials and translational efforts in the context of the last decade's explosive growth in theranostic nuclear medicine.

Description of the Work or Project

The Group has a longitudinal interest in the development of a range of radiometal and non-standard positron-emitting radionuclides for human applications and basic science, with a special focus on novel accelerator targetry, especially with solid materials.[1,2] Its success with the production of clinically-needed radionuclides like ^{64}Cu, ^{89}Zr, and more recently ^{86}Y has enabled translational research in academic and commercial settings alike, supporting basic research efforts that in turn generate novel scientific output (^{51}Mn, ^{45}Ti, ^{103}Pd), funding and translational opportunity, and create a setting that is ideal for the education of trainees in accelerator targetry, radiochemistry, radiobiology, and nuclear medicine.

Conclusions

The Cyclotron Group's experiences in academic radionuclide production offer a model for collaboration and broad engagement with nuclear medicine that is of potential interest to other institutions. This is especially true as translation of basic science and workforce development move to the forefront of the field's priorities.

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ADVANCES IN RADIOISOTOPE PRODUCTION CAPABILITIES AT OAK RIDGE NATIONAL LABORATORY

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Introduction

Radioisotopes are routinely produced in nuclear reactors and particle accelerators around the world. Oak Ridge National Laboratory (ORNL) is home to the High Flux Isotope Reactor (HFIR) which routinely operates with a steady state thermal neutron flux greater than $2x10^{15}$ n/cm^2-s. This, combined with the adjacent heavy duty shielded hot cells of the Radiochemical Engineering Development Center (REDC), presents a unique environment for production of actinides such as ^{252}Cf and ^{238}Pu, as well as direct produced high specific activity radioisotopes such as ^{75}Se, ^{63}Ni, and ^{188}W. ORNL is the primary supplier in the western world of many radioisotopes that are critical to energy supply, medicine, manufacturing, and national security. As demand increases and as facilities age, ORNL is pursuing continuous improvement of existing radioisotopes and innovation in the development of new supplies.

Development of New Radioisotopes

ORNL has developed, or is in the process of developing, new supplies for several radioisotopes, including ^{170}Tm, ^{14}C, ^{192}Ir, ^{85}Kr, ^{147}Pm, and ^{228}Th. While some of these isotopes have previously been produced by ORNL and others, the methods of production may no longer be achievable due to excessive waste generation, lack of feed materials, or other technical and logistical challenges. This talk will provide an overview of ORNL's approach for introducing these radioisotopes to the supply chain.

Addressing the Growing Demand for Radioisotopes

Over the past several years the mission of ORNL's radioisotope programs has grown dramatically, with an increased focus on robust and sustainable processes to maximize the overall throughput of their unique world class facilities – HFIR and REDC. This talk will explore how ORNL is innovating in the reactor production of radioisotopes – both in the design and analysis of irradiation targets – as well as pursuing modern technologies in radioisotope processing – such as automation and online analysis. We will discuss challenges with waste generation and disposition, as well as the impacts of the growing demand for radioisotopes on existing facilities. Finally, we will address the challenges of knowledge management and staff development in a rapidly expanding industry in need of exceptional talent.

Conclusions

ORNL is focused on supplying critical radioisotopes to the world, many of which cannot be supplied at the required quality and quantity by existing producers. The combination of rapid growth in demand, aging facilities, and a newer workforce results in complex challenges associated with the maturation and scale-up of radioisotope production. ORNL is committed to meeting the needs of the internation community and is investing in process improvement and innovation to meet these challenges.

INNOVATIVE ^{68}GA AND ^{89}ZR PRODUCTION UTILIZING ALCEO AND SYNTHERA PLATFORMS: A NEW COMMERCIAL SOLUTION FOR RADIOPHARMACEUTICAL PRODUCTION

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Introduction:

The demand for positron emission tomography (PET) isotopes like gallium-68 (^{68}Ga) and zirconium-89 (^{89}Zr) has significantly increased due to their crucial role in diagnostic imaging and targeted radiopharmaceutical therapies. ^{68}Ga is widely used for PET imaging of neuroendocrine and prostate tumors, while ^{89}Zr is ideal for immunoPET applications due to its longer half-life, making it suitable for antibody-based imaging. Recent technological advancements have enabled more efficient and reliable isotope production systems, with a focus on automation and integrated solutions. This study presents the combined use of the Alceo (Comecer) and Synthera (IBA) systems for streamlined, high-purity production of ^{68}Ga and ^{89}Zr, aiming to improve yield, reduce manual intervention, and enhance reproducibility in radiopharmaceutical manufacturing.

Description of the Work or Project

The automated irradiation and dissolution/purification of ^{68}Ga and ^{89}Zr was performed using the fully automated ALCEO 4.0 (Comecer) integrated with two Synthera extension modules (IBA). The Alceo system was utilized for both target shuttle transferring and dissolution processes, while each of the two Synthera modules have been used for the chemical dissolution and the purification process. For the ^{68}Ga production, 100mg of ^{68}Zn were electroplated onto a platinum substrate (shuttle) and irradiated for 3h, 60uA at 12.1MeV. The shuttle has an integrated aluminum degrader cap which can degrade cyclotron energy according to the cross section of the desired nuclear reaction. After irradiation, the shuttle has been dissolved and purified with the Synthera modules, Tk200 and ZR resin (Triskem) have been used and integrated and the kits. For the ^{89}Zr production, a commercial ^{89}Y metal foil 99,9%, 15,5mm diameter, 0,25 mm thickness has been placed into the shuttle and irradiated for 3h, 25uA at 12.1MeV. Dissolution and purification processes have been performed with the IBA modules, ZR resin (Triskem) have been used and integrated and the kits. Both purified products (^{68}Ga and ^{89}Zr) have been tested for QC controls: half-life, gamma spectra and ICPMS has been performed to monitor the quality of [^{68}Ga]$GaCl_3$ and [^{89}Zr]Zr-oxalate.

Results

The production yields for both ^{68}Ga and ^{89}Zr were respectively: 31,04 ± 4,23 mCi/μA and 0,52 ± 0,12 mCi/μAh. The quality controls shown a high radiochemical and radionuclidic purity.

Conclusion

The novel integration of the Alceo (Comecer) and Synthera (IBA) systems represents a significant advancement in the field of PET isotope production. By combining automated target processing, dissolution, and purification in a single workflow, the system enhances efficiency and reproducibility while maintaining high purity and yield. The advantages of the Synthera modules are the small size, and for this reason up to 6 synthera modules can be installed inside an hot cell; this allows the back to back productions of 3 runs in the same day (for the first time in the market), reducing labor intensity but also minimizes radiation exposure for operators, aligning with modern radiopharmacy safety standards. Further studies will explore optimization for other isotopes and the potential for scaling production in larger facilities.

ONLINE MONITORING FOR COLUMN SEPARATION OF ^{177}LU FROM ENRICHED ^{176}YB IRRADIATED TARGET

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Introduction

Extraction chromatography is a widely used technique for chemical separation of Ytterbium (Yb) and medically relevant Lutetium-177 (^{177}Lu); however, chemical similarity between Lu and Yb requires a larger column size and more eluent for gram-scale Yb target separation. Therefore, it is essential to fully understand the process of separating Yb and Lu in the column and to extract only the required 177Lu fraction to improve the efficiency of the chemical separation operation. A CZT detector is small and can be powered by USB, making it suitable for online remote measurements. In this study, we tracked the behavior of ^{176}Yb and ^{177}Lu through online measurements using a CZT detector to evaluate whether appropriate column separation operations are possible.

Experimental

A CZT detector (RadAngel, Kromek) was used for measurements, and a Ge detector (ORTEC) confirmed the elution profile. Enriched $^{176}Yb_2O_3$ (99.14%, Isoflex, 1.0 mg) was irradiated for 6 h at 5 MW in the Kyoto University Reactor (KURR). The irradiated sample was dissolved in 4 M HNO_3 and loaded into an LN2-Resin column (11 mm × 240 mm) for separation of Yb and ^{177}Lu using 1.5 M HNO_3. The eluted solution was monitored online with the CZT detector, and fractions of 250 drops were analyzed by γ-ray spectroscopy with a Ge detector to compare with the elution curve.

Results and discussion

A Ge detector measurement confirmed only the production of high radioactivity ^{177}Lu, and low radioactivity ^{175}Yb in the irradiated sample after 5 days irradiation. The elution curves of ^{175}Yb and ^{177}Lu obtained with the CZT and Ge detectors showed the same trend (Figure 1). In addition, online measurements using a CZT detector confirmed that the column length used in the experiment was sufficient to separate ^{175}Yb and ^{177}Lu.

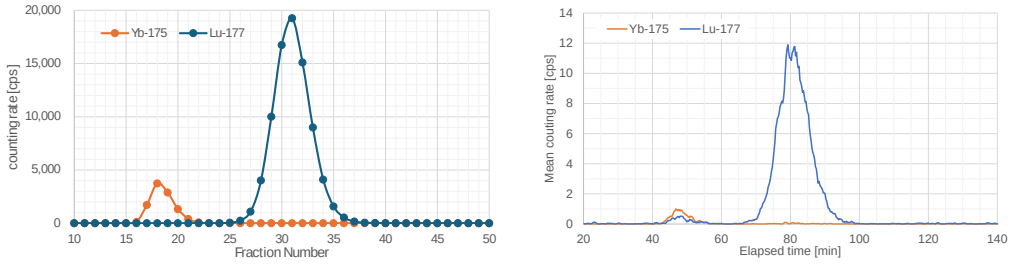

Figure 1. Elution profile of extraction chromatography with an 11 mmφ × 240 mmL column packed with LN2 resin measured with a Ge detector (Left) and a CZT detector (Right)

Conclusions

This study used a CZT detector for online γ monitoring during column separation of enriched ^{176}Yb and ^{177}Lu. The enriched isotope enabled clear distinction between high-activity low-energy γ-rays of ^{177}Lu and low-activity high-energy γ-rays of ^{175}Yb. This approach supports precise ^{177}Lu fraction recovery and reduces worker exposure during high-activity separations in hot cells.

MOLECULAR PLATING TECHNIQUE TO PREPARE THIN TARGETS FOR PRODUCTION CROSS SECTION MEASUREMENT OF THE ^{NAT}GD(P,X)^{155}TB REACTION

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Introduction and Description of the Project

Research on radionuclide production for nuclear medicine is crucial to advance diagnostic and therapeutic applications. This study investigates the production of Terbium (Tb) radionuclides through proton-induced reactions on natural Gadolinium (^{nat}Gd) targets. Targets were prepared via the molecular plating (MP) technique. Excitation functions for ^{155}Tb and co-produced radionuclides were measured, with emphasis on ^{155}Tb ($T_{1/2}$ = 5.32 d) due to its favorable decay properties for SPECT imaging [1].

The MP process is a simple and reproducible electrodeposition method in non-aqueous solutions under high voltages (100–800 V), allowing the fabrication of homogeneous layers [2,3]. Experimental parameters were optimized using Ti substrates as cathode, Pt as anode, and Gd^{3+} ions (0.05 mg·mL^{-1}) in isopropyl alcohol. The electrolyte solution was homogenized with a mechanical stirrer (250 rpm) at room temperature.

Irradiations were carried out at the GIP ARRONAX cyclotron facility [4] using the stacked-foil technique. Two irradiation campaigns (40–47 min, 125–150 nA) were performed with stacks containing ^{nat}Cu and ^{nat}Ti foils as flux monitors. Gd was deposited on the Ti foil and Al foils have been used as degraders, to protect the deposition and as a catcher.

Results and conclusion

The manufactured targets were homogeneous and Gd well-adhered to Ti substrates. After 200 min of plating, an average of 1.41 ± 0.04 mg of Gd was deposited over 0.31 ± 0.06 cm². Cross section measurements showed good agreement with the literature and simulation data [5–7], while also providing new experimental values for ^{155}Tb and co-produced radionuclides. These results confirm the feasibility of molecular plating as a reliable target preparation method for cross section measurements and radiopharmaceutical production, paving the way for future studies with enriched Gd targets and extending the application to other lanthanides.

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MANGANESE-52: FROM CYCLOTRON PRODUCTION TO ELECTROCHEMICAL PURIFICATION AND PET/MR NANOPROBE FORMULATION

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Introduction

The advent of positron emission tomography (PET) imaging has revolutionized the concept of molecular imaging for personalized cancer management. Presently, there is a thrust towards production of new radiometals for the formulation of 'next-generation' PET radiopharmaceuticals. Manganese-52 (^{52}Mn, $T_{½}$ = 5.59 d, β^+ = 29.4%, E_{avg} = 0.24 MeV) is a promising cyclotron-produced radiometal for developing novel radiopharmaceuticals. Particularly, its long half-life enables labeling of monoclonal antibodies and nanoparticles (NPs) for PET imaging, while its low positron energy ensures high spatial resolution. The paramagnetic Mn(II) state allows combined PET/MR imaging, integrating functional and anatomical data for precision oncology. Herein, we have developed an electrochemical method for the separation of cyclotron produced ^{52}Mn from the target material and synthesized intrinsically ^{52}Mn labeled manganese sulfide NPs for dual modality PET/MR imaging.

Description of Work

Manganese-52 was produced via ^{52}Cr (p, n) ^{52}Mn reaction by irradiating potassium dichromate in the BARC-TIFR pelletron facility using 16 MeV proton beam (current = 110 nA). In order to separate no-carrier-added (NCA) ^{52}Mn from the bulk irradiated $K_2Cr_2O_7$ a protocol was optimized by electrodeposition of ^{52}Mn on Pt electrode. A commercial Pt electrode was employed as the working electrode. An Ag/AgCl/KCl (saturated) electrode ($E_{Ag/AgCl}$ = + 0.197 V vs. the standard hydrogen electrode) served as the reference electrode, while a platinum wire was used as the counter electrode. The separated ^{52}Mn was used for the synthesis of intrinsically radiolabeled human serum albumin (HSA) encapsulated [^{52}Mn]MnS@HSA NPs by adding ^{52}Mn in manganese chloride and sodium sulfide solution in presence of HSA. In vitro PET and MR images of the radiolabeled NPs were taken by varying the concentration of the NPs.

Results

The average production yield of ^{52}Mn at the end of bombardment (EOB) was 6.1 ± 1.3 MBq μA^{-1} h^{-1} (n = 3). Additionally, upon assessing the initial cyclic voltametric parameters, ^{52}Mn deposition took place using constant potential amperometry, applying a potential of -1.3 V vs. Ag/AgCl reference electrode to a platinum mesh working electrode. The average separation yield of NCA ^{52}Mn was ~81 % and was reproducible in all batches. The γ-spectra of the separated samples displayed only the photo peaks of $^{52/54}$Mn and ICP-AES analysis of the decayed sample confirmed Cr impurity was <0.1 ppm. The extraneous ^{54}Mn peaks can be avoided in future studies by using enriched ^{52}Cr target for irradiation. Nevertheless, [^{52}Mn]MnS@HSA NPs synthesized using electrochemically separated ^{52}Mn showed promising results in PET/MR imaging in in vitro settings.

Conclusions

The present strategy simplifies ^{52}Mn production in terms of separation and would increase affordable access to this radioisotope for PET/MR imaging.

Keywords: ^{52}Mn production, electrochemical separation, PET/MR imaging, MnS nanoparticle

COBALT-60 GAMMA IRRADIATION FOR CULTURAL HERITAGE PRESERVATION: CASE STUDIES ON ARCHIVAL PAPER AND PARCHMENT

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Introduction

The preservation of Cultural Heritage (CH) artifacts, particularly those composed of organic materials such as paper and parchment, presents significant challenges. These materials are highly susceptible to chemical degradation and biodeterioration, requiring innovative conservation methods. Gamma radiation offers a promising solution due to its deep penetration, allowing for the treatment of large, delicate artifacts without the need for removing packaging, ensuring a homogeneous and residue-free process [1]. Despite these advantages, the use of this technology in CH conservation remains limited, in some countries like Italy, due to concerns about potential aesthetic, structural, or physico-chemical changes to the treated materials**.**

Description of the Work

This work explores the potential of gamma irradiation, applied under controlled conditions in accordance with IAEA guidelines [2], as an effective and non-invasive treatment for eliminating biological contaminants while preserving the structural and chemical integrity of CH objects. The study focuses on two case studies: (i) original archival paper and parchment documents from the Archive of the Montecassino Abbey (Italy) and (ii) historically significant paper supports from the National and University Library in Zagreb (Croatia). Irradiation experiments were conducted at the Calliope facility (ENEA, Italy) [3], which houses a Cobalt-60 radioisotope source. The facility is equipped with a specialized characterization laboratory where multi-analytical and non-destructive measurements [4], including Raman and FTIR/ATR spectroscopies and colorimetric analysis, were carried out. These analyses, combined with microbiological testing, were employed to assess the biocidal effectiveness of the treatment and examine potential alterations in the materials.

Conclusions

This approach demonstrates significant promise, as the results indicate that Cobalt-60 gamma irradiation at absorbed doses between 8 and 12 kGy is highly effective in achieving near-total microbial decontamination without compromising the molecular integrity and chromatic properties of the materials. The results suggest that gamma irradiation offers a more efficient, scalable, and safe alternative to traditional conservation methods. It is crucial to disseminate these findings to encourage broader adoption of this technique in CH conservation practices worldwide.

Keywords: Cobalt-60, Gamma Irradiation, Cultural Heritage Preservation, Paper, Parchment, Non-invasive Treatment

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MANUFACTURING AND RECYCLING OF ZNO TARGETS FOR ^{67}CU PRODUCTION

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Introduction

Copper-67 (^{67}Cu) is one of the most promising theranostic radionuclides having both diagnostic (gamma) and therapeutic (β^-) emission. In addition, ^{67}Cu can be paired with the positron-emitters copper-64 and copper-61 to perform PET imaging prior to therapy. In the context of cyclotron-based production of Cu-radioisotopes, zinc is one of the materials used as a target. The CUPRUM-TTD ($^{67/64}$CU PRoduction and Use in Medicine – Target Technology) project at INFN-LNL aims to develop the entire technological cycle for the production of ^{67}Cu, starting from the proton irradiation of ^{70}ZnO material in a medical cyclotron.

Description of the Work or Project

The use of the Spark Plasma Sintering (SPS) technique allows the manufacturing of solid coin-shaped targets using ZnO powder with different microstructures (micro and nano-sized).
The developed target configuration consists of a Nb backing with an Au foil, onto which a ZnO pellet can be attached using additional Au foil. Other strategies, such as utilisation of Au or Ag bulk backing, can also be adopted using SPS. It has been demonstrated that the targets withstand irradiation up to 50 μA, with a beam energy of 18.5 MeV, corresponding to a thermal power density of 1.2 kW/cm^2. Data collection from more than fifty SPS sintering experiments indicates that the relative density of ZnO pellets (Ø 10 mm, 600 μm thick) is more than 95 %. Additionally, a recovery process that is suitable for returning the material to its original powder form was proposed. The zinc precipitation process with sodium hydroxide achieved a recovery yield of approximately 85 %. The recovered powder was successfully utilised to manufacture new pellets and targets (ZnO-Au/Au-Nb) with the same SPS parameters. The recovered targets withstand thermomechanical test with irradiation[1].

Conclusions

This work describes the whole technological cycle of ZnO thick target manufacturing employing the SPS technique. It was demonstrated that sintering can be successfully performed with original and recovered powders, thus ensuring the sustainability of the ^{67}Cu production.

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PROBING MUON ISOTOPE PRODUCTION AND PAST ASTROPARTICLE FLUXES USING NUCLEAR RECOIL TRACKS IN PALEO-DETECTORS

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Introduction

The study of cosmogenic nuclides, produced by cosmic ray interactions with terrestrial targets, is a well-established technique in physics. We introduce the PRImuS project, which presents a complementary and novel methodology: using the stable nuclides within natural minerals not just as targets for transmutation, but as the active components of a vast, time-integrating particle detector. This "paleo-detector" approach utilizes the physical damage tracks left by recoiling nuclei, rather than the chemical presence of new isotopes, to investigate particle interactions over geological timescales.

Description of the Work or Project

Analogous to established fission-track studies, this method analyzes the nanometer to micrometer-scale damage tracks left in a crystal lattice by energetic nuclear recoils. The primary mechanism is the interaction of high-energy cosmic ray muons with the stable isotopes composing the mineral. These interactions induce nuclear fragmentation, creating a cascade of secondary particles and a recoiling residual nucleus. This recoiling nucleus is often a new cosmogenic isotope, different from the original target. It is the physical damage track from this recoil that we aim to detect. The expected track length spectrum is modeled via a simulation chain:

1. **Muon-Nucleus Interaction**: A Geant4-based simulation models the muon interactions and stores the final specific recoil energies of the resulting isotopes.
2. **Recoil and Energy Loss**: The stopping and range of the recoiling ion within the bulk mineral is calculated using SRIM tables, allowing for the direct conversion of the recoil energy spectrum into an observable track length spectrum.

Conclusions

Our phenomenological studies on Messinian evaporites and xenoliths from the Caine des Puys volcanic field show that the track record from muon-isotope interactions in mineral samples from a wide range of different geological scenarios should be detectable.
PRImuS is an experimental project funded by INFN that aims to verify these models, opening the possibility of using cosmogenic isotope production in an original way to study the history of our planet and astrophyisical sources.

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WASTE TO WONDER: CARBON-14 INNOVATION

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Introduction

Ontario Power Generation (OPG) has long been at the forefront of providing Ontario with clean, reliable, and safe electricity through its fleet of CANDU nuclear power reactors. Beyond powering homes and businesses, these reactors have also played a pivotal role in the production of medical isotopes, which are essential for a wide range of applications in healthcare and industry. As the global demand for medical isotopes continues to rise, OPG remains committed to innovation and sustainability, ensuring that Ontario's nuclear assets deliver benefits far beyond electricity generation.

Description of Work

In recent years, the global supply of purified Carbon-14 (C-14) has faced significant challenges. Carbon-14 is a radioactive isotope widely used as a biotracer in scientific research to map chemical and biological pathways and is essential in the development and certification of pharmaceuticals, cosmetics, and agrochemicals, supporting innovation and safety in these industries. Since 2022, geopolitical tensions, particularly the Russo-Ukrainian conflict, have severely disrupted the production and distribution of this critical isotope, as Russia was historically a primary supplier. Recognizing the urgent need to address this shortage, OPG has initiated a pilot project with CCNuclear and its isotope producer subsidiary, RC-14, to repurpose OPG's existing reserves of Carbon-14, an intermediate-level radioactive waste product.

The pilot project involves the implementation of advanced removal and purification systems to extract Carbon-14 from stored waste streams. By leveraging OPG's technical expertise and infrastructure, the project seeks to transform what was previously considered a waste byproduct into a valuable resource for the life sciences sector.

The initial phase of the pilot project has yielded promising results. OPG, in partnership with CCNuclear and RC-14, has successfully extracted Carbon-14 from its waste reserves, demonstrating the feasibility of recovering this valuable isotope. While the material has not yet been processed or purified for commercial use, these early efforts lay the groundwork for establishing a sustainable, domestically controlled supply of Carbon-14 in the future. Moreover, the project has yielded environmental benefits by reducing the volume of stored radioactive waste at the NSS Western facility. This aligns with OPG's commitment to responsible waste management and environmental stewardship, demonstrating how innovative thinking can turn a challenge into an opportunity.

Conclusion

OPG's initiative to extract and supply Carbon-14 from its existing waste reserves exemplifies the organization's leadership in both nuclear innovation and environmental responsibility. By transforming a waste byproduct into a globally sought-after isotope, OPG is working to address a critical supply shortage while supporting advances in medicine, research, and industry. The collaborative pilot project with CCNuclear and RC-14 highlights the potential for further innovation within the nuclear sector, ensuring that Ontario's nuclear assets continue to deliver value for society in diverse and meaningful ways.

INNOVATIVE MATRIX FOR RADIACTIVE WASTE CONDITIONING; GEOPOLYMERS AND DIATOMACEOUS EARTH

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Introduction

In the radioactive waste management field, cement is one of the most studied materials thanks to its considerable extent of knowledge, precursor availability, and low cost of production. Thus, extensive research is focused on improving its properties for radioactive waste conditioning capabilities[1]. Alternative conditioning matrices such as geopolymers with excellent mechanical properties enabled it to become a high-performance substitute of Portland cement for specific wastes (e.g., organic oily wastes, decommissioning wastes)[2].

Description of the Work

Geopolymers are synthesized from alumino-silicate sources (clay) and high alkaline solutions in three steps: dissolution, polycondensation, and stabilization. In this study, we are using synthetic metakaolin clay as the backbone of the geopolymer system with aim to encapsulate and incorporate nuclear waste without further treatment processes. In addition to the clay, we propose using diatomaceous earth, fossilized remains of diatoms, which are a type of hard-shelled microalgae containing high amounts of silica to improve both the geopolymer matrix and its retention capabilities for waste material. Different amounts of clay and diatomaceous earth with various alkaline solution concentrations have been tested to determine the optimum geopolymer formulations and to reduce the environmental impact along with the cost. The produced geopolymers have been studied with X-ray diffraction (XRD) and Fourier Transform Infrared Spectroscopy (FTIR) to enlighten their structure. Precursors for geopolymers have been studied with X-ray fluorescence spectroscopy (XRF) to characterize their chemical compositions. In the first step, the conditioning properties of the geopolymer matrix will be tested using surrogate waste. Chemical durability are tested through leaching and retention experiments. Post mortem solid phase analysis will be performed.

Conclusions

The structural properties of geopolymers correspond with the literature[3]. Cs retention experiments on kaolin, metakaolin and diatomaceous earth for solutions ranging from 10^{-2} M to 10^{-8} M showed promising results with 99% of retention. Also, cured geopolymers produced with surrogate waste solutions containing Cs, Co, Cr, Ce, Mn, Ni, and Fe are prepared. Leaching experiments on these geopolymers will allow to calculate their retention capacities.

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3D GAMMA-RAY IMAGING IN NDA RADIOLOGICAL CHARACTERIZATION ACTIVITIES FOR DECOMMISSIONING AND WASTE MANAGEMENT

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Introduction

Since 2020, Nucleco has actively employed static 2D gamma-ray imaging systems for on-site non-destructive assay (NDA) tasks, including radiological surveys and the characterization of components with diverse geometry and material composition. Thousands of operational measurements have demonstrated the effectiveness of 2D imaging in visualizing the spatial distribution of radioactivity and supporting informed, safer decision-making.

Description of the Work or Project

Despite its operational value, 2D gamma-ray imaging lacks depth resolution, resulting in interpretative ambiguity in the presence of overlapping sources, heterogeneous shielding, or complex structures. To overcome these limitations, since 2022 Nucleco has adopted and contributed to the development of a free-moving 3D gamma-ray imaging system. By integrating gamma-ray imaging with real-time detector tracking, the technique enables volumetric reconstruction of radionuclide distributions.

The system was validated in laboratory settings, assessing spatial accuracy, energy response and performance under varying shielding conditions. Subsequent field applications have demonstrated enhanced capabilities over 2D imaging. In radioactive waste characterization, 3D imaging allowed improved hotspot localization and activity distribution estimation. During inspections of a fuel element, it supported Nuclear Material positioning analysis under restricted access. A notable case involved the reactor pool of the former Latina nuclear power plant, where high dose rates and limited accessibility make conventional approaches complex. In this scenario, 3D imaging provided a volumetric contamination map, supporting intervention planning, optimization of work sequences and improved radiation protection for operators.

Conclusions

The integration of static 2D and free-moving 3D gamma-ray imaging significantly enhances NDA-based radiological characterization in decommissioning and waste management activities. While 2D systems remain valuable for rapid assessment, 3D imaging offers improved accuracy in source localization and activity distribution, especially in complex or hazardous environments. Field experience indicates the operational maturity of the technology, with clear benefits in safety, decision support and regulatory compliance. Future efforts will focus on metrological optimization, automated reconstruction algorithms and broader implementation in decommissioning and safeguards.

Keywords: 3D gamma-ray imaging; NDA; radiological characterization; decommissioning; radioactive waste.

PRELIMINARY RESULTS FROM THE DECOMMISSIONING OF AN ITALIAN COMMERCIAL PWR

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Introduction

As part of the Italian decommissioning program, Nucleco S.p.A. conducted the sampling and radiological characterization of the vessel head of an Italian commercial PWR. The study investigates the contamination profile and chemical behavior of the oxide film formed on the inner stainless-steel surface during reactor operation and decommissioning activities.

Description of the Work or Project

During reactor operation, an oxide film forms on the inner stainless-steel surface of the vessel; this layer, typically about 100 µm thick, consists of a chromium-oxide base with iron and nickel oxides in the outer region. The contamination profile was investigated through both NDA and DA techniques, supported by HPGe and gamma-camera imaging to establish an initial radiological distribution. Contrary to expectations, only trace amounts of ^{137}Cs were detected, whereas significant contributions from ^{241}Am and ^{60}Co were observed.

Figure: Initial condition of the sample vessel head, undermark the black oxide film development on the stainless steel layer.

The dissolution of the oxide film represented one of the main challenges. Tests performed using different chemical attack methods including weak acids, aqua regia, and strong acids; highlighted the stratified nature of the contamination. From a radiochemical perspective, the primary goal was to distinguish the contamination component (^{241}Am) from activation products (^{60}Co), since a purely contaminant-driven profile was considered unlikely. Despite the use of strong acids, the removal of ^{241}Am proved difficult, indicating a marked retention within the oxide layer. In contrast, ^{60}Co was found predominantly in the outermost portion of the sample.

Conclusions

The preliminary results highlight a complex contamination pattern within the oxide layer, marked by significant ^{60}Co in the outer region and persistent ^{241}Am retention likely linked to isotope stratification during reactor operation. These findings suggest possible radionuclide transport within the vessel and potential fuel-related contributions. Further investigations will focus on defining the oxide thickness, composition, and stratification mechanisms, as well as clarifying the origin and distribution of the detected radionuclides. Nucleco will continue exploring additional analytical approaches to refine this interpretation.

Keywords: CRUD, Vessel, Oxide layer, Decommissioning, Radioactive Waste

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STATUS OF THE SIMβ-AD PROJECT: METHODOLOGY TO ESTIMATE ACTIVATION OF RADIOACTIVE WASTE PRODUCED BY CYCLOTRON FACILITIES

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Introduction

The Sim β-AD project, launched in 2022, tackles the radiological characterization of radioactive waste generated by cyclotron facilities, including β-only emitters such as ^{63}Ni, ^{55}Fe and ^{49}V. A comprehensive approach is required to manage uncertainties, secondary waste, and the need for representative samples. The objective of Sim β-AD is to develop a methodology that couples an innovative active neutron detector with Monte-Carlo simulations. Neutron fluence computed by the RayXPert software will be validated against in-situ measurements performed with *AlphaBeast* [1] CMOS-based neutron detectors, then used to estimate activation of materials inside cyclotron bunkers.

Description of the Work or Project

Numerical simulations benchmarked the following transport codes: FLUKA[2, 3], MCNP6 [4], PHITS [5], GATE[6] and RayXpert® V2.0 [7].
Experiments covering a broad spectrum of particles, energies and intensities were conducted in partnership with facilities listed in Table 1. *AlphaBeast* neutron detectors have been cross-checked with solid nuclear tracks detectors (SNTD) to validate their use in mixes radiation fields. Experimental results were compared with numerical calculations from various Monte-Carlo codes.

Table I: Facility involved in the Simβ-AD project

Facilities	Applications	IBA cyclotron?	Particles, energy and intensity
CEMHTI, Orléans	Irradiation	No	h, 16 MeV, 25 µA d, 17,5 MeV, 30µA
CYRCé, Strasbourg	Radionuclides production	No	h, 16,5 MeV, 35 µA
CYCERON, Orléans	Radionuclides production	Yes	h, 18 MeV, 35µA
CPO, Orsay	Protontherapy	Yes	h, 235 MeV, 600 nA

Conclusions

Preliminary results show that RayXpert's hadron module agrees well with the other Monte Carlo codes across all test cases. Initial irradiation experiments inside a cyclotron bunker demonstrate consistency between measurements and calculations, with ratios ranging from 0.5 to 1.5.

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EXPERIMENTAL STUDY OF EXCITATION FUNCTIONS FOR PROTON-INDUCED REACTIONS ON 141Pr

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Introduction

Proton-induced reactions on praseodymium-141 (^{141}Pr) offer promising pathways to produce radiolanthanides used in targeted radiotherapy and theranostic applications. Among these, ^{140}Nd is particularly attractive due to its emission of low-energy Auger electrons and the in vivo PET imaging capability of its daughter, ^{140}Pr. However, reliable cross-section data for these reactions remain sparse and inconsistent, necessitating new experimental studies.

Description of the Work or Project

This study presents precise experimental measurements of activation cross sections for several radionuclides produced via ^{141}Pr(p,xn) and ^{141}Pr(p,x) reactions in the 27–60 MeV proton energy range, using the stacked-foil activation technique and γ-ray spectrometry. The production of ^{139m,140,141}Nd and ^{139}Ce was investigated. Two irradiations were carried out at the AIC-144 isochronous cyclotron at IFJ PAN. Monitor foils and Geant4/SRIM simulations ensured accurate energy determination, while γ-ray analysis was conducted with a high-resolution HPGe detector and ROOT framework.

Results

Well-defined excitation functions were derived and compared with theoretical predictions from the TALYS code and previously published data. Our results show generally good agreement with theoretical models, while highlighting discrepancies in the ^{139}mNd channel. For ^{140}Nd production, cross-sections were deduced indirectly via decay of ^{140}Pr, enabling estimation of PET-relevant yields. The consistency of overlapping data from two independent irradiations confirms the robustness of our measurements.

Conclusions

This work provides new and consistent cross-section data for ^{141}Pr(p,x) reactions, crucial for optimizing the production of therapeutic radionuclides like ^{140}Nd. The results contribute to refining nuclear reaction models and support the development of novel radiopharmaceuticals based on radiolanthanides. Future research should extend measurements to lower energy ranges to fully map excitation functions for clinical applications.

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COMPARISON BETWEEN DIFFERENT DIRECT PRODUCTION ROUTES OF THE THERANOSTIC ^{47}Sc

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Introduction

^{47}Sc is a promising theranostic radionuclide that presents suitable decay characteristics for SPECT imaging and β^- therapy, that can be also paired with the β^+ emitter counterparts ^{43}Sc and ^{44}Sc for PET applications. The lack of ^{47}Sc production is limiting its use in preclinical and clinical trials; for this reason, the scientific community requires the investigation of the possible production pathways of this radionuclide. A comparison of different proton and deuterons production routes is discussed, considering yield and radionuclidic purity, in order to identify the best production parameters. Besides, dosimetric simulations are performed to evaluate the impact of radioisotopic impurities.

Description of the Work

At the INFN-LNL, in the framework of LARAMED (LAboratory of RAdionuclides for MEDicine) collaboration, the production of ^{47}Sc has been investigated since 2017 through some dedicated projects [1,2]. The PASTA (Production with Accelerator of Sc-47 for Theranostic Applications) and REMIX (Research on Emerging Medical radIonuclides from the X-sections) projects, funded by INFN in 2017/2018 and 2021/2023 respectively, aim to study the ^{47}Sc proton-induced production cross section starting from different target materials, namely ^{nat}V, ^{48}Ti, ^{49}Ti and ^{50}Ti. Additionally, in the context of the SPES_MED project, funded by INFN CSN3 for the years 2025-2027, deuteron-induced nuclear cross sections of ^{47}Sc from enriched ^{49}Ti targets were investigated. The aim of this study is to provide a comprehensive understanding of the ^{47}Sc production, to identify the most effective nuclear reaction that allows enough ^{47}Sc production, while simultaneous minimizing the co-production of all possible contaminants. Particular attention must be paid to the other Sc-isotopes since they cannot be chemically separated from ^{47}Sc and can contribute to the dose increase to the patients. Starting from experimental results, dosimetric calculations performed with OLINDA/EXM software are performed to compare the production routes investigates.

Conclusions

The activity performed in this work will allow to determine the most promising production method with cyclotrons of the theranostic ^{47}Sc.

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THE COPPER TRILOGY: EXPLORING ^{61}Cu, ^{64}Cu AND ^{67}Cu AT THE BERN MEDICAL CYCLOTRON

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Introduction

Copper radionuclides are attracting increasing interest in nuclear medicine thanks to their suitable half-lives, favorable decay characteristics, and versatile chemistry. ^{60}Cu [$t_{1/2}$ = 23.7 min], ^{61}Cu [$t_{1/2}$ = 3.339 h] and ^{62}Cu [$t_{1/2}$ = 9.67 min] are pure β^+-emitters suited for positron emission tomography (PET) imaging. ^{64}Cu [$t_{1/2}$ = 12.7006 h] combines electron capture (44%), β^--decay (38.5%) and β^+-decay (17.5%), finding application in both the diagnostic and therapeutic contexts. ^{67}Cu [$t_{1/2}$ = 61.83 h] has emerged as an attractive isotope for targeted radionuclide therapy (RNT). Together, the ^{61}Cu/^{67}Cu and ^{64}Cu/^{67}Cu pairs represent true theranostic systems, enabling the same element to be used for both imaging and treatment. Despite this potential, establishing reliable production routes with sufficient yields and radionuclidic purity remains a key challenge for clinical translation.

Material and Methods

At the Bern medical cyclotron laboratory[1], a dedicated research program was established to investigate the accelerator-based production of copper radionuclides using an 18 MeV HC IBA cyclotron, equipped with a solid target station (STS) and a 6.5 m beam transfer line (BTL). Zinc targets with different isotopic compositions (natural Zn, enriched ^{64}Zn, ^{67}Zn, and ^{70}Zn) were irradiated to explore the feasibility of ^{64}Zn(p,α)^{61}Cu, ^{67}Z(p,α)^{64}Cu and ^{70}Zn(p,α)^{67}Cu production routes[2-4]. Cross-section measurements were performed irradiating the entire mass of thin zinc targets with a proton beam of uniform surface distribution. The excitation functions of all nuclear reactions leading to radiocoppers were measured in the energy range of interest. A high-purity germanium (HPGe) detector was used for activity quantification. In cases where multiple reactions contributed to the same isotope, a method based on solving linear systems of equations was applied to disentangle the individual contributions. Based on these measurements, production yields and radionuclidic purities were calculated for different irradiation parameters. Optimized production scenarios were then identified for ^{61}Cu, ^{64}Cu and ^{67}Cu, and experimental production tests were performed to validate the results.

Conclusions

This work has provided a comprehensive dataset of cross sections, yields, and purities for ^{61}Cu, ^{64}Cu, and ^{67}Cu in the energy range up to 18 MeV. The results demonstrate the feasibility of producing the theranostic pairs ^{61}Cu/^{67}Cu and ^{64}Cu/^{67}Cu within a single medical cyclotron facility, highlighting the potential of existing infrastructure to enable decentralized and distributed production of copper-based radiopharmaceuticals for nuclear medicine.

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Design and Construction of Ga-68 Generator with Microbead-Based Absorbent

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Introduction

Gallium-68 (^{68}Ga) is a positron-emitting radionuclide used in PET/CT imaging, obtained from a ^{68}Ge/^{68}Ga generator without needing an accelerator. It has a short half-life ($T_{1/2}$: 67 min) and is increasingly used in nuclear medicine for diagnosing conditions like prostate and neuroendocrine tumors. The radionuclide generator's column material, typically metal-based materials, faces challenges like low acid resistance, high ^{68}Ga elution yield and low ^{68}Ge breakthrough. A natural biopolymer has shown potential as a new adsorbent material due to its biocompatibility and ability to interact with metal ions. This study explores using natural biopolymer combined with metal oxide to improve the ^{68}Ge/^{68}Ga generator's performance, focusing on enhanced adsorption/desorption capacity of ^{68}Ge/^{68}Ga and acid resistance.

Description of the Work and Results

The ^{68}Ge/^{68}Ga generator column packing material was prepared by natural biopolymer and mixing it with a titanium(IV) isopropoxide. The mixture was homogenized and dropped into an ammonia solution to form micro beads. This process resulted in the formation of micro-sized material with improved characteristics. The average particle size of the micro-bead is around 250-350 μm. The distribution coefficients (K_d) of ^{68}Ge and ^{68}Ga with micro-bead were measured at various HCl concentrations to assess adsorption and desorption capacity. The K_d values were calculated using the initial and final activities of 68Ga, along with the solution volume and micro-bead mass. The ^{68}Ge/^{68}Ga separation factor using micro-bead is about >10,000 at the concentration of 0.1 M HCl. In the ^{68}Ge/^{68}Ga generator column study, the micro-bead was packed into an empty column and loaded with 1,480 MBq of purified ^{68}Ge solution in 0.1 M HCl. After reaching the equilibrium of ^{68}Ge/^{68}Ga, the column was rinsed with 0.1 M HCl to remove unbounded ^{68}Ge and left for 24 hours to assess performance. For the performance evaluation of ^{68}Ga elution yield and ^{68}Ge breakthrough, a 5 mL fraction was collected at a 2.5 mL/min flow rate for ^{68}Ga elution yield. The remaining activity after 24 hours was measured to determine a ^{68}Ge breakthrough. The ^{68}Ga elution yield is ~70% with 0.1 M HCl in the 5 mL volume due to the high separation factor of ^{68}Ge/^{68}Ga. The breakthrough of ^{68}Ge was confirmed to be $<10^{-3}$%. The metallic impurities in the ^{68}Ga eluate were measured by inductively coupled plasma-mass spectrometry (ICP-MS) to secure biological safety and optimize the radio-labeling yield. The contents of metallic impurities in the eluate ^{68}Ga is ppb level and it will not affect the radio-labeling reaction. For PET imaging, ^{68}Ga labeled prostate-specific membrane antigen-11 was injected into anesthetized mice, and PET images were taken 60 minutes post-injection.

Conclusions

In this study, the ^{68}Ge/^{68}Ga adsorption and desorption efficiency of developed column material were thoroughly evaluated to enhance the performance of ^{68}Ge/^{68}Ga generator system. The column material demonstrated an effective ^{68}Ga elution yield, indicating its potential stable use in various acidic environments. Despite exposure to physical stress over extended periods, the adsorbent maintained its structural integrity, with minimal metallic impurities detected in the ^{68}Ga eluate. These finding suggest that micro-bead is a promising material for use in ^{68}Ga/^{68}Ga generators, offering improved quality of radionuclide.

PREPARATION AND CHARACTERIZATION OF TERBIUM-161 AS A STEP TOWARDS CLINICAL TRANSLATION

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Introduction

Terbium-161 (^{161}Tb) is an emerging therapeutic radionuclide that combines the favorable decay properties of lutetium-177 (^{177}Lu) with short-range conversion and Auger electrons, improving effectiveness for small tumor lesions and micrometastases. These features make it a promising candidate for next-generation therapeutic radiopharmaceuticals. In our translational research program, ^{161}Tb will be used in a clinical study with [^{161}Tb]Tb-CP04, a CCK2R receptor agonist, designed to treat medullary thyroid carcinoma. This work focuses on irradiating, separating, and quality assessment of ^{161}Tb for radiopharmaceutical manufacturing and clinical use.

Description of the Work or Project

Terbium-161 was produced via the ^{160}Gd(n,γ)^{161}Gd→^{161}Tb nuclear reaction following the neutron irradiation of enriched [^{160}Gd]Gd_2O_3 target material (≥ 97.5%) in the MARIA Research Reactor (NCBJ, Poland). The separation of ^{161}Tb from the gadolinium target was optimized using a two-step extraction chromatography method using LN2 and DGA Normal resins (Triskem). ^{161}Tb was eluted using a nitric acid gradient ranging from 0.25 M to 1 M HNO_3, achieving a recovery efficiency exceeding 98% from the LN2 resin. ^{161}Tb fraction was subsequently transferred onto a DGA column and eluted with 0.05 M HCl, enabling both product concentration and the effective removal of residual metallic impurities. Quality control testing, including radionuclide, chemical, and radiochemical purity analyses, confirmed the high quality of [^{161}Tb]$TbCl_3$ in 0.05M HCl. The radiolabeling efficiency of the DOTA-TATE (NCBJ RC POLATOM) exceeded 98% with an apparent molar activity (AMA) of 150 MBq/nmol (^{161}Tb:peptide molar ratio of 1:5). Moreover, stability studies confirmed that the synthesized [^{161}Tb]Tb-DOTA-TATE complexes maintained radiochemical stability at room temperature for up to 48 hours.

Conclusions

An efficient ^{161}Tb production method based on two-step extraction chromatography was established, yielding [^{161}Tb]$TbCl_3$ of suitable quality for radiopharmaceutical manufacturing. These results encouraged further study of the efficacy of [^{161}Tb]Tb-CP04 in the MTC-Tb clinical trial.

Acknowledgments

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DEVELOPING PRODUCTION AND RADIOCHEMICAL SEPARATION FOR EMERGING RADIONUCLIDES FOR TARGETED RADIONUCLIDE THERAPY AT TRIUMF

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Introduction

Targeted Radionuclide Therapy (TRT) holds significant promise for cancer treatment through the use of β^- and α particles, as well as Auger and conversion electrons, delivered via selective targeting systems. Several promising radionuclides for TRT are produced using TRIUMF's unique infrastructure in Vancouver, Canada. These include alpha-emitting isotopes such as Ac-225/Bi-213, Pb-212/Bi-212, and Th-227/Ra-223, as well as a diverse range of Auger electron-emitting radionuclides such as Hg-197m/g, Pd-103/Rh-103m, La-135, Tb-155, Er-165, among others.
This presentation will focus on the radiochemical aspects of producing selected TRT radionuclides within the broader Canadian initiative to establish a national network of theranostic radiopharmaceuticals under the *New Frontiers in Research Fund – Transformation* (NFRFT) program.

Description of the Study

Several facilities at TRIUMF are currently being leveraged for the production of medical radionuclides alongside scientific experiments conducted by other research groups. For instance, the residual beam from the main 480 MeV cyclotron is used for producing alpha emitters such as Ac-225 and Pb-212. The ISAC facility, which employs online mass separation, enables the collection of medically relevant radionuclides, including Tb-155, Ac-226, and others.
Additionally, the availability of a low-energy medical cyclotron (TR-13) offers opportunities for the production of emerging Auger electron emitters for TRT applications. The upcoming IAMI facility will further support the clinical translation of novel radiopharmaceuticals, complementing the capabilities of the TR-24 (24 MeV) cyclotron.

Results

Regular production of Ac-225 via a Ra-225 generator is carried out based on the beam availability of the main cyclotron. In addition, other long-lived generator-based radionuclides - such as Th-228 and Ac-227, used to produce Pb-212 and Th-227, respectively - are available year-round in pre-clinical quantities.

Hg-197m/g is produced bi-weekly on a routine basis, while other radionuclides such as Er-165, La-135, and Pd-103 are produced on demand. Several others, including Sb-119 and Tb-155, are currently under development.
These radionuclides are used internally by the Life Sciences team at TRIUMF and are also supplied to partners within the NFRF-T consortium.

Conclusions

Leveraging TRIUMF's unique infrastructure and expertise, our team utilizes available accelerators and facilities to produce medical radionuclides and advance the development of novel theranostic radiopharmaceuticals—positioning Canada at the forefront of this rapidly evolving field.

Acknowledgments

We gratefully acknowledge funding from New Frontiers for Research Funds Transformation program and consortium members for their support for pre-clinical evaluation. The NSERC Discovery program, Canadian Institute for Health Research (CIHR) Project Grant. TRIUMF receives federal funding via a contribution agreement with the National Research Council of Canada. We thank the TR13 Cyclotron Operations Group, consisting of Toni Epp, Ryley Morgan, Spencer Staiger, and led by David Prevost, for regular irradiations of solid targets.

RECENT ADVANCES IN NANTES AROUND THE ARRONAX FACILITY

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Introduction

Applications of radiations for health is a long story that have started soon after the discovery of radioactivity. Nowadays, radiations are used in oncology (external radiation, targeted therapies, SPECT, PET), neurology and cardiology. Since 2013, a new wave of applications in nuclear medicine has started, focused on therapeutic agent and the so-called theranostics approach [1]. This has resulted in the approval of several new products such as ^{177}Lu-DOTATATE for neuroendocrine tumors in 2018 and ^{177}Lu-PSMA for metastatic prostate cancers in 2021. Almost at the same time, alternative ways of dose delivery were investigated in external radiotherapy, the so-called spatial dose fractionation (SFRT) and ultra-high dose-rate (UHDR, "FLASH" effect). All these aspects are at the heart of the research program conducted in Nantes around the ARRONAX facilities and its accelerators.

Description of the Project

GIP ARRONAX is hosting a high energy high intensity multiparticle cyclotron (C70XP). It allows access to a wide variety of beam in terms of projectiles (p, d, alpha), of incident energies (up to 70 MeV for p and alpha) and of intensities (from a thousand of particles per second up to several hundreds of µA). Several upgrades have been made since the installation of the machine to enlarge its capacity. In 2017, a radiopharmacy have been setup in collaboration with the Nantes University hospital to allow dose productions for clinical trials [2], in 2019, a pulsing system have been developed and installed [3]. In 2025, an internal target system has been installed to allow access to variable energies for our alpha beam and in parallel, a biomedical cyclotron (KIUBE-180) equipped with a beam line and target station connected to the existing rabbit system, is being commissioned.

Conclusions

These developments allow the ARRONAX facility to better fulfil its missions that are to support research in nuclear medicine by providing non-conventional radionuclides and radiopharmaceuticals for clinical trials and also support research in related fields: radiotherapy and radiobiology, radiolysis, physics, ion beam analysis, mass separation through the SMILES project, detector testing… This presentation will show the broad spectra of research activities conducted in the facility and its current status.

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RADIONUCLIDES PRODUCTION FOR BIO-MEDICAL APPLICATIONS AT CERN-MEDICIS AND FOR THE PRISMAP EUROPEAN PROGRAM

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Introduction

The CERN-MEDICIS facility is a unique facility located at CERN dedicated to the production of non-conventional radionuclides for research and development in imaging, diagnostics and radiation therapy, by offline mass separation. It is at the heart of the PRISMAP European Program, supporting the ongoing research across Europe and beyond, by providing immediate access to novel radionuclides and to facilities to researchers.

Description of the Work or Project

CERN-MEDICIS exploits in a dedicated classified work sector, an isotope separator beam line, a radiochemistry laboratory, a target irradiation station at the 1.4 GeV Proton Synchroton Booster (PSB) and receives activated targets from external institutes during CERN Long Shut-Downs. It collects radionuclides in the form of a radioactive ion beam (RIB) implanted into a substrate. After collection, the batch is prepared to be dispatched to a research center. Since its commissioning in December 2017, the facility has provided novel radionuclides such as Ba-128, Tb-155, Sm-153, Tm-165 Ra-224/Pb-212 and Ra-225/Ac-225with high molar activity, some for the first time, to European research institutes part of the collaboration.

Conclusions

CERN-MEDICIS has advanced significantly to reach mature processes for some of the radionuclides with the first clinical translation of the most promising radionuclides being under discussion. In line with this, recent updates to the CERN-MEDICIS infrastructure and performances will be reported together with its contribution to the PRISMAP program.

THE SPES_MED ACTIVITIES AT THE LEGNARO NATIONAL LABORATORIES

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Introduction

The production of medical radionuclides is one of the research activities carried out in the framework of the SPES (Selective Production of Exotic Species) project under the completion stage at the Legnaro National Laboratories of the National Institute for Nuclear Physics (INFN-LNL). The heart of SPES is the 70 MeV proton-cyclotron having a dual-beam extraction, installed and commissioned in a new building equipped with ancillary laboratories currently under construction. The SPES main goal is the realisation of an advanced ISOL (Isotope Separation On-Line) facility to produce re-accelerated exotic ion beams for fundamental nuclear physics studies. The cyclotron double-beam extraction system allows to simultaneously carry out applied research, such as radionuclides production for medicine (SPES-γ). This work outlines the main goals of the new "SPES_MED" project funded by INFN-CSN3, gathering the interdisciplinary communities of the LARAMED (LAboratory of RAdionuclides for MEDicine) and ISOLPHARM (ISOL technique for radioPHARMaceuticals) teams.

Description of the Work

The SPES_MED project involves the INFN divisions of Pisa (PI), Pavia (PV), Padova (PD), Milano (MI) and the LNL. The main objectives of SPES_MED, to be achieved from 2025 to 2027, are: 1. Perform measurements of nuclear cross sections aiming at the optimization of medical radionuclides production, also using nuclear modelling tools to find out the best irradiation conditions (LNL, MI); 2. Provide a precise measurement of the ISOL production yields originating from SiC and TiC targets (LNL, PI, PD, PV); 3. Compare the produced data with the existing simulation libraries, with the purpose of providing an experimental benchmark when the theoretical predictions fail (PD, PV, LNL).

Conclusions

This work is focused on the main results obtained by the LNL team during the first year of SPES_MED. Results on the nuclear cross section measurements for the production of ^{47}Sc and ^{155}Tb will be presented, as well as the production of ^{28}Al using the ISOL facility and SiC targets.

PROGRESS TOWARDS THE PRODUCTION OF Hg-197 m/g FOR TARGETED AUGER ELECTRON THERAPY

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Introduction

Targeted Auger Electron Therapy (TAET) holds significant promise for precision cancer treatment, leveraging short-range, high linear energy transfer (LET) Auger electrons to destroy cancerous cells while minimizing collateral damage to healthy cells. Auger emitters such as Sb-119, Er-165, Hg-197 m/g, and Pd-103 can be easily produced using low-energy medical cyclotrons like TRIUMF's TR-13.[1] Of particular interest is Hg-197 m/g, a theranostic isotope suitable for both imaging and therapy. Current collaborations with the Ramogida (Simon Fraser University) and the Reilly (University of Toronto) groups focus on developing delivery systems such as chelates, antibodies, and gold nanoparticles.[1,2] The goals of this research work are to improve the purity of Hg-197 m/g, optimize activity concentration, address pH challenges, and ensure a safe and controlled process.

Description of the Work or Project

Hg-197 m/g is produced via the ^{197}Au(p,n)$^{197m/g}$Hg reaction on the TR-13, where the irradiated target is dissolved in aqua regia, filtered, purified on an LN column resin with 6 M HCl, and concentrated under vacuo.[3,4] While the rotary evaporator enables a safe isolation of Hg-197 m/g, challenges related to low purity and high acidity initially limited significantly the downstream applications, including radiolabeling and the synthesis of Hg-197 gold nanoparticles. To that end, optimization of the key steps, radiochemical separation and purification, were conducted. Safety parameters were considered during the evaporation step to mitigate the associated Hg toxicity.

By implementing a more controlled evaporation, preventing backflow on the rotary evaporator, and reducing the final concentration volume to less than 100 µL, substantial improvements were achieved. The resulting clear colourless Hg-197 m/g sample reached 1 MBq/ µL, with a pH 5-6 (in the gold nanoparticle solution) and a radiochemical yield of over 90%. Process time was also significantly reduced – from over 2 days to under 6 hours.

Additionally, comprehensive Inductively Coupled Plasma Mass Spectrometry (ICP MS) analyses were conducted from target preparation through to the final product to identify key metal contaminants and sources, providing critical guidance for resins screening aimed at finer purification.

A Weak Base Extraction Chromatograhic (WBEC) resin was also investigated as a replacement to the rotary evaporator, a potential source of impurities, allowing elution in a radiolabeling-

ready matrix such as NH_4OAc. A notable reduction in metal contaminants was observed with this secondary column, and radiolabeling optimization is currently under underway.

Conclusions: While optimization of the Hg-197 m/g process, including both targetry and purification steps, is on-going, the results presented herein mark a key advancement, particularly with one-step chelator labeling and gold nanoparticles.[3] The development of a straightforward, safe, and automated preparation method for Hg-197 m/g, with high radionuclidic, radiochemical, and chemical purity, along with controlled pH and activity concentration, will be a significant milestone in the production of Hg-197 m/g-based radiopharmaceuticals. This development will also enable scalable production and will greatly contribute to the advancement of TAET.

Keywords: Auger Electrons; Hg-197 m/g; Theranostics; Radiopharmaceuticals; Production.

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TOWARDS SUSTAINABLE NANOCARRIERS FOR METAL-BASED DRUG DELIVERY: RADIOLABELING OF CELLULOSE NANOCRYSTALS WITH COPPER-61

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Introduction

Cellulose nanocrystals (CNCs) have emerged as biocompatible and versatile nanomaterials for biomedical applications in drug delivery, owing to their tunable surface chemistry and peculiar rod-like shape which, compared to spherical carriers, leads to higher cell internalization.[1] In particular, TEMPO-mediated oxidation introduces carboxylic groups on their surface, improving colloidal stability and enabling conjugation of different molecules, including biologically active ligands.[2,3] In this context, this study investigates a novel application, assessing the ability of CNCs to interact with copper ions through radiolabeling experiments conducted using copper-61.

Description of the Work or Project

Copper-61 was produced by proton irradiation of natural zinc solid targets (18 MeV, 20 μA, 30 minutes), followed by radiochemical purification. Radiolabeling studies were carried out by incubating both starting and functionalized CNCs with copper-61 under various buffer and pH conditions at 37 °C for 15 minutes and overnight. Radiochemical incorporation and stability were evaluated by thin-layer chromatography (TLC). Both the starting material, of which surface was associated with the presence of carboxylic groups, and the CNCs functionalized in aqueous medium *via* DMTMM-mediated coupling with a copper-chelating ligand (5AMHQ: 5-aminomethyl-8-hydroxyquinoline)[4] were evaluated in terms of interaction with copper ions under different concentrations and experimental conditions.

Results

Radiolabeling of CNCs with copper-61 was successfully achieved for the functionalized derivatives, with the highest efficiency observed for the 5AMHQ-modified CNCs under both mild and strong acidic conditions. The labeling yield reached approximately 1 kBq/nmol, and preliminary stability studies indicated that the radiometal remained associated with the CNCs matrix after incubation in aqueous medium for 24 hours. In contrast, unmodified CNCs showed negligible copper binding, confirming the importance of the added chelating system for efficient coordination.

Conclusions

This study demonstrates, for the first time, the feasibility of radiolabeling functionalized CNCs with copper radioisotopes, highlighting their potential as biocompatible and efficient nanoplatforms for metal ion coordination and delivery. The promising radiolabeling results obtained with the 5AMHQ-functionalized CNCs suggest that these nanoarchitectures could be further optimized for applications in diagnostic imaging (*e.g.*, PET with copper-64 or copper-61) or targeted radiotherapy (*e.g.*, copper-67).

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Accelerate.EU: Unlocking the Potential of Astatine-211 for Targeted Alpha Therapy

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Introduction

Astatine-211 (At-211) is one of the most promising alpha-emitting radionuclides for targeted alpha therapy (TAT), combining optimal physicochemical and radiobiological properties. With a 7.2-hour half-life and high linear energy transfer (~97 keV/μm), At-211 delivers localized, potent cytotoxicity against micro-metastatic lesions while minimizing off-target effects. As the heaviest halogen, it shares chemical properties with iodine, enabling the use of established radioiodination chemistry for stable covalent labelling — a key advantage over metallic alpha emitters. However, its clinical translation remains limited by production and logistics constraints linked to the (α,2n) reaction on bismuth-209.

Description of the Project

The Accelerate.EU consortium (17 European partners) aims to overcome these challenges by establishing a fully integrated At-211 value chain covering isotope production, radiochemistry, preclinical validation, and clinical translation.
An initial network of coordinated At-211 production centers is already providing early supply of the isotope to support preclinical development and upcoming clinical trials, ensuring just-in-time delivery and harmonized radiolabelling protocols. In parallel, a novel α-beam-only cyclotron with internalized targets will be developed to enable cost-effective, GMP-compliant, and scalable At-211 production.
Theranostic pairs targeting fibroblast activation protein (FAP), neurotensin receptor-1 (NTR1), and Substance P (Sub P) are being developed, with F-18 and Ga-18 labelled analogues for companion diagnostics.

Conclusions

Accelerate.EU will establish the first European hub dedicated to At-211 radiotheranostics, ensuring a sustainable supply and translational readiness.
The preclinical programme includes At-211-NTR1i studies in pancreatic ductal adenocarcinoma (PDAC) and At-211-FAPi in TNBC, alongside At-211-Sub P for glioblastoma (GBM). These efforts will support two clinical trials: a phase I study in TNBC (At-211-DualFAPi) and a pilot study in GBM (At-211-Sub P).
By linking nuclear physics, radiochemistry, and oncology, Accelerate.EU is paving the way for clinically accessible, high-precision At-211 therapies, strengthening Europe's leadership in alpha theranostics.

OPTIMIZING SCANDIUM-44 PRODUCTION AND RADIOLABELING FOR POTENTIAL CLINICAL APPLICATION IN NUCLEAR MEDICINE

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Introduction

Scandium-44 is a promising candidate for positron emission tomography (PET) imaging[1] due to its favorable physical properties, including a half-life of 4.04 hours and high positron emission efficiency ($E_{\beta^+}av$ = 630.2 keV, Eγ = 1157 keV, I = 99.9%). It can be produced at medical cyclotrons via the $^{44}Ca(p,n)^{44}Sc$ nuclear reaction using highly enriched ^{44}Ca targets. However, production runs have faced challenges in reproducibility, including variability in product pH, chemical purity, and specific activity of the final product[2]. The present study focuses on optimizing the production and purification of ^{44}Sc, towards improving chemical purity and apparent molar activity, enhancing its potential for both preclinical and clinical applications.

Work performed

Bench experiments were performed to evaluate DGA (TrisKem International) and DOODA (Eichrom Technologies) extraction resins, for their ability to efficiently separate scandium from macro quantities of calcium, using hydrochloric acid, nitric acid and ammonium acetate as eluents, respectively. A cation exchange resin was added to concentrate Sc in 0.5M ammonium acetate at pH 4.1, suitable for radiolabeling. Parameters such as column height and pH of eluent were evaluated to optimize the yield of scandium in a minimal volume. At all tested pH values (e.g., pH 3.5, 4.1, 4.3, and 4.5) with a column height of 3 mm, the yield exceeded 95%. The most effective radiochemical separation procedures, using DGA or DOODA resins, was tested with the irradiated targets. In both cases, the yield was approximately 850 MBq after 30 minutes' irradiation and following chemical separation. The chemical and radionuclidic purity of the ^{44}Sc final product was assessed through HPLC and γ-ray spectrometry, respectively. Radiolabeling efficiency was evaluated using DOTATOC, with the apparent molar activity 10 MBq/nmol, and a radiochemical purity ≥94% for both separation procedures evaluated. Additionally, radiolabeling with other ligands are currently in the testing phase.

Conclusions

Advancements in the production and purification of ^{44}Sc have shown promise towards improved reproducibility. However, the ^{44}Sc final product purity can be improved with higher yields from longer irradiation of targets. Based on these results, DGA and DOODA resins show comparable performance. Future efforts will also focus on upscaling the ^{44}Sc production and procedures into radiopharmaceutical manufacture.

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PREDICTING RADIOBIOLOGICAL ENHANCEMENT: MONTE CARLO MODELING OF GOLD NANORODS AND RADIOPHARMACEUTICALS

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Introduction

The SEGNAR project aims to develop a theranostic system combining gold nanorods (AuNRs) with 99mTc-based radiopharmaceuticals to improve cancer treatment. ^{99m}Tc, traditionally used for imaging, is here explored as a therapeutic agent whose Auger and internal conversion (IC) electron emissions can produce highly localized and lethal DNA damage when brought near the cell nucleus.

Description of the Work or Project

The study uses Monte Carlo simulations in Geant4/Geant4-DNA to model the interaction of ^{99m}Tc emissions with tissues and AuNR systems, with and without ^{99m}Tc-sestaMIBI. The simulations track low-energy electrons and describe their transport in biological environments. This approach allows evaluation of dose enhancement in different AuNR configurations. To link these physical results to biological effects, the Microdosimetric Kinetic Model (MKM) is extended to include the properties of AuNRs and ^{99m}Tc decays and the radiobiological parameters of a specific cell line. This extension enables prediction of lesion yields and cell survival.

Conclusions

These results support the development of an optimal AuNR–^{99m}Tc system and provide a framework for understanding how the biological effects of ^{99m}Tc depend on both the number of ^{99m}Tc atoms reaching the cell nucleus and their coordination with the gold nanorods. They also offer a strong basis for upcoming experimental validation and for advancing targeted theranostic strategies in cancer therapy.

IMMOBILISATION OF CATIONIC AND ANIONIC RADIONUCLIDE SPECIES IN ZEOLITITE-BASED ACID GEOPOLYMERS

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Introduction

Radioactive waste (RW) conditioning is a crucial step in producing durable waste forms capable of safely immobilising radionuclides. In recent years, geopolymers have gained attention as alternatives to conventional cementitious materials for low- and intermediate-level RWs (Galluccio et al., 2025). Alkaline geopolymers have shown high retention for several cations, especially the highly mobile fission product $^{137}Cs^{+}$. However, their performance is much less satisfactory for radionuclides such as ^{99}Tc, ^{93}Mo, ^{79}Se, ^{36}Cl, and ^{129}I, which typically occur as anionic species. To address this challenge, phosphate-based geopolymers (PGPs) activated with phosphoric acid have demonstrated greater efficiency in immobilising anions, owing to their positive surface charge (Niu et al., 2024).

Description of the Work or Project

This research aims at developing a PGP matrix capable of immobilising a broad spectrum of contaminants, including cations and anions relevant to nuclear waste management. Novel PGP formulations were prepared using a zeolitite (a zeolite-rich rock) as the sole precursor. This precursor is particularly attractive due to its high content in chabazite (~65 wt%), a zeolite with excellent cation-exchange capacity and selectivity for Cs^{+}. Experimental variables, explored for the production of PGP specimens, included activator concentration and liquid-to-solid ratio. To assess leaching behaviour, stable isotopes of Cs, Mo, I, and Se were used to trace samples, providing insights into both cation and anion retention after a standardized water leaching protocol (ANSI). The resulting samples were further characterised through powder X-ray diffraction and scanning electron microscopy, to evaluate phase composition and morphology.

Conclusions

All samples exhibited high Cs retention (~98% after 7 days), an unprecedented result that outperforms literature studies for PGPs. Regarding anions, the immobilisation mechanism was mostly electrostatical, resulting in promising results for Mo and I. Instead, Se retention was inefficient, hence further investigation is required. The findings of this work can be useful for the development of future zeolitite-based PGP formulations, paving the way for more effective and environmentally sustainable RW management strategies. This work was conducted within the EURAD-2 project. EURAD-2 is co-funded by the European Union under Grant Agreement n° 101166718.

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STRUCTURAL INSIGHTS INTO NOVEL CHELATORS FOR ACTINIDE AND LANTHANIDE SEPARATIONS

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Introduction

Efficient isotope production and nuclear-fuel processing depend on highly selective separations of f-elements in chemically complex media (e.g., strong acids with competing ions). Currently used ligands often force trade-offs among stability, selectivity, and recyclability, leading to slow and inefficient operations. We present a structure–property framework for next-generation chelators for actinide and lanthanide[1] separations that leverages conformational preorganization and exploits minute differences in f-element coordination environments. These chelators exhibit improved ion recognition and selectivity, with potential impact ranging from medical-isotope production to spent nuclear-fuel reprocessing.

Description of the Work or Project

We designed polydentate O/N-donor ligands with conformational “locks” to reduce entropic penalties upon metal-ion binding. Complexes with Ln(III) and selected An(III) ions were prepared and characterized by single-crystal X-ray diffraction, UV–Vis spectroscopy, and NMR, establishing inner-sphere geometries and metal–donor group distances. Density functional theory quantified preorganization energies and probed binding thermodynamics.
Across the lanthanide series, observed trends follow the lanthanide contraction[1] with distinct inflection points. Ligand-backbone rigidity and donor-group positioning tightly control first-sphere coordination, enabling better discrimination of adjacent lanthanides through measurable differences in coordination geometry and physicochemical properties. These features can be harnessed to enhance the separation of adjacent lanthanide pairs.

Conclusions

The discovery and development of novel chelators for actinide and lanthanide separations are underpinned by a detailed understanding of how chelator structure governs selectivity. By precisely controlling the first-sphere coordination environment around the metal ion, we have established a robust, preorganized ligand backbone that drives preferential binding. Comprehensive synthesis and structural characterization across the lanthanide series and selected actinides advance fundamental coordination chemistry and identify practical approaches to faster and more efficient separations. These chelators lay the groundwork for improved production of high-priority radioisotopes and more effective reprocessing of spent nuclear fuel.

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SPECIATION AND VOLATILITY OF TELLURIUM EVAPORATED FROM LEAD-BISMUTH EUTECTIC

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Introduction

Lead-bismuth eutectic (LBE) is a promising coolant for next-generation lead-alloy fast reactors due to its favorable thermophysical properties. To ensure reactor safety, it is crucial to understand the volatility and chemical speciation of radioactive impurities such as tellurium (Te) – a major fission product. Tellurium is volatile in its elemental form, and some of its isotopes act as precursors to radioactive iodine, making its behavior particularly important for safety assessments and source-term evaluation.

Description of the Work

We investigated Te behavior in LBE using two complementary experimental techniques. *Thermosublimatography* was applied to elucidate the gas-phase speciation of Te evaporating from LBE, while *transpiration* experiments combined with radioactive tracer detection enabled precise measurements of extremely low vapor pressures of Te-bearing species over the temperature range of 300–600 °C. Experiments used Te-doped LBE ($x_{Te} = 1 \cdot 10^{-3}$), fused silica/stainless-steel columns, and He (dry, humidified, 10% H_2) with γ-spectrometry and SEM/EDX characterization.

Thermosublimatography revealed two deposition zones when Te was evaporated from LBE in fused silica columns: a high-temperature deposit (~500 °C) of PbTe and a low-temperature deposit (~200 °C) of crystalline Te. Further experiments showed that PbTe decomposes, releasing a volatile Te fraction that deposits at lower temperatures. This process is enhanced by water vapor and suppressed under reducing conditions. In stainless-steel columns, only PbTe deposition was observed.

Transpiration experiments revealed that the Henry's constant for Te follows the high-temperature trend, reflecting stronger Te retention in LBE than predicted by an ideal-solution model.

Conclusions

Te primarily volatilizes as PbTe rather than as elemental Te, reducing Te release to the cover gas by approximately three orders of magnitude at 380 °C. However, PbTe decomposition on fused silica in the presence of trace water vapor highlights the need for proper cover-gas conditioning and trapping materials selection. Generally, the combination of both, thermosublimatography and transpiration techniques, provides a more comprehensive understanding of Te speciation and volatility, offering valuable insights for coolant management and cover-gas chemistry control in lead-alloy fast reactors.

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ENABLING FUSION ENERGY: OPG'S TRITIUM LEGACY AND FUTURE

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Introduction

The global pursuit of fusion energy as a clean, virtually limitless power source relies on the availability of key isotopes, particularly tritium. Ontario Power Generation (OPG), through its fleet of CANDU (CANada Deuterium Uranium) reactors and the Darlington Tritium Removal Facility (DTRF), is uniquely positioned to support the emerging fusion industry. This abstract outlines OPG's role in enabling fusion energy by supplying tritium, a critical fusion fuel, and describes the technological and operational framework for this initiative.

Description of Work

CANDU reactors, unlike most other reactor types, use heavy water (D_2O) as both coolant and moderator. This design facilitates the production of tritium as a byproduct of neutron interactions with deuterium in the reactor's heavy water systems. To reduce worker dose and further minimize environmental emissions due to this tritium, OPG established the Darlington Tritium Removal Facility, the world's largest tritium extraction plant. The DTRF safely extracts, immobilizes and stores tritium from the reactor systems, reducing radiological risks and creating a valuable stockpile of this rare isotope.

Tritium extracted by OPG has been used in a variety of markets for over 30 years. These include self-luminous devices such as exit signs and watch dials, scientific research, and radiopharmaceuticals. OPG has developed a robust tritium business including immobilization, storage, and transportation of tritium, ensuring compliance with stringent regulatory standards and the needs of diverse customers.

Recognizing the strategic importance of tritium for fusion research, OPG has developed protocols and infrastructure to reliably supply tritium to fusion developers. This includes partnerships with national and international fusion projects, and ongoing investments in tritium transportation technologies. OPG's expertise in tritium handling operations and stewardship is further leveraged to ensure compliance with regulatory standards and to support the safe commercialization of fusion fuel.

To date, the DTRF has successfully extracted and stored significant quantities of tritium, making OPG one of the world's leading suppliers of this isotope. OPG's tritium supply chain has supported research projects and pilot fusion devices, contributing to the advancement of fusion science. Ongoing collaborations have positioned OPG as a critical partner in the global fusion ecosystem, with the capability to scale up supply as fusion energy transitions from research to commercial deployment.

Conclusion

Ontario Power Generation's integration of CANDU reactor technology and the Darlington Tritium Removal Facility represents a cornerstone in the supply of tritium for fusion energy. By harnessing its unique infrastructure and expertise, OPG is enabling the development of fusion as a viable energy source for the future. Continued investment in tritium transportation and collaboration with the fusion industry will ensure OPG remains at the forefront of this transformative field, supporting a clean and sustainable energy future for Canada and the world.

THERANOSTICS: RECENT ADVANCES IN THE DEVELOPMENT OF RADIOPHARMACEUTICALS FOR BRIDGING DIAGNOSIS AND THERAPY

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Introduction

The combination of diagnostic imaging and targeted therapy within a single molecular framework, commonly referred to as theranostics, has become a cornerstone of precision medicine. By using diagnostic and therapeutic radiopharmaceuticals with the same molecular scaffold, these approaches enable the visualization, quantification, and treatment of pathologies with unprecedented specificity. Clinically established theranostic pairs include PSMA-targeted agents (e.g., [^{68}Ga/^{177}Lu]PSMA-617) for prostate cancer and somatostatin analogs (e.g., [^{68}Ga/^{177}Lu]DOTATATE) for neuroendocrine tumors. Beyond these established examples, novel targeting vectors and radionuclides are currently under investigation.

Description of the Work or Project

This lecture will highlight recent progress and ongoing challenges in the development of new theranostic agents. It will provide an overview of advances in radiometal labeling using bifunctional chelators, which enable stable and efficient coordination of diagnostic (e.g., ^{68}Ga, ^{64}Cu) and therapeutic (e.g., ^{177}Lu, ^{90}Y, ^{225}Ac) radiometals under mild conditions. In addition, a particular focus will be placed on radiohalogens like $^{123/124}$I for PET and SPECT imaging and ^{211}At for α-particle therapy. These nuclides expand the theranostic toolbox beyond radiometal-based agents, offering tunable chemistry for labeling small molecules, peptides, or antibodies, while also enabling improved matching of diagnostic and therapeutic radiopharmaceuticals. However, radiolabel stability remains a major challenge, both in radiometal–chelator complexes and in halogen–carbon bonds. Therefore, innovative chemical strategies aimed at enhancing in vivo stability and minimizing radiolysis will also be discussed. Another complementary development that will be addressed is the use of bioorthogonal labeling approaches, such as the inverse electron demand Diels–Alder (IEDDA) reaction. When applied in conjunction with pretargeting approaches, such reactions allow for highly selective and efficient in vivo ligation of radiolabeled compounds at disease sites. This strategy can significantly improve imaging contrast and therapeutic indices by minimizing off-target radiation exposure and radiolysis.

Conclusions

Altogether, this lecture will provide a comprehensive overview of emerging theranostic agents, recent advances in radiohalogen chemistry, and next-generation click-based labeling strategies to highlight how integration of these innovations could shape the future of personalized nuclear medicine.

APPLICATION OF ACCELERATOR-BASED RADIOCARBON DATING TO FORENSICS

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Introduction

Radiocarbon dating has proven to be a valuable tool in forensic science across a variety of applications, including the analysis of skeletal remains, drugs of abuse, food products, and combating the illegal trade of materials derived from endangered species. A key feature in these applications is the utilization of the "bomb peak"—the increase in atmospheric radiocarbon levels caused by aboveground nuclear tests—which provides improved chronological resolution for samples younger than ~70 years (Hajdas et al. 2021). Studies have demonstrated the potential of this approach, and the International Atomic Energy Agency (IAEA) has recently supported a Coordinated Research Program (CRP) to promote the integration of nuclear-based techniques, including Accelerator Mass Spectrometry (AMS) radiocarbon dating, into routine forensic practices (Quarta et al. 2022).

We will focus on introducing the core principles of accelerator-based radiocarbon dating specifically for forensic applications, emphasizing bomb-peak dating through Accelerator Mass Spectrometry (AMS) analysis of the ^{14}C bomb pulse from nuclear tests. Different forensic fields will be examined, including skeletal remains analysis (Quarta et al. 2024), non-human biological materials, and illicit products, with attention to achievable uncertainty levels and chronological resolution (year-scale for modern samples via bomb-pulse calibration). Key methodological limitations, will also be discussed.

We will then review different, relevant case studies such as the identification of the human skeletal remains in war scenarios, the fight against the illicit trafficking of ivory, the fight against the illicit trafficking of cultural heritage (Hajdas et al. 2022).

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ULTRA-LOW BACKGROUND GAMMA-RAY SPECTROMETRY LABORATORY FOR NUCLEAR SECURITY

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Introduction

Nuclear forensics, treaty monitoring, and environmental safeguards programs rely heavily on the ability to characterize samples for trace radionuclides. Often these are environmental samples, e.g. high-volume air particulate samples or swipe samples, or other types of material contaminated with small activities of radionuclides. To enhance overall sensitivity and capability quantify these trace radionuclides we have established a new ultra-low background gamma-ray spectrometry laboratory at Los Alamos National Laboratory (LANL). This new laboratory, called "The Ice House," is located in a historic tunnel on site at LANL that was built in the late 1940s.

Description of the Work or Project

The Ice House laboratory is a medium-depth underground laboratory with 100 m of Bandelier Tuff overburden at the end of a 67 m horizontal shaft and provides approximately 300 mwe of shielding from cosmic ray background. We currently operate two HPGe detectors in the Ice House, one in a commercially produced shield, and one in a home-built shield made with low-background lead bricks manufactured from "dead lead" recovered from the historic Boston sewer system. Neither Ice House detector currently has active cosmic-veto shielding. Comparisons of gamma-ray background count rates and characteristics for the Ice House detectors with our best surface laboratory detector with active cosmic veto shielding are shown in Table 1, and a comparison of background spectra for the surface detector and better Ice House detector is shown in Figure 1.

Table 1: HPGe characteristics and background gamma count rates

Location	Detector	Shield	Gammas/minute (25 – 2000 keV)
Surface Lab	119% P-Type	Lead Commercial + Cosmic Veto	358
Ice House	116% XtRa™	Lead Commercial	118
Ice House	131% XtRa™	Low Background Lead	16

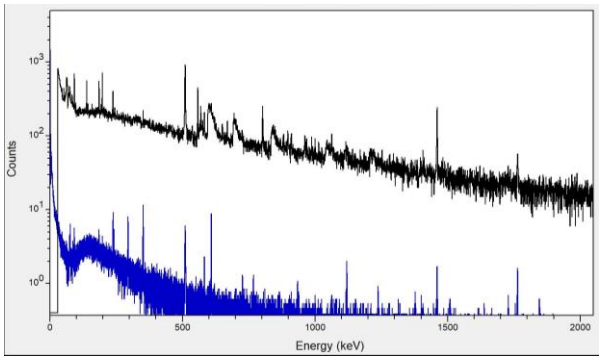

Figure 1: Surface (black) and Ice House Detector (blue) Background Spectra (1000 min)

The home-built low-background lead shield does significantly improve backgrounds over the commercial shield. However, it is also clear that the Ice House detectors would still benefit from active shielding, and maybe more importantly from radon exclusion given the Th and U series radionuclide peaks present.

Conclusions

The new Ice House laboratory is providing a convenient, local capability for low-background gamma-ray spectrometry at LANL. While the goal is to expand the number of detectors, it is already producing high-sensitivity radionuclide measurements with substantially better detection limits in support of multiple nuclear security programs.

RADIOMETALS PRODUCTION FROM LIQUID TARGETS: ICNAS EXPERIENCE

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An historical and technical overview of ICNAS pioneer work in the production of radiometals from liquid targets in a medical cyclotron setup designed for the production of 18F radiopharmaceuticals is presented, from initial motivation to present routine production of GMP compliant clinical doses of 68Ga, 64Cu, 61Cu and 89Zr.

These developments contributed to an European Pharmacopea monograph on 68Ga chloride production from liquid targets, under which ICNAS provides Portuguese PET-CT sites with 3 daily batches for clinical use under proprietary Marketing Authorization, and to weekly produtions of 64Cu, 61Cu and 89Zr for research and pre-clinical studies.

Further related developments on targetry and connected to new cyclotron features as the customizable beam energy in IBA Kiube cyclotron are also presented.

TARGET DEVELOPMENTS FOR RESEARCH AND PRODUCTION OF RADIONUCLIDES AT GIP ARRONAX

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Target manufacturing methods are key for radionuclide production. On the one hand, thin targets are useful for research activities such as cross section measurements using the stacked foils technique or to develop new chemical separation schemes using radiotracer. On the other hand, thick targets are mandatory for cost effective production of large radionuclide quantities as needed for radiopharmaceuticals. At GIP ARRONAX [1], we are focusing our work on innovative radionuclides for nuclear medicine and as such, we have to develop and characterized our own targets using the most appropriate technique. Over the last 15 years, we have developed the following techniques for target preparation:

Electrodeposition
Radiopharmaceuticals such as Cu-64, Cu-67 and Pb-203 are produced at GIP Arronax through irradiation of enriched target with light particles: Ni-64 for Cu-64, Zn-70 and Zn-68 for Cu-67 [2] [3] and Tl-205 for Pb-203 [4]. These enriched targets are manufactured by electrodeposition, which allows the preparation of both thin and thick layers.

Deposition under vacuum
Natural Bi targets are prepared by deposition under vacuum and subsequently irradiated with alpha particles to produce At-211, a promising α-emitter for targeted therapy. Thus technique allows for uniform thin or thick targets.

Molecular plating and co-electrodeposition
Obtaining enriched lanthanide deposits suitable for irradiation using electrodeposition or vacuum deposition remains challenging. In the case of electrodeposition, very negative standard potentials prevent metallic deposition, while vacuum deposition gives low yields and is problematic due to the high cost of enriched lanthanides. Molecular plating offers an alternative, yielding well-adhering, non-metallic deposits that require additional characterization. This technique has proven effective for lanthanide targets. Co-electrodeposition has also been developed, in which insoluble oxides (e.g., Gd_2O_3) are trapped in a nickel deposit [5]. Although deposition yields are low, residual particles in solution can be recycled for further use. These approaches are particularly suited for preparing thin deposits.

Pelletizing
Pelletizing provides an efficient method for preparing thick targets when electrodeposition or vacuum deposition is not feasible. Materials investigated include RbCl for Sr-82 production, Gd_2O_3 for Tb-155 production and Mo for Ru-97 production.

In this work, we intend to present an overview of the target manufacturing techniques currently applied at GIP Arronax, along with the characterization that have been developed to validate them and explain the choice of the most suitable method based on the physicochemical properties of each element.

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OPTIMIZING SOLID-TARGET PRODUCTION OF NON-CONVENTIONAL THERANOSTIC RADIONUCLIDES AT THE BERN MEDICAL CYCLOTRON

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Introduction

Theranostics in nuclear medicine relies on radionuclides to label radiopharmaceuticals for both diagnosis (β^+ or γ emitters for PET or SPECT) and therapy (α, β^- or Auger emitters). Securing their supply in adequate quality and quantity is essential for both pre-clinical and clinical applications. The widespread availability of 15-20 MeV medical cyclotrons offers a valuable opportunity, provided that suitable targets and irradiation tools are developed. In particular, solid targets enable high-yield radionuclide production, making their distribution and commercialization possible.

Material and Methods

The Bern medical cyclotron laboratory[1] features an IBA Cyclone 18/18 HC cyclotron (18 MeV protons, max. 150 μA extracted current, 8 exit ports), equipped with an IBA Nirta Solid Target Station (STS) and a 6-m-long external research Beam Transfer Line (BTL). The BTL brings the beam to a second bunker with an independent access. This setup allows industrial GMP radiopharmaceutical production in parallel with multidisciplinary scientific activities.

Results and Discussion

A dedicated aluminium capsule with magnetic closure was designed and built to irradiate enriched materials, either in the form of 6 mm pellets or foils, using the STS, thereby enabling safe post-irradiation handling in hot-cells. Beam extraction was optimized through specific upgrades of the accelerator, including the design of dedicated extraction carousels to improve the positioning of the strippers. The beam was carefully aligned and monitored with specific beam monitoring detectors, such as the Pi2[2] which is based on an ultra-thin scintillating screen. To achieve an optimized production yield with the required radionuclidic purity, we developed methodologies to accurately measure the beam energy and the cross sections. On this basis, the production yield and the purity have been studied for several medically relevant radionuclides (^{43}Sc, ^{44}Sc, ^{47}Sc, ^{61}Cu, ^{64}Cu, ^{67}Cu, ^{68}Ga, ^{99m}Tc, ^{155}Tb, ^{165}Er, ^{167}Tm)[3]. Nuclear data have been improved for most of these radionuclides.

Conclusions and outlook

Tools and techniques are developed at the Bern medical cyclotron laboratory to enhance and optimize the performance of solid target stations. These innovations can be implemented on any medical cyclotron. The promising results obtained open excellent prospects for the use of compact medical cyclotrons in theranostic applications in nuclear medicine.

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MULTI-PHYSICS DESIGN AND OPTIMIZATION OF ^{89}ZR PRODUCTION TARGET

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Introduction

Due to its 78.4 h half-life, stable labeling, and high imaging resolution, Zirconium-89(^{89}Zr) is a promising radionuclide for immuno-PET and radioimmunotherapy[1]. Although the ^{89}Y(p,n)^{89}Zr reaction peaks near 14 MeV, irradiation near this energy produces impurities and long cooling time. Using 10 MeV proton irradiation avoids competing reactions, reduces cooling time and enhances ^{89}Zr purity. This work uses a multi-physics integrating Monte Carlo and Computational Fluid Dynamic (CFD) approach to capture the coupled effects of irradiation and heat transfer and enable accurate prediction and optimization of target performance.

Description of the Work

In this study, we designed a ^{89}Zr production target and simulated its irradiation under 10 MeV proton by coupling PHITS[2] and ANSYS Fluent[3]. PHITS calculated ^{89}Zr yield and heat deposition, and the heat source was imported into Fluent via UDFs for steady-state thermal analysis. Experimental validation used temperature strips in the target chamber. Results are shown in Table 1 and Table 2.

Table 1. ^{89}Zr Activity Benchmark

Beam Intensity (μA)	Irradiation time (h)	Cooling time (h)	Activity (PHITS, mCi)	Activity (Experiment, mCi)
20	2	24	10.45	9.77
25	3	18	19.32	16.9

Table 2. Target Temperature Benchmark

Measurement method	Point 1 (°C)	Point 2 (°C)
ANSYS Fluent	50.0	50.6
Temperature strips	49	54

The target chamber was optimized via simulation to improve cooling and ^{89}Zr yield. Two designs were evaluated: (1) an inclined substrate and (2) adding a cylindrical structure beneath the substrate. Simulations showed that the first design boosts ^{89}Zr yield by ~30% and reduces target center temperature by 100 °C, while the second design lowers it by 79 °C. However, the fabrication of the second design is much easier and cheaper.

Conclusions: This work demonstrates that coupled framework is accurate and reliable for predicting both yield and thermal behavior in target systems. The approach lays a solid foundation for optimizing target chamber design, particularly thermal management, to enable sustained high-current ^{89}Zr production on 10 MeV medical cyclotrons.

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DEVELOPMENT OF NI ELECTROPLATING FOR ^{61}CU AND ^{64}CU PRODUCTION IN CLINICAL CYCLOTRONS: COSTA RICA CASE STUDY

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Introduction

The IBA-cyclotron installed at the University of Costa Rica is aiming to produce radioisotopes based-on solid targets, as well as the recently IBA-cyclotron installed in GIP Arronax [1], France. Nickel (Ni) electroplating is a promising and well documented route to manufacture targets for ^{61}Cu and ^{64}Cu production. However, several parameters must be optimized to enhance efficiency and reduce costs. This work studies approaches to adapt target fabrication for small clinical cyclotrons, providing information that can be used to produce Cu isotopes. It has been accomplished by both simulations and experimental trials.

Material and Methods

Electrolyte solutions have been prepared using nickel sulfate into a buffer of ammonia. PHREEQC simulation [2] has been used to study solution species and identify the most suitable pH range for deposition. The required thickness was simulated with RYC [3] for different irradiation energy ranges and geometries. A series of electrodeposition trials were carried out, varying stirring conditions, current density, ammonium/ammonia buffer and Ni concentrations, and pH to evaluate the current efficiency, deposition rate, pH variation and the quality of deposits. Scanning electron microscopy (SEM) was employed to characterize the morphology and Energy-Dispersive X-ray Spectroscopy (EDS) was used to determine the purity of the deposit.

Results

Results show that deposition efficiency is strongly dependent on current density, which was identified as the most critical parameter. Current densities of -8, -20 and -50 mA/cm^2 were studied with oxidation of the deposit observed at the highest value. pH also plays a central role, given its influence on nickel complexation, hydrogen and oxygen evolution reactions and effects on the deposit quality. The high pKa (9.25) of buffer helps preventing strong variation of pH while working on the surroundings of this value. Stirring is crucial to control locally pH fluctuations, to avoid deposit and anodic oxidation, and it is strongly dependent on cell geometry. Thermodynamic modeling revealed that hex-ammine nickel complexes are dominant at pH 9.8, while setting pH around 8.5 is favorable for tetra- and pent-ammine complexes. These results reveal that as the pH decrease, the complexation of Ni is also decreased. Complexation helps to avoid precipitation of nickel hydroxide. SEM imaging showed changes in deposit morphology with variation of pH and current density. EDS revealed that deposits were composed of Ni, without contamination from other components of the electrolyte solution.

Conclusions

This work demonstrated the effect of the main parameters on electroplating of Ni by adapting the target to the geometry necessary for clinical cyclotrons. For 18 MeV beam, a target surface of 59 mg/cm^2 is mandatory but this value could be reduced to 30 mg/cm^2 if a proper energy

degrader is employed. These findings provide evidence for developing affordable and efficient production routes of ^{61}Cu and ^{64}Cu in low-income centers, facilitating future expansion of solid target short half-life isotopes.

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R&D ON MEDICAL RADIONUCLIDE PRODUCTION AT INFN-LNL: FOCUS ON SOLID TARGET MANUFACTURING TECHNIQUES

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Introduction

In recent years, the scientific community has shed light on innovative radionuclides that hold great promise for the so-called "precision medicine". Among them, radiometals with theranostic/therapy properties are gaining attention because they can be used to label molecules better suited to specific pathologies. The most desired radiometals are typically produced using the direct activation method, which involves cyclotron irradiation of a solid target. To this end, the SPES cyclotron at INFN-LNL may represent a resource for the advancement of research in this field. The manufacturing of solid targets is a complex process that relies on many aspects, covering different areas of knowledge. Thus, research and development activities on solid target manufacturing technology are crucial to ensuring a reasonable supply of radionuclides with the requested radionuclide/radiochemical purity.

Description of the Work or Project

Over the past decade, in the framework of the LARAMED program (Laboratory of RAdionuclides for MEDicine) and its associated projects[1], innovative techniques in this field have been explored to meet the main requirements for designing and manufacturing solid targets for nuclear cross-section measurements and for actual radioisotope production. Among them, HIgh energy VIbrational Powder Plating (HIVIPP), Magnetron Sputtering (MS), and Spark Plasma Sintering (SPS) processes have shown great potential. Indeed, the manufactured targets of different materials have been successfully used for nuclear cross-section measurements and for radionuclide production by a medical cyclotron. It is essential not only to select a suitable technique but also to develop the apparatus that ensures the reproducibility of the process. INFN-LNL is the first research facility to use the SPS process for target manufacturing, showing its great potential in the field[2]. The advantages of SPS are time, energy, and material efficiency compared to other methods. The targets, manufactured using SPS, were used to produce several promising radionuclides: $^{52/51}$Mn, ^{89}Zr, $^{61/64/67}$Cu and ^{155}Tb.

Conclusions

Continued investigation of target manufacturing techniques is necessary, since no single method can be suitable for all materials and to satisfy all the needs of nuclear medicine.

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ADDITIVE MANUFACTURING OF URANIUM CARBIDE TARGETS FOR THE PRODUCTION OF RADIOISOTOPES FOR NUCLEAR PHYSICS AND MEDICINE

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Introduction

The development of targets is a key aspect in the production of radioisotopes for nuclear physics and medicine. In ISOL (Isotope Separation On-Line) facilities, porous uranium carbide is the most used target material. In this work, we present the use of additive manufacturing to produce innovative uranium carbide/carbon nanocomposites.

Description of the Work or Project

In the framework of the Open Access to JRC Physical Research Infrastructures of the European Commission, in the ActusLab-PAMEC (Properties of Actinide Materials under Extreme Conditions) facility at JRC-Karlsruhe, we developed a technique to produce uranium carbide/carbon nanocomposites in the form of 3D complex structures. To do so, we worked with the sol-gel method, exploiting the unique photochemical properties of UO_2^{2+} complexes[1]. The technique we used is indeed based on the use of uranyl cations as a photoinitiator for the development of photocurable sol-gel-based formulations, coupling the photochemical reactions of uranyl cations with photopolymerisation processes. The obtained material has been 3D printed and subsequently thermal treated to form uranium carbide (UC_2) and carbon in the form of nanocomposites with complex structures, such as Kelvin cells (Figure 1) or gyroids.

Figure 1: UC_2/C nanocomposite as-printed (left) and after thermal treatment (right).

Conclusions

The obtained materials represent the first example of 3D printed uranium-based monoliths produced by photopolymerization, and pave the way for new developments in target materials and geometries for the production of radioisotopes.

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NOVEL RADIOISOTOPE PRODUCTION IN RESEARCH REACTORS IN POLAND AND EASTERN EUROPE

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Introduction

Nuclear research reactors are crucial facilities for producing radioisotopes. The Maria research reactor at the National Centre for Nuclear Research (NCBJ) in Otwock, Poland, with a maximum power of 30 MW and a neutron flux of 2.5×10^{14} $cm^{-2}s^{-1}$, is classified as a medium-flux reactor. Along with other research reactors in the region, it plays a vital role in the global supply of Mo-99, I-131, and other vital radionuclides used in medicine, such as Lu-177 and Ho-166.

Description of the Work

The Maria research reactor and GMP-certified facilities at the Radioisotope Centre POLATOM are part of the NCBJ's unique research infrastructure. Extensive research on developing technologies for neutron-irradiated radionuclides and their therapeutic applications is conducted in collaboration with clinical partners and funded by national and European sources. Recently, NCBJ/POLATOM led the SECURE project (1), which focused on advancements in designing irradiation targets and production methods for both existing and new isotopes used in nuclear therapy and diagnostics. The organization also contributed to the PRISMAP project (2) and IAEA-coordinated research efforts. As a result, technologies for producing isotopes such as Tb-161 and Sc-47 have been successfully implemented (3,4). The potential of NCBJ to supply medical isotopes is further strengthened through the CERAD project (5).

Conclusions

Radiopharmaceuticals are a vital category of medicinal products in modern nuclear medicine. In the age of expanding Radioligand Therapy, RLT, the importance of research reactors in producing medical isotopes is clear.

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DEVELOPING A REACTOR-BASED ISOTOPE PRODUCTION ROADMAP IN KOREA WITH THE NEW RESEARCH REACTOR

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Introduction

In recent years, the successful development and commercialization of radiopharmaceuticals such as Lutathera and Pluvicto have led to a sharp increase in global demand for medical radioisotopes. Consequently, the stable supply of beta-emitting isotopes such as Lutetium-177 and alpha-emitters such as Actinium-225 has become increasingly critical, driving significant investments from both governments and major pharmaceutical suppliers. Research reactors play a pivotal role as essential infrastructure for the production of therapeutic and diagnostic radioisotopes.

Discussion

MIRARO, the new research reactor of Korea, and the Fission Molybdenum-99 Production Facility (FMPF) are scheduled to be constructed in 2027, and to commence operation in 2028. In recent years, KAERI has been developing an LEU-based fission Mo-99 process to be implemented in MIRARO, which is currently under construction in the city of Busan, Korea. However, for the commercial production of Mo-99, scale-up and extensive validation experiments are needed using HANARO. The quality of the process as well as the product should be verified and demonstrated through repeated cold and hot tests. Safety and efficacy data of the Active Pharmaceutical Ingredients (APIs) should also be generated through the demonstration.
Currently, the design and construction of the demonstration system are expected to be completed by 2025, and cold and hot demonstration experiments using the system are planned to begin in 2025. In addition, KAERI plans to carry out the development of hot cell facilities and production processes for Lu-177, with the goal of routine supply by 2030.

Conclusions

This presentation will provide an overview of the current construction status of Korea's new research reactor and outline a roadmap for the supply of medical radioisotopes utilizing this facility. MIRARO will primarily produce major radioisotopes such as Mo-99, I-131, I-125, Ir-192, and Lu-177..

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THE USE OF LOW POWER RESEARCH REACTORS TO DEVELOP NEW PROTOCOLS IN THE PURSUIT OF EXOTIC RADIONUCLIDE PRODUCTION

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Introduction

The field of medical radionuclide production is well established, sinking its roots in the possibilities given by nuclear reactors and cyclotrons alike. Nonetheless, there is a constant drive for the development of new and exciting protocols leading to the discovery of novel radionuclides with vast applications.

Description of the Work or Project

It is in this setting that Pavia's TRIGA MK II [1] research reactor fulfils its purpose, where the synergic collaboration with the University's departments, allows for the upbringing of a new wave of bachelor's, researchers, and doctorates in the domain of nuclear sciences, which in turn grants quality publications and efficient use of the facility both in terms of research progress and in meeting LENA's training goals. The apparent limit of low-power reactors with insufficient fluxes for the commercial production of commonly employed radionuclides can be mitigated by switching the focus to a research and training approach. The identification of various exotic radioisotopes of interest, such as ^{111}Ag, ^{161}Tb, ^{64}Cu, ^{166}Ho, along with the more common ^{99m}Tc, and the establishment of fruitful collaborations with many organisations, such as INFN for the ISOLPHARM [2] project, and ENEEP, have helped to highlight the potential of this type of facility and the possible contributions that they can bring to life (see table 1 below). This work will focus on the milestones of the LENA facility, particularly in terms of training and research, with specific emphasis on the data gathered over the years.

Nuclide	Target
^{111}Ag	^{110}Pd
^{161}Tb	^{160}Gd
^{64}Cu	^{64}Zn
^{166}Ho	^{165}Ho

Table 1: List of nuclides treated in this work and their corresponding starting material

.

For each nuclide, the description of the production and separation routes and challenges encountered during the development phase will be provided.

Conclusions

While the production of radioisotopes in a facility such as a low-power reactor is usually restricted to the largest neutron flux available, it is not necessarily the case when trying to showcase the versatile capabilities of a research reactor to students with diverse backgrounds. An academic research reactor like the TRIGA in Pavia can be considered a meeting point for different research areas paving the way for in vivo and in vitro studies greatly increasing the chances of the development of new radiopharmaceuticals.

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THE FAILURE OF PM-147 SORCES: DAMAGING THE IMAGE OF THE ISOTOPE INDUSTRY

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Pm-147 is a reactor-produced radionuclide widely used in industry as a source of beta radiation with an average electron energy of 61.8 keV. Promethium-147 sources are used for thickness measurement of various materials, as well as for the production of phosphors, atomic batteries, etc.

Traditionally, two methods have been used to produce Pm-147. The first method is reactor irradiation of Nd-146. As a result of an (n,γ) reaction, Nd-147 (10.987 d) is formed, which then decays via beta-minus decay into Pm-147. The second method is from U-235 fission products during the reprocessing of spent nuclear fuel, as Pm-147 is a fission fragment. Russia has a well-developed technology for reprocessing spent nuclear fuel, which allowed for the stable and cost-effective production of various radionuclides, including Pm-147, for the needs of the nuclear industry. However, with the subsequent development of reactor technologies, the reactor campaign duration increased from 3 to 5 years, which significantly complicated fuel assembly handling. Due to the need for longer cooling times for fuel assemblies in cooling ponds, obtaining Pm-147 from spent nuclear fuel became economically unviable.
By 2020, a shortage of Pm-147 began to be observed on the global market. At the same time, there are numerous enterprises worldwide with industrial equipment designed to operate with sealed Pm-147 sources. The unexpected shortage of such an important radionuclide casts a shadow over the entire nuclear industry and damages the image of reliability of nuclear technologies.
This report is dedicated to the work on finding a way out of this crisis situation, conducted by RITVERC in collaboration with RIAR. To resolve the crisis, RITVERC, together with RIAR, initiated a project to restart isotope production via the reactor method by irradiating an Nd-146 target.

As a result of this work, Pm-147 was produced in the high-flux SM-3 reactor from natural neodymium; radiochemical separation technology and radiometric methods for monitoring intermediate and final products of radiochemical processing were developed. A Pm-147 preparation of the required radionuclide purity was obtained, and a technology for manufacturing sealed radionuclide sources based on it was developed.

KIJANG RESEARCH REACTOR LICENSING AND CONSTRUCTION STATUS

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Introduction

The Kijang Research Reactor (KJRR) is a radioisotope production reactor mainly for stable domestic supply of medical radioisotopes. The construction of KJRR started in May 2022 and the reactor facility operation license has been requested in October 2023 targeting the first reactor criticality in December 2027. The construction progress rate is 37.06% as of September 30, 2025.

KJRR Project Status

The Kijang Research Reactor (KJRR) facility consists of five main buildings (reactor building, fission moly production building (FMPB), utility building, radioisotope production building, and radioactive waste treatment building) and auxiliary buildings such as electricity building, cooling tower, demineralized water production building, natural evaporation building, stack, etc. The reactor pool surface is about few meters below the ground level. The service pool is separated from the reactor pool by a pool door and the spent fuel storage racks are located at the bottom of the other end of the service pool. There are 22 fuel assemblies of which 6 follower fuel assemblies are for reactor shutdown. The nuclear fuel is U-7Mo of LEU and the fission moly target is UAlx of LEU, which will be manufactured and supplied by KAERI. The 6 holes for on-power loading of fission moly are located in the reactor core box of 9 by 7 lattice and 5 holes for neutron transmutation doping (NTD). The 6 and 8 inched of Si-ingot can loaded for NTD and 12 inch holes can be replaced with 6 inch holes when there is market demand for 12 inch Si-ingot.

The irradiated fission moly target is moved to the FMPB through the transfer elevator. There are two tracks of 6 hot cells (transfer hot cell, receiving hot cell, dissolution hot cell, separation hot cell, purification hot cell, and packaging hot cell) for Mo-99 production. Underneath the dissolution hot cell, there is a uranium filter cake storage room which can store the U filer cakes from 50 years of moly production.

Conclusions

The reactor commissioning division has been organized in August 2024. The electric power system has been initially energized in June 2025 and followed by electric system performance tests which are in the third stage of pre-use inspection. The final pre-use inspection starts with the nuclear fuel loading in the reactor core approaching to the first criticality followed by reactor performance tests. The planning for reactor facility operation starts at the end of 2025 to secure the operation budget needed from 2028.

Reference

Integral Project Schedule rev. 2 (project internal version)

Keywords *Kijang Research Reactor, Mo-99 production, neutron transmutation doping*

USING 3D PRINTING STRUCTURES AS A TOOL FOR OPTIMIZING THE SYNTHESIS PROCESS OF ^{18}F-FDG

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Introduction

^{18}F-FDG is one of the most widely used radiopharmaceuticals in nuclear medicine. Its production is carried out through automated synthesis modules that employ disposable cassettes, specific reagents, the mannose triflate precursor, and solid-phase extraction cartridges for purification of the final product. Internationally, several companies manufacture and market ^{18}F-FDG productions kits, including ABX and Huayi. To prevent leaks during the process, whether due to human error or system failure, a 3D-printed structure was designed to support the cartridges that take part of the Integrated Fluidic Processor (IFP).

Description of the Work or Project

The use of disposable cassettes in automated ^{18}F-FDG production has occasionally led to synthesis failures, including leaks during the purification stage of the radiopharmaceutical. These issues may arise from human errors, such as improper cartridge placement and/or from system failure such as overpressure during synthesis. To address these challenges and prevent radiological protection issues associated with cartridges misalignment in the synthesis module, a 3D-printed support structure was developed. This device was designed to securely contain and stabilize the three purification cartridges (SCX, Alumina and HLB) along the QMA cartridge of the ^{18}F-FDG synthesis kit. The structure is shown in figure 1.

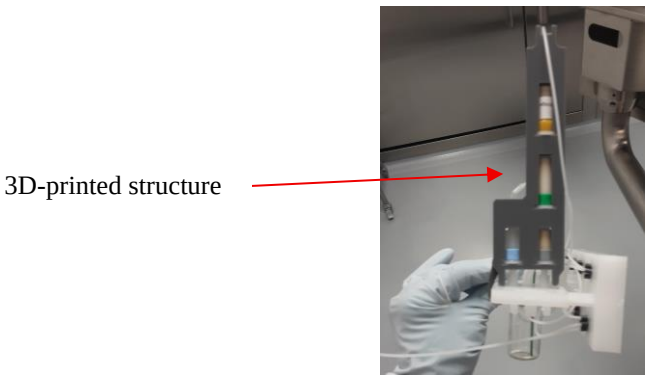

Figure 1. 3D-printed structure for the cartridges in the ^{18}F-FDG synthesis kit.

Conclusions

The implementation of this support mechanism successfully established a system for containing potential leaks during ^{18}F-FDG production, thereby increasing user confidence and improving the reliability of the radiopharmaceutical synthesis process. Its integration does not represent a significant increase in synthesis cost, is reusable for each production cycle, and can be easily incorporated into the cassette assembly.

Keyword: 3D printing, automated synthesis, ^{18}F-FDG, disposable cassettes

Cu-64 enables nanobody-based myeloid cell PET imaging in multi-center translational workflows

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Introduction

Nanobody-based PET tracers have emerged as highly specific tools for imaging defined immune cell subsets with rapid tissue penetration and fast blood clearance. Short-lived positron emitters as ^{18}F are well-suited due for such rapid pharmacokinetics but can limit coordinated multi-center workflows. We therefore explored ^{64}Cu as a radionuclide platform for nanobody imaging targeting immune cells in the context of viral infection.

Description of the Work or Project

We selected a previously validated SIRPα-specific nanobody targeting pan-myeloid cells and optimized its design for site-specific coupling of the chelator NODAGA. ^{64}Cu was produced via ^{64}Ni(p,n)^{64}Cu on a medical cyclotron with trace-metal-clean purification to achieve radiolabeling at high molar activity.

Radiolabeling was performed under mild conditions with full quality control, including biological assays. The 12.7 h half-life of ^{64}Cu enabled post-labeling stability testing and controlled inter-laboratory shipment of the ready-to-inject tracer from Tübingen to BPRC (Rijswijk, NL), where non-human primate (cynomolgus macaque) PET/CT imaging was conducted on clinical scanner platforms.

In vivo, SIRPα-directed PET revealed the spatiotemporal distribution and recruitment dynamics of myeloid cells, whereas TSPO-PET reflected macrophage activation states. These complementary signals illustrate distinct biological dimensions: SIRPα maps total myeloid cell presence and redistribution, while TSPO highlights metabolically active, tissue-remodeling macrophage populations.

Conclusions

^{64}Cu provides strategic advantages for nanobody-based PET beyond biological half-life matching, particularly for multi-site translational workflows. As distributed imaging pipelines and cross-institutional validation become increasingly important, this strategy supports both methodological rigor and practical feasibility of collaborative PET imaging.

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RADIOACTIVE ^{11}C-ION BEAMS FOR SIMULTANEUS TREATMENT AND IN-BEAM PET IMAGING OF MOUSE OSTEOSARCOMA MODEL

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Introduction

Charged particle therapy with protons and stable carbon ions enables highly precise dose delivery, but it is sensitive to uncertainties in the beam range[1]. In-beam positron emission tomography (IB-PET) allows for a non-invasive in vivo range monitoring during irradiation[2]. However, low count rates, biological washout, and broad activity distributions have limited its clinical use. An alternative is the use of radioactive ion beams (RIBs) for simultaneous treatment and IB-PET imaging. RIBs can provide improved signal quality and a closer match with the dose fall-off, enabling more precise in vivo beam range monitoring. Until recently, clinical use was constrained by the challenges of producing RIBs at sufficient intensity[3].

Description of the Work

With the intensity upgrade of the SIS-18 synchrotron at GSI Darmstadt, RIBs can now be produced at intensities sufficient for preclinical therapeutic applications[3]. Within this framework, the BARB experiment was initiated, aimed at performing the first in vivo tumour treatment with RIBs[4]. A mouse osteosarcoma was irradiated with ^{11}C-ions, and treatment delivery was monitored online using the SIRMIO in-beam PET scanner[5]. The tumour was implanted in the neck, near the spinal cord, increasing the risk of radiation-induced myelopathy from even slight beam-range variations. Complete tumour control was achieved with a single 20 Gy fraction, with IB-PET imaging allowing precise dose-range localization and sparing of the spinal cord[4].

Conclusions

This study demonstrates, for the first time, the feasibility of using ^{11}C-ion RIBs to achieve tumour control while enabling simultaneous precise in vivo IB-PET monitoring of dose range. RIBs therapy offers a pathway toward safer, margin-reduced, image-guided treatments. These results can represent a significant step toward the future clinical translation of RIB therapy[4].

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KFSH&RC'S 45-YEAR RADIOPHARMACEUTICAL JOURNEY: A LEGACY OF INNOVATION, AUTOMATION, AND CLINICAL IMPACT

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For over 45 years, the Cyclotron and Radiopharmaceuticals Department (C&RD) at the King Faisal Specialist Hospital and Research Center (KFSH&RC) has been a key player in radiopharmaceutical production in Saudi Arabia. Established in the late 1970s, it was among the first in the region to produce medical radionuclides locally, minimizing reliance on imports and ensuring timely access to essential diagnostic and therapeutic agents, particularly for cancer and cardiovascular conditions. The department has developed over 25 types of radiopharmaceuticals and has produced more than 650,000 doses, supplying over 50 specialized medical centers across the Kingdom[1]. C&RD adheres to international Good Manufacturing Practices (GMP), Saudi Food and Drug Authority (SFDA) regulations, and ISO 9001 Quality Management System standards, ensuring high safety, purity, and efficacy[1,2].
Innovative achievements include regional production of advanced compounds such as FES and F-PSMA for diagnosing breast and prostate cancers, and the complete automation of [^{18}F]SFB[3] synthesis. Research efforts have focused on improving radiotracer purity, studying rare tumors, and exploring next-generation PET agents and alpha-emitter radiopharmaceuticals.

As a leader in nuclear medicine, C&RD-KFSHRCRC aims to expand automation, develop theranostic agents, and achieve national self-sufficiency in radiopharmaceuticals, aligning with Saudi Arabia's healthcare innovation goals.

In summary, the department's legacy is defined by scientific rigor, clinical relevance, and strategic foresight. From manual synthesis to automated platforms and nanomedicine[4], the department continues to shape the future of molecular imaging in the Kingdom and beyond.

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Imaging Performance of a Planar Segmented HPGe Detector for γ-Ray Detection and Quantification

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Introduction

Segmented high-purity germanium (HPGe) detectors offer excellent energy resolution and sensitivity to the position of γ-ray interactions. Image quality depends on how precisely interaction positions are identified through electrode segmentation and pulse-shape analysis (PSA). Compton imaging using a planar segmented HPGe detector as a single-module has been investigated by reconstructing two-site (Fold-2) events and evaluating the achievable image resolution and efficiency in a compact configuration that is relevant to security, waste characterization, and cultural-heritage diagnostics.

Description of the Work or Project

A physics-based Solid-State Detector model produced a library of unit-energy superpulses of gamma ray interactions covering the active volume. GEANT4 simulations of a ^{137}Cs point source at a 10 cm standoff generated Fold-2 full-energy events. For each event, an adaptive grid search algorithm over relative drift-time offsets aligned two candidate templates, and constrained least squares provided the energy weights and two interaction positions. These positions served as inputs to analytical back-projection of Compton cones. For a central source, the reconstructed image shows a compact hotspot with FWHM 47.77 ±0.98 mm. For an off-axis source at $x = -100$ mm, the FWHM broadens to 52.83±2.34 mm with slight asymmetry, consistent with solid-angle and kinematic-acceptance effects

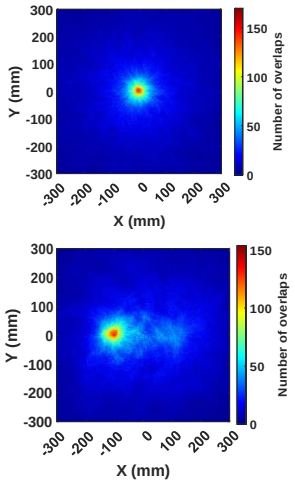

Figure 1. Reconstructed image slices of a ^{137}Cs point source located centrally (up) and offset (bottom)

Conclusions

These results show that a single planar segmented HPGe detector can perform Compton imaging as a stand-alone detector. Adding a thin scatter layer is expected to increase the number of usable events, favor smaller scatter angles, and improve angular resolution. The approach is applicable to isotope applications across medicine, safety and security.

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Keywords

Compton imaging; HPGe; pulse-shape analysis; γ-ray detectors; isotopes

PRODUCTION OF RADIOACTIVE NANOPARTICLES OF ^{44}Sc AND ^{43}Sc: PIONEERING THE FUTURE OF MEDICINE

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Introduction

Scandium-44 (^{44}Sc) and Scandium-43 (^{43}Sc), have gained significant attention in recent years due to their promising applications in nuclear medicine, targeted radiotherapy, and imaging techniques. On the other hand, Nanomaterials have revolutionized cancer research by their high surface area, tunable size, and functionalization capabilities. Considering these effective properties of radioactive materials and nanomaterials, we have undertaken a research program to synthesize Radioactive nanoparticles of Sc isotopes (RaNPs-Sc). The whole process has been carried out in fully automated fashion.

Description of the Work

We investigated the production of ^{44}Sc via the ^{44}Ca(p,n) ^{44}Sc and ^{43}Sc via the ^{43}Ca(p,n) ^{43}Sc nuclear reaction using a proton beam (8 MeV). The separation of radioactive Sc from Ca was carried out using DGA resin successfully and confirmed using ICP-OES, demonstrating high purity and recovery of Sc. Using the same apparatus, non-active NPs-Sc were synthesized via co-precipitation method by reacting separated Sc radioisotopes with ammonium bicarbonate, facilitating controlled precipitation with average size of 1nm in automated fashion (Figure 1).

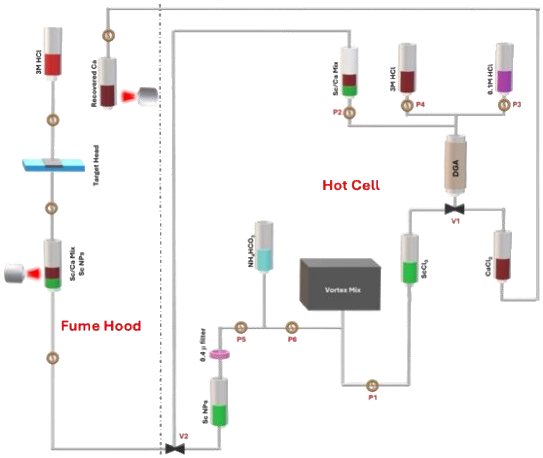

Figure 1. Schematic representation of the entire automation process. The target is positioned inside the fume hood, where irradiation and dissolution of irradiated target occur. After the dissolution step, the subsequent separation and synthesis processes are conducted within the hot cell.

Conclusions

Production of ^{44}Sc and ^{43}Sc was successfully carried out using an automated process, ensuring precision and reproducibility. The procedure effectively confirmed successful dissolution and separation. We hope to present the synthesis of highly radioactive nanoparticles which will exhibit significant potential for applications in cancer treatment, offering a promising avenue for targeted delivery and enhanced therapeutic efficacy.

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DELAYED PET IMAGING OF PROSTATE CANCER USING LONG-LIVED RADIONUCLIDES

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Introduction

In the setting of biochemical recurrence (BCR) of prostate cancer with rising prostate specific antigen blood marker levels, the precise localization of corresponding lesions by "conventional" PET/CT imaging using ^{18}F- or ^{68}Ga-labeled radiotracers targeting the prostate specific membrane antigen (PSMA) remains challenging due to negative or inconclusive results.[1,2] One reason is the relatively high bladder uptake at early time points overlapping with disease recurrence, often manifesting in the former prostate bed. A potential solution is delayed PSMA-PET/CT imaging using long-lived radionuclides such as Zr-89 and Cu-64.

Description of the Work or Project

For the detection of BCR in patients with inconclusive or negative PET/CT scans using [^{18}F]DCFPyL or [^{68}Ga]Ga-PSMA-11, we recently established the production of [^{89}Zr]Zr-PSMA-617.[3] We also developed a novel homotrimeric PSMA conjugate based on the NOTI chelating platform.[4] This trimer exhibited an altered biodistribution profile compared to monomeric radiotracers such as PSMA-11. Furthermore, the trimer showed an increased binding to serum proteins resulting in prolonged blood circulation. Indeed, PET/CT imaging using [^{89}Zr]Zr-PSMA-617 allowed the unambiguous identification of BCR in patients at 48 h post administration due to low activity in the bladder and significantly increased tumor-to-background ratios. Similarly, BCR could also be detected with the ^{64}Cu-labeled trimer. Noteworthy, due to the initial lower kidney uptake and corresponding lower activity in the bladder, corresponding lesions could already be detected as early as 3 h post administration.

Conclusions

In patients with inconclusive or negative conventional PSMA-PET/CT, BCR could be detected by [^{89}Zr]Zr-PSMA-617 and [^{64}Cu]Cu-Trimer PET/CT. While the optimal imaging time point was 48 h for [^{89}Zr]Zr-PSMA-617, comparable results could be obtained already 3 h post administration with the [^{64}Cu]Cu-Trimer being the consequence of its altered biodistribution compared to monomeric radiotracers.

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NOVEL MICROWAVE DISSOLUTION METHODS FOR NUCLEAR FORENSICS APPLICATIONS

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Introduction

Destructive elemental and isotopic analysis of bulk material is a key tool for nuclear forensics investigations since non-destructive analysis is not always representative of the whole sample. The rate determining step of many analytical protocols is sample dissolution. Rapid and complete dissolution is essential. A wide range of sample types may be collected that challenge dissolution procedures, therefore dissolution methods must also be robust to variations in sample matrix and composition.

Description of Work

A cellulose-based filter can be used to collect environmental materials of importance to nuclear forensics. This sample type is challenging due to a high organic content, requiring strong oxidising agents, such as perchloric acid, for decomposition of species that interfere with chemical separation. This presentation details a new method which uses microwave digestion to rapidly dissolve this material. Irradiated uranium produced by Idaho National Laboratory and, separately, elemental standards of Ce, Sm, Tb, Y, Eu, Sr and Mo were used for method validation. Samples were added to the microwave vessels prior to dissolution and measured post-dissolution by gamma spectrometry and Inductively Coupled Plasma Optical Emission Spectroscopy (ICP-OES) to assess chemical recovery.

Conclusions

This method has improved dissolution timelines, whilst ensuring 100% analyte recovery (Figure I). Future research is planned to test how robust this method is to variations in environmental matrix present on the filter. A range of environmental and geological matrices will be examined to assess the performance of this method when applied to the large range of samples that may be receipted as part of a nuclear forensics investigation.

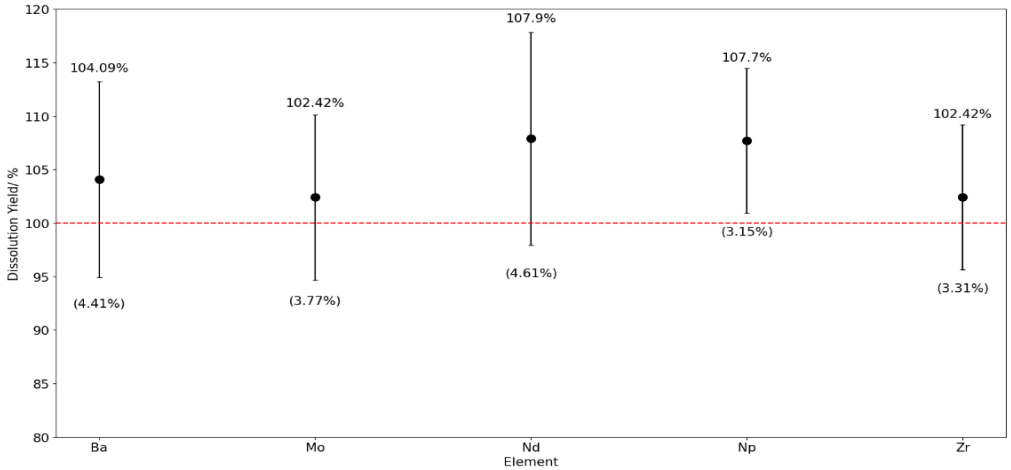

Figure 1 *Dissolution recoveries of Ba, Mo, Nd, Np and Zr from the dissolution of a filter paper doped with solution of actinides and fission products and solid geological matrices. Red horizontal line represents a 100% analyte recovery. Recovery determined by ratioing pre-dissolution High Purity Germanium (HPGe) gamma spectrometry measurements of doped filter to HPGe gamma spectrometry measurements of an aliquot of post-dissolution 'A' Solution. Uncertainties bars are k = 2, uncertainties quoted are RSD quoted to k = 1.*

Particle Size Characterization of $^{238}PuO_2$ Particles via Autoradiography and Scanning Electron Microscopy Automated Particle Analysis for Incident Response

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Introduction

In the event of a ^{238}Pu release incident, establishing the particle size range of the material is imperative to understand why the release occurred, determine the extent of dispersion, and provide key parameters for dose estimates in cases where inhalation exposures occur. These are often challenging measurements due to the combination of small particle size and low number of particles in any single sample. Here we improve and expand upon previous work combining autoradiography and scanning electron microscopy (SEM) with energy dispersive x-ray spectroscopy (EDS) automated particle analysis (APA) software to locate, characterize and determine the particle size distribution of trace $^{238}PuO_2$ particles.

Description of the Work or Project

Sample collection swipes contaminated with $^{238}PuO_2$ from a material release incident were prepared into 1" silicon wafers particle mounts. Each Si wafer was counted for total alpha activity and autoradiographed to produce a spatially resolved image of alpha activity. The autoradiographs provided estimated locations of $^{238}PuO_2$ particles by overlaying a semi-transparent image of the autoradiograph on an image of the sample. Samples were loaded into the SEM and Oxford Instrument's APA software, AZtec Feature, was used to investigate regions on the sample where the autoradiograph displayed high activity. A precise correlation between the sample image and the autoradiography was made and used for navigation. Using this final correlation, the SEM stage was moved to every region displaying visible activity. All located $^{238}PuO_2$ particles were measured for physical dimensions and analyzed via EDS for chemical composition. This technique resulted in a particle size distribution for 78 $^{238}PuO_2$ particles; a significant improvement from previous work[1,2].

Conclusions

Rapid location and analysis of $^{238}PuO_2$ particles by combining autoradiography with APA software on SEM-EDS provides a novel approach building on previous work to characterize trace actinide particles in contaminated materials. This analysis provides important, time-sensitive information in the case of material release incidents and lends well many applications that require characterization of nuclear material particles.

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Key Words

SEM, EDS, autoradiography, $^{238}PuO_2$, automated particle analysis, nuclear safeguards

ANALYSIS OF SMALL SAMPLES OF SPENT NUCLEAR MATERIALS FOR INTERPRETING REACTOR OPERATING HISTORY

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Interpreting the operating history of a nuclear reactor is a key question in safeguards, nuclear forensics, and studies of environmental contamination. It can help answer questions related to the amount and quality of Pu or other radioactive materials that were produced during the irradiation. Traditional approaches to characterizing spent nuclear fuels rely either on radiometric counting and/or mass spectrometry, usually relying on chemical purification of the specific analyte to increase precision and accuracy. Here we present an approach using resonance ionization mass spectrometry (RIMS) to precisely analyze small, solid samples of spent nuclear materials to characterize isotope ratios of multiple elements simultaneously, without prior chemical separation. Dispensing with chemical separation avoids the addition of chemistry "blanks" (background), measuring multiple elements from the same volume allows the correlation of multiple irradiation characteristics, and working from small samples decreases the radioactive hazards in the laboratory.

We have applied Lawrence Livermore National Laboratory's state-of-the art characterization capabilities [1] to several samples of spent nuclear material (see Figure 1). This presentation will explain how we can analyze nearly any combination of 3 elements including U, Pu, Am, Sr, Rb, Mo, Zr, Nd, Ba, Cs simultaneously [1], usually with enough material remaining to analyze the others in a subsequent analysis. We will show how connecting multiple isotope ratios across elements and comparing those analytical results to computational models provide an improved understanding of the operating history of a nuclear reactor.

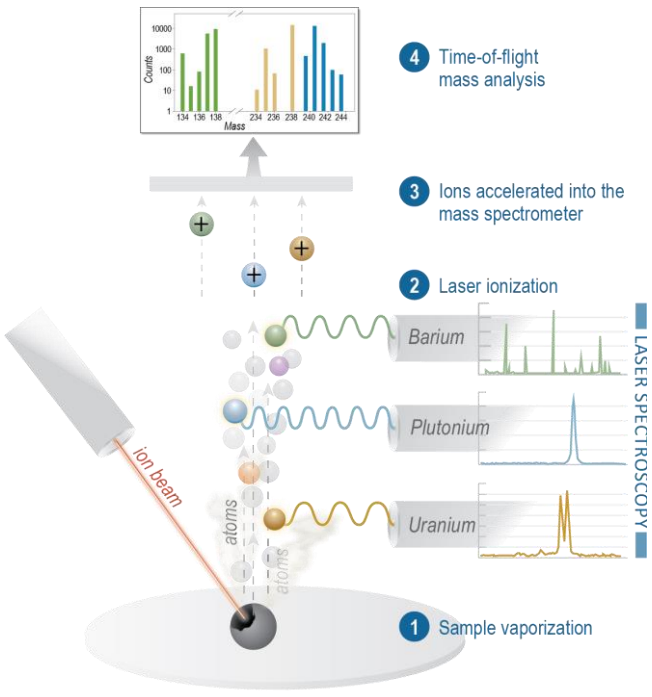

Figure 1: A diagram of analysis using the LLNL LION instrument to resonantly ionize multiple elements, simultaneously (in this case U, Pu, and Ba). (1) After sample atomization, (2) neutral atoms are ionized using tailored laser wavelengths, (3) the resonantly ionized ions are then accelerated into a drift tube and (4) mass analyzed by time-of-flight mass spectrometry.

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VALIDATION OF A FAST METHOD FOR DETERMINATION OF AM-241 IN NASAL MUCUS SAMPLES USING HIGH RESOLUTION GAMMA SPECTROMETRY

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Introduction

In occupational radiation protection and in emergency situations, fast assessment of nasal mucus contamination may represent a valuable tool, in that it enables to quickly obtain indication for possible administration of appropriate chelating agents or equivalent drugs to workers or other potentially contaminated people, e.g. in a mass accident.
With the aim of bypassing the typical time-consuming and sometimes complex radiochemical procedures used in quantitative determinations of virtually every alpha emitting radionuclide by alpha spectrometry, in this work we present the validation of an original and simple analytical method exploiting high resolution gamma spectrometry for the quantitative determination of Am-241 in nasal mucus samples.

Description of the Work or Project

The analytical method can be summarized as follows. After appropriate washing/decontamination of the face of the potentially contaminated worker/person, their nasal mucus is collected on a commercially available paper tissue. The tissue is transferred into a small plastic container of the type used for routine urine clinical tests, then 4 mL 1 mol L^{-1} HCl in deionized water are added to the sample. The sample is pushed to the bottom of the plastic container with the aid of the pipette tip used to dispense the hydrochloric acid solution (or other equivalent method), in order to obtain a sample counting geometry as uniform and reproducible as possible. The container is finally closed with its lid and the sample is counted in a HPGe detector for 15 minutes. Energy calibration of the HPGe detector is performed with appropriate standard radioactive sources, while efficiency calibration is carried out via Monte Carlo method, using sample composition and geometry, as well as detector characterization, as input data.
The method has been validated with samples actually spiked with Am-241, at three different activity levels of interest, evaluating trueness, precision, repeatability and reproducibility.
Both the internal validation and the results obtained across the years in external proficiency test exercises (Procorad circuit) confirm the fitness of the analytical method for the intended purpose.

Conclusions

In this paper the authors present a novel, fast and simple analytical method for the quantitative determination of Am-241 in nasal mucus samples. The method exploits high resolution gamma spectrometry and, with commercial HPGe detectors and standard electronics, it ensures a detection limit as low as 0.50 Bq/sample with 15 minutes counting time.
The method may then quickly provide medical officers and other appropriate professional staff with an indication for preventive or therapeutic administration of chelating agents or equivalent drugs.

RAPID COLUMN-BASED SEPARATION OF KEY ACTINIDE AND FISSION PRODUCTS OF URANIUM FOR NUCLEAR FORENSIC ANALYSIS

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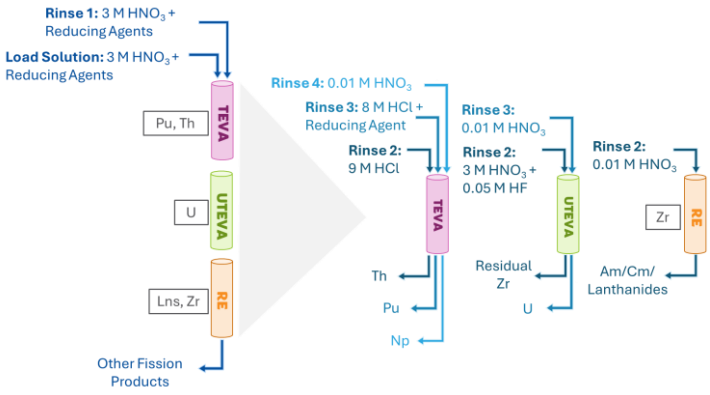
Introduction

Analysis of uranium fission and actinide products is of interest in a variety of fields including nuclear fuel analysis, reactor technology development, nuclear data measurements, nuclear fuel recycling efforts, and nuclear forensic analysis. Accurate measurements of some radionuclides can be difficult in the presence of high yield isotopes, and therefore, separation techniques have been developed to aide measurements for these varied applications. Many current methods are labor and time intensive and are limited in the sample masses that can be processed. In this work, a simplified column-based separation method is being developed for rapid purification of uranium fission products and actinides that are critical for safeguard measurements of nuclear material accountability.

Description of the Work or Project

An extraction chromatography column-based separation method using TEVA (TetraValent Actinides), UTEVA (Uranium and TetraValent Actinides), and RE (Rare Earth) resins (Figure 1) is being developed to separate a variety of radionuclides resulting from uranium fission. Following dissolution of a bulk uranium sample via a microwave dissolution method, a single load solution matrix is used to load three columns in tandem, simplifying previous separation processes by avoiding evaporation and reconstitution steps. Several species of interest, such as key actinide, are retained on the resins during loading, while many fission products such as isotopes of Ru, Ba, Zr, and Nb have been shown to pass through the resins on loading. The resins are then separated to selectively elute several elements of interest such as U, Th, Pu, Np, and Am/Cm/lanthanides. High recovery yields (>90%) have been measured for many actinides, lanthanides, and other fission products through these separation methods. Progress will be presented toward a more complete separation of Pu and Np through selective reduction on a TEVA resin as well as actinides separations that may be possible through development of a more complex RE resin separation.



Conclusions

The present work has successfully demonstrated the separation of key actinides, such as U, Th, Pu, and Np, from a complex matrix of uranium fission products. This streamlined, rapid separation method could provide timely information for nuclear safeguards applications.

Figure 1: Separation Scheme for Uranium Fission Products and Actinides
After initial loading, the columns are separated for further rinsing to selectively separate key radionuclides. Grey boxes indicate important retained elements on each column.

Short-lived Radionuclides for Incorporation into Radiological Response and Nuclear Forensic Training Materials

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Introduction

Training radiological and nuclear first responders is crucial in developing a robust response capability to catastrophic events such as radiological dispersal device (RDD) detonation or nuclear detonation. The scenarios present first responders with unique environments that are difficult to capture and experience in a simulation, especially with regards to radiological dose and contamination considerations.

In this work, we describe novel methods of producing radiological and nuclear first responder training materials. We incorporate short-lived radionuclides that could produce realistic open-air radiological fields and contamination areas allowing for training in realistic radiological conditions, while decaying rapidly and posing no permanent environmental impact.

Description of the Work or Project

We have explored the production of several short-lived alpha- and beta-emitting radionuclides such as Sc-47 ($t_{1/2}$ = 3.35 d), Cu-64 ($t_{1/2}$ = 12.7 h), Cu-67 ($t_{1/2}$ = 2.58 d), Ra-223 ($t_{1/2}$ = 11.4 d), Br-82 ($t_{1/2}$ = 1.4 d). Isotopes were produced either via neutron irradiation at the Oregon State University TRIGGA Reactor or via gamma irradiation at the Idaho State University Accelerator Center. Our goal was to produce short-lived radionuclide containing sol-gel based nuclear explosive debris with realistic size, shape, color and dose rates. We studied the incorporation and quantitative retention of KBr through the various stages of the surrogate debris production process and across various precursor solutions to maximize KBr retention and achieve targeted dose rate metrics. Examples of Cu-64 containing sol-gel and KBr retention are shown below.

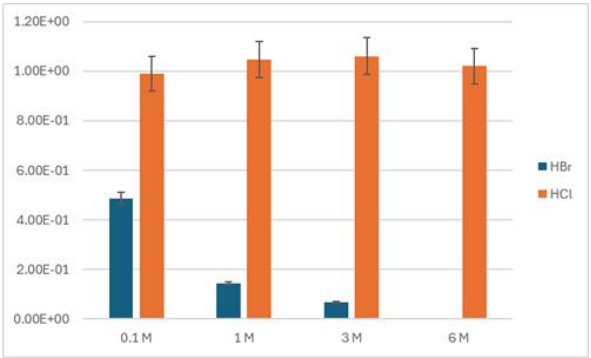

Figure 1. (Left) Irradiated Cu-64 doped sol-gel based surrogate debris. (Right) Retention of Br-82 in sol-gel based surrogated debris as a function of acid type and concentration.

Conclusions

We produced sol-gel based surrogate nuclear debris training materials containing various short-lived radionuclides. We found that the retention of KBr was highly dependent of the specific production pathway, likely due to the propensity for oxidation of the Br^- to Br_2 gas. However, Br retention was optimized by transitioning to a HCl production pathway retaining effectively all of the Br and producing dose rates of >200 mR/h/g. These materials could be very useful as realistic dose and contamination producing training tools that decay rapidly and pose little environmental impact.

PRODUCTION OF ^{203}PB FOR IMAGING AT THE IBA CYCLONE 30XP IN JÜLICH

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Introduction

^{212}Pb is currently gaining more and more interest in the targeted alpha therapy community, due to its shorter decay chain in comparison to ^{225}Ac. Companies like Orano Med LLC are currently approbing ^{212}Pb-DOTAMTATE in medical trials showing approved outcomes when compared to the industry standard Lutathera. [1] Due to the high radiation dose on patients, utilazitaion of a matched pair theranostic partner to ^{212}Pb is essential. Utilizing the Jülich's IBA Cyclone 30XP we use the ^{205}Tl(p,3n)^{203}Pb reaction which can be used in SPECT imaging and has a half-life of 51.9 hours.

Description of the Work or Project

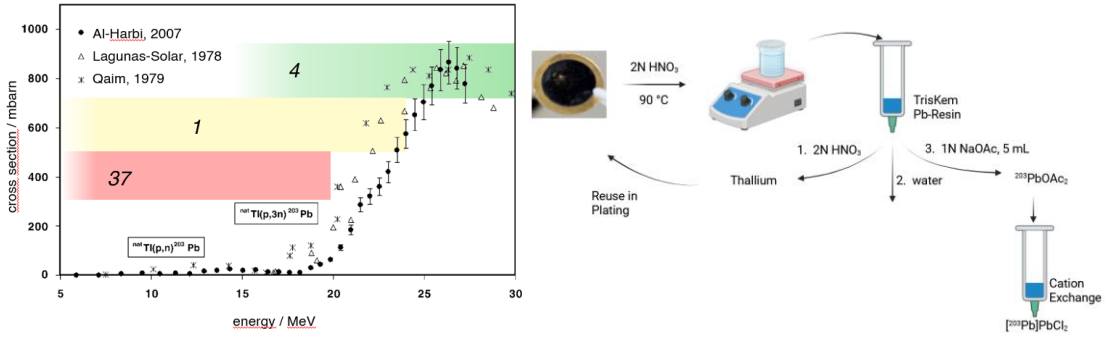
We investigate the production of suitable metallic thallium surfaces for irradiation with 28 MeV protons.[2] For this, we electroplate thallium on different metal foils under various conditions, using steady state and pulsed electroplating to mitigate the incorporation of hydrogen gas.

The targets were irradiated at our IBA Cyclone 30XP and processed shortly after, by dissolution in concentrated HCl and purification using cation specific resins and cation exchange resins.

We present the Production yields and isolation optimization towards an automatized process.

Conclusion

We are capable of producing ^{203}Pb at its cross section maximum in high chemical and isotopic purity as non-carrier-added [^{203}Pb]$PbCl_2$ in aqueous HCl solution. The production yield was 28.8 ± 9.5 MBq/µAh (n = 7) from natural thallium the purified product was yielded 4 hours after EOB. Irradiation of natural thallium leads to significant coproduction of ^{201}Pb, which would result in additional radiation exposure if medically applied. Further studies with ^{205}Tl to reduce the ^{201}Pb coproduction will be presented.



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TECHNETIUM-94M PRODUCTION BY CYCLOTRON IRRADIATION OF PHOSPHOMOLYBDIC ACID USING AN AUTOMATED LIQUID TARGET SYSTEM

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Introduction

Technetium-99m (^{99m}Tc) is widely recognized as an optimal radionuclide for single photon emission computed tomography (SPECT) imaging [1]. However, the limited spatial resolution has led to increasing interest in positron emission tomography (PET) imaging radioisotopes. Technetium-94m (^{94m}Tc) is viewed as a potential PET candidate due to its favourable positron branching ratio (70.2%), moderate positron end-point energy (2.44 MeV), and suitable half-life (52 minutes). Initial work showed that phosphomolybdic acid (PMA) has great potential as target material for ^{94m}Tc production [2]. The work presented here is the continued optimization of the ^{94m}Tc production capacity using an in-house designed PLC controlled liquid target automation (LTA) system.

Description of project

A 16.5 MeV GE PETtrace cyclotron was configured with a standard GE Nb liquid target having a 200 µm Nb target foil and a 25 µm HAVAR vacuum foil, degrading the proton energy to 12.9 MeV [2]. A 0.16 M PMA solution (~2.4 mL) was loaded into the target using the LTA and evaluated at 10-20 µA irradiations for 10-60 minutes. All activities were measured using a HPGe detector. Additionally, computational modelling of the PMA irradiation has been explored using MCNP6.3, a general Monte Carlo radiation transport code, and the SRIM (stopping and range of ions in matter) software to understand how the thermal and physical effects in a liquid target potentially affect the activity yield. In the initial irradiation setup, activity yields up to 157 MBq ^{94m}Tc were achieved for 15 µA irradiations at 60 minutes with the recovery in the product vial observed to be >98% [2]. Our results using the LTA system showed activity yields up to 152 MBq for the same irradiation parameters, while the recovery in the product vial was around 90%. The ^{94m}Tc saturated activity yield from the LTA system was 18.9 MBq/µA. From literature, the theoretical saturated yield for ^{94m}Tc was reported to be 37.9 MBq/µA [2], resulting in the experimentally measured yield being 50% of the theoretical value. Our recent SRIM program results provided a saturated yield of 35.5 MBq/µA and MCNP6.3 analysis provided a saturated yield of 37.1 MBq/µA, with the experimental yields being 47% and 49% respectively less than the theoretical simulated values.

Conclusion

Consistent ^{94m}Tc production was observed using the in-house designed LTA system, with the PMA demonstrating great characteristics as a target material. Next steps are to continue adjusting the simulations to account for any liquid dynamical changes, experimentally investigate maximum irradiation parameters, and tracer ^{94m}Tc labelling for preclinical evaluation.

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A novel Accelerator-Based Setup for National Scale ^{99Mo} Production: Radiation Protection Aspects

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Introduction

The ^{99}MoBest project develops an innovative accelerator-based production concept to meet Germany's entire ^{99}Mo demand (~60 TBq/week), replacing current reactor-based methods. The approach prioritizes radiation protection throughout the facility lifecycle, from operation to decommissioning, focusing on minimizing long-lived waste and structural activation through optimal material selection and geometry design. The irradiation facility is set to be part of the HBS site, a linear proton accelerator capable of a peak current of 100 mA with 70 MeV protons, which can be used in several experimental setups. These protons are used to irradiate a tantalum target, producing reactor-like neutron fluxes via the (p,n)-reaction, which activate a natural molybdenum target to the required demand.

Description of the Work or Project

The development follows an iterative process designed to optimize ^{99}Mo production while balancing the requirements for chemical reprocessing and minimizing activation in structural materials to reduce waste generation. To support this optimization, a comprehensive FLUKA model was developed to assess radiation protection aspects and adapt to evolving target designs. The model provides critical data—including displacement per atom (DPA) calculations and energy deposition profiles—essential for collaboration with project partners. The project focuses primarily on the Target-Moderator-Reflector (TMR) region, which significantly influences the neutronics characteristics and is therefore crucial for determining the final production capacity, while also verifying the current shielding concepts for the increased proton currents of up to 12 mA.

Conclusions

This study examined nine distinct material combinations to assess their impact on ^{99}Mo production and the generation of critical activation products in several regions of the irradiation Bunker. Be, MgO, and Pb were evaluated as potential reflector materials, while D_2O, H_2O, and ZrH served as candidate moderators. The resulting isotopic inventories and activities varied significantly due to differences in reflector activation characteristics and moderator thermalization efficiency. The MgO reflector with H2O moderator combination emerged as best compromise, optimizing ^{99}Mo yield while minimizing long-lived activation products and reducing material-specific handling hazards.

TOWARDS RADIONUCLIDICALLY PURE n.c.a. ^{166}Ho VIA AN INDIRECT REACTOR PRODUCTION ROUTE FOR THERAPEUTIC APPLICATIONS

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Introduction

In recent decades, ^{166}Ho ($t_{1/2}$=26.7 h) has emerged for its broad therapeutic use in nuclear medicine, particularly owing to its high-energy β^- particles ($E_{\beta^-,ave}$=662 keV)[1]. Currently, ^{166}Ho is applied clinically in carrier-added (c.a.) form. However, its direct production from natural holmium generates the long-lived contaminant ^{166m}Ho ($t_{1/2}$=1132 y). To address this, we investigated an indirect production irradiating enriched dysprosium-164 oxide ($^{164}Dy_2O_3$) for the large-scale production of non-c.a. (n.c.a) ^{166}Ho, free from ^{166m}Ho. This route also enables the pursuit of a generator system.

Description of the Work

Several quartz ampoules containing 8 µg of $^{164}Dy_2O_3$ (enr. 96.8%) were irradiated at the Institut Laue-Langevin's high-flux reactor. We performed γ spectrometry measurements to compile a comprehensive radionuclide inventory and to quantify their relative production yields. Irradiation runs using 1.2×10^{15} cm^{-2}s^{-1} neutron flux yielded a ^{166}Dy ($t_{1/2}$=81.6 h) end-of-irradiation activity per unit metal mass of 221 (28) GBq/mg. Based on these findings, Figure 1 shows a simulated timeline for a large-scale production.

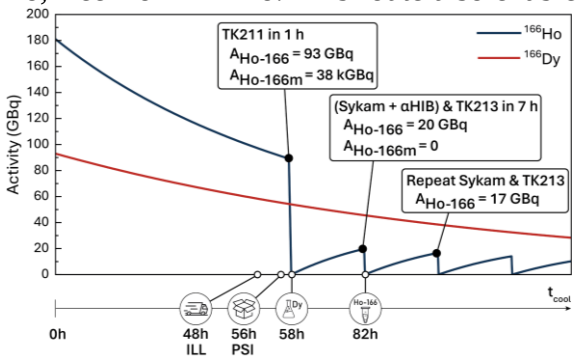

Figure 1: Production timeline for 650 µg of $^{164}Dy_2O_3$ irradiated at ILL for 6 days with 1.2×10^{15} cm^{-2}s^{-1} neutron flux.

Extraction and cation exchange chromatographic resins were investigated to develop an efficient procedure for Dy/Ho separation. Fractions collected during the chromatographic studies were analyzed using ICP-OES. Numerous experiments were conducted to thoroughly evaluate the influence of different parameters (eluent concentration, column dimensions, solution pH, flow rate, etc.) affecting Dy/Ho separation resolution and process duration.

We devised a three-column separation system, suitable for multiple elution of ^{166}Ho. TK211 extraction resin enabled rapid Dy recovery (>80% within 1 hour from loading). Ho was isolated using Sykam cation exchange resin and elution with α-hydroxyisobutyric acid. TK213 extraction resin was used to remove metal contaminants, convert the product into chloride form, and elute ^{166}Ho in 1.5 mL volume to maximize its activity concentration.

Conclusions

We developed a fast, reproducible purification method for n.c.a. ^{166}Ho production for targeted radionuclide therapy. The system could deliver approximately 100 GBq cumulatively via multiple collections, enabling systematic preclinical studies and potential future clinical use.

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TOWARDS SUSTAINABLE PRODUCTION OF 225AC FROM 226RA FOR TARGETED ALPHA THERAPY

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Introduction

Nuclear data regarding production of medical radionuclides for theranostics has become increasingly important. To obtain information about excitation functions, multiple experiments must be performed with high accuracy. Every production route might require different target characteristics to provide reliable nuclear data. To predict commercial production supply, optimal irradiation conditions and post-processing need to be identified.

Description of the Work or Project

The present study lays the foundation for efficient preparation and post-processing of ^{226}Ra targets that can lead towards sustainable production of ^{225}Ac for targeted alpha therapy in nuclear medicine[1]. Focus is on thin and thick target production by electrodeposition from aqueous-alcohol based electrolyte using tailor-made electrodeposition cell[2]. Experiments were performed with ^{nat}Ba, as a chemical homologue of ^{226}Ra and ^{223}Ra as a γ-tracer. Viability of electroplated thick targets was studied by varying experimental parameters. The homogeneity and morphology of produced targets have been evaluated on micro and macro scales using optical microscopy, profilometry, SEM and radioluminography.

Impurities present in the ^{226}Ra stocks might affect the electrodeposition process, target stability, post-processing and purity of the final product. Based on the character and level of impurity, the effect varies significantly. Several methods for removing these chemical impurities were tested and evaluated with ICP-MS and γ-spectrometry.

Conclusions

As a result of adjusting chemical and physical parameters, thin and thick electroplated targets were fabricated, and the limitations of electroplating were discovered. The impact of chemical impurities found in typical sources of ^{226}Ra has been investigated in this work. A radiochemical separation method was found as an efficient solution for managing present impurities. The contamination study indicates that high-purity stock solutions are necessary for stable and homogenous target production. The advantages of electroplating are useful for producing thin targets, but for scaled-up production of ^{225}Ac, other methods should be employed.

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DEUTERON-INDUCED REACTIONS ON NATURAL ZIRCONIUM FROM THRESHOLD TO 50 MeV: PRODUCTION OF ^{86g}Y

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Description of the Work

Two stacks of thin Zr foils were irradiated with 30 and 50 MeV deuterons, respectively, using the Lawrence Berkeley National Laboratory 88-Inch Cyclotron, and 19 excitation functions for ^{nat}Zr(d,x) reactions were measured over a beam energy range of 6.3–47.64 MeV, where the independent cross sections for ^{nat}Zr(d,x)^{88}Nb and ^{nat}Zr(d,x)^{86m,g}Y were measured for the first time. The well-characterized ^{nat}Fe(d,x)^{56}Co, ^{nat}Ni(d,x)^{56}Co, ^{nat}Ni(d,x)^{58}Co, ^{nat}Ni(d,x)^{61}Cu, ^{nat}Ti(d,x)^{46}Sc and ^{nat}Ti(d,x)^{48}V monitor reactions were used to determine the deuteron beam current throughout the stacks. All cross sections were determined using High Purity Germanium (HPGe) detector γ-ray spectroscopy. A variance minimization technique was employed to simultaneously constrain the deuteron beam currents with multiple monitor reactions, thus reducing systematic uncertainties. An additional 16 channels are reported for reactions on the nickel, titanium, and iron monitor foils, leading to a total of 35 excitation functions, with 7 reaction channels reported for the first time in this work. The measured excitation functions are compared to calculations provided by the reaction modeling codes TALYS − 2.0[1], ALICE – 2020[2], CoH − 3.5.3[3] and EMPIRE − 3.2.3[4], as well as the TENDL – 2023[5] data library. The degree of agreement between theory and experiments is discussed.
The possible production of the important PET radionuclide ^{86g}Y via the ^{nat}Zr(d,x) route was critically examined. The physical yields for ^{nat}Zr(d,x)86Y and other yttrium isotopes produced were calculated and compared to other production pathways. Due to high-level of associated radionuclide impurities, this route cannot deliver ^{86g}Y suitable for medical applications.

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CROSS SECTION RESULTS ABOUT THE ^{49}TI(D,X) REACTION FOR THE PRODUCTION OF ^{47}SC AND ITS CONTAMINANTS

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Introduction

^{47}Sc is an interesting radionuclide for theranostic applications in nuclear medicine thanks to its favourable decay characteristics, namely β^- particles of 162.0 keV mean energy useful for therapy, and γ rays of about 159 keV energy that fit the standard SPECT cameras. ^{47}Sc can also be used matched to ^{43}Sc or ^{44g}Sc, two β^- emitters exploitable for PET imaging, to constitute a true theranostic pair. Currently, the scientific community is facing the challenge to identify a production route which can provide the largest amount of ^{47}Sc with an appropriate purity for medical applications. At the INFN-LNL, in the framework of LARAMED (LAboratory of RAdionuclides for MEDicine), the production of ^{47}Sc has been investigated through some dedicated projects [1].

Description of the Work or Project

In the context of the SPES_MED project, funded by INFN CSN3 for the years 2025-2027, deuteron-induced nuclear cross sections of ^{47}Sc and its contaminants from enriched ^{49}Ti targets were measured. The enriched targets, manufactured with the HIVIPP (HIgh energy VIbration Powders Plating) technique [2] at the INFN-LNL, were activated at the GIP ARRONAX facility cyclotron [3], where a tunable 16÷33 MeV deuteron beam is available. Different irradiation runs allowed to measure the production cross sections of ^{47}Sc and its contaminants which were compared with the scarce literature and theoretical simulations. The experimental results of all the produced radionuclides allowed to evaluate the validity of the ^{49}Ti(d,x)^{47}Sc pathway. A comparison with previously investigated production methods was also performed.

Conclusions

This work aimed at showing that ^{49}Ti(d,x)^{47}Sc is a valid alternative production way that can contribute to the worldwide availability of ^{47}Sc.

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PRODUCTION CROSS SECTION MEASUREMENTS OF ^{111}AG WIITH THE REACTION ^{NAT}PD(α,X)

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Introduction

The radionuclides used in targeted radionuclide therapy emit charged particles, such as α, β^- and Auger electron, that makes possible the delivery of a significant dose to the tumor cells while sparring the healthy tissues surrounding them. The radioisotope ^{111}Ag ($T_{1/2}$ = 7.45 days, $E_{max,\beta-}$ = 1.04 MeV) is a β^- emitter that is promising for this kind of application [1]. Its low energy β^- has a medium tissue penetration of average 1.8 mm which enables the targeting of medium tumors [2]. Additionally, its γ rays at 245 keV (1.3 %) and 342 keV (6.7 %) are well suited for SPECT imaging which is helpful for monitoring more precisely the in vivo dose delivered [1]. Several routes have been studied to produce ^{111}Ag either with research reactors [3], cyclotrons [4][5], photonuclear reactions [1] or on-line mass separators [2]. The production cross sections of ^{nat}Pd(α,x)^{111}Ag [6][7], one of the reactions for the alpha route, has only been measured by two teams. However, these measurements do not cover the whole region of the peak and what's happening after it.

Description of the work

Several measurements of the production cross sections of the ^{nat}Pd(α,x)^{111}Ag reaction have been performed at the GIP ARRONAX with an alpha beam of 67.4 MeV to get experimental data above 40 MeV. The "stacked-foils" method has been used during our experiments. The intensity of the beam has been monitored through the ^{nat}Al(α,x)^{22}Na nuclear reactions [8]. HPGe detectors were used to perform the γ-spectrometry of each foil: short acquisitions were done directly after the irradiation to measure short-lived radionuclides and longer acquisitions days after to measure ^{111}Ag and the contaminants ^{105}Ag, ^{106m}Ag and ^{110m}Ag. The analysis of the spectra was performed using multiple γ-rays for each radionuclide when possible.

Conclusion

The new production cross section measurements obtained at GIP ARRONAX, up to 65.4 Mev, showed a good agreement with the literature [6][7]. The maximum cross section was thus defined and is reached at around 50 MeV for about 16 mb. The excitation function obtained, coupled with the production cross sections of the contaminants ^{105,106m,110m}Ag, make it possible to pick optimal parameters to produce ^{111}Ag. Thus, allowing the comparison with the other production routes in terms of yield, purity and specific activity. These new experimental data could also help in refining the theoretical models to better describe the nuclear reactions.

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RADIOISOTOPES PRODUCTION WITH RFT-30 CYCLOTRON

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Introduction

RFT-30 cyclotron at Korea Atomic Energy Research Institute (KAERI) is 30 MeV spiral accelerator developed as national R&D project. It has succeeded in producing various radiometal isotopes for medical use such as Zr-89, Cu-64/67, Sc-44, Co-57 and Ge-68.

Description of the Work and Result

RFT-30 cyclotron is equipped with four beamlines, and each beamline has its own targetry and irradiation station developed in-house according to the type of radioisotope. By improving the high frequency system and manufacturing major components of cyclotron, the amount of beam current was increased while maintaining the stability of the beam current, enabling continuous irradiation for more than 1day on average of 150 μA. Based on this system, developed targetry and separation method made it succeed production medical radioisotopes. Each targetry was developed to suit the properties of radioisotopes production (Zr-89, Cu-64/67, Sc-44, and Ge-68). Radioisotopes were purified by ion-exchange chromatography respectively. Zr-89 was separated using a hydroxamate-based ion exchange resin after beam irradiation on the target material Y-89 and Cu-67 was separated through solid phase ion exchange resin after Zn-70 was plated on a plate. Sc-44 was separated using an amide-based solid ion exchange resin after beam irradiation using a Ca-44 pellet target. Through chemical separation processes, high-quality radioisotopes with a purity of over 99.9% are produced, and an automated separation and production system is being developed for mass production. These radioisotopes has been supplied hospitals, university and companies.

Conclusions

RFT-30 cyclotron integrated research facility has been established to develop medical radioisotopes and supply radioisotopes to domestic research institutions.

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THE SPES FACILITY AT LNL: STATUS AND PERSPECTIVES

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Introduction

The construction and commissioning of the SPES facility is the flagship project of the INFN Legnaro National Laboratories. The goal is to build a state of the art accelerator facility to carry on research in the fields of Fundamental Physics and Interdisciplinary Physics. The core of the project is represented by a high-intensity cyclotron capable of delivering proton beams at 35-70 MeV with a maximum total current of 750 microA on two simultaneously operated exit ports.

Description of the Work

A wide range of applications is foreseen spanning from the production and re-acceleration of Rare Isotope beams using the ISOL (Isotope Separation On Line) technique to Research and Development of innovative radioisotopes for medical diagnostics and therapies. The production and supply of radioisotopes to industry is also envisaged.

Conclusions

In this contribution, the status of the project will be summarized and the recent commissioning achievements will be illustrated.

Accelerator-Based Medical Isotope Production at Institute of Modern Physics (IMP)

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Introduction

As the core of the nuclear medicine, medical isotopes have been profoundly embedded in multiple critical segments, including disease diagnosis, precision therapeutics, and healthcare security, thereby assuming an irreplaceable role in the global healthcare system[1]. For a long time, the global supply of medical isotopes has been highly concentrated in reactors, such as Canada's NRU reactor and France's OSIRIS reactor. However, most of these reactors have been shut down due to operating beyond their designed service life. In the future, more aging reactors will be shut down one after another, resulting in that the international supply of the radionuclides is not satisfied with the global demands[2].

Particularly in China, the majority of medical isotopes applied in clinical is mainly dependent on imports, where supply falls short of demand has already emerged. In 2021, the Chinese government issued the "Medium- and Long-Term Development Plan for Medical Isotopes (2021-2035)"[3], which stipulated that the independent supply of medical isotopes should be achieved. Accordingly, the various scientific research institutions and enterprises in China are vigorously promoting the research and development of medical isotopes production.

Description of the Work or Project

At IMP, efforts are actively advancing technologies for the accelerator-based production of medical isotopes, including ^{99m}Tc/^{99}Mo, ^{68}Ge/^{68}Ga, ^{211}At, ^{225}Ac, ^{223}Ra, ^{212}Pb[4-7]. Notably, the Heavy Ion Research Facility in Lanzhou (HIRFL)--the largest heavy ion research facility in China and one of a few large-scale full-ion accelerating systems in the world--can accelerate high energy hydrogen ions, providing a platform for researching on the production of ^{225}Ac. Building on this capability, the research team leveraged HIRFL's beam to bombard metallic ^{22}Th targets, generating ^{225}Ac through spallation reactions. In this experiment, an independently designed remote-controlled target-unloading robot was developed to upload and transport the high-radiation-dose ^{232}Th target. More importantly, about 40 μCi of ^{225}Ac was efficiently obtained using a self-developed fully automated multi-chromatography separation system with the recovery of 80%, radioactive nuclide purity exceeding 98%, radiochemical purity reaching over 99%, and chemical impurity content below 2.5 μg/mL.

Conclusions

This breakthrough by IMP, has established an integrated full-chain production system encompassing irradiation and automated separation. Furthermore, the Gansu Isotope Laboratory, located in Lanzhou New Area, is simultaneously constructing a curie-level ^{225}Ac production line, which will continue to provide strong guarantees and support for the localized and large-scale production of ^{225}Ac nuclides in the future.

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OPTIMIZATION AND VALIDATION OF THE INDIRECT ^{155}TB PRODUCTION ROUTE IN THE APHRODITE-155 PROJECT

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Introduction

Terbium radionuclides are emerging as key isotopes for theranostic applications, offering matched pairs for imaging and therapy. Among them, **^{155}Tb** is a promising SPECT radionuclide suitable for dosimetric validation of therapeutic analogues such as ^{161}Tb and ^{177}Lu. Its routine production, however, remains challenging due to limited yields from direct reactions and the scarcity of enriched target material. The **APHRODITE-155 project** explores an *indirect production route* based on the decay of ^{155}Dy obtained through ^{159}Tb(p,x) nuclear reactions, integrating nuclear data acquisition, process modeling, and radiochemical separation optimization.

Description of the Work

The University of Milan (UNIMI) team contributes to **WPs 4–6**, focusing on nuclear reaction cross-section measurements, thick-target yield (TTY) calculations, and development of a robust separation protocol for the recovery of ^{155}Tb from irradiated terbium matrices.
Proton irradiations of ^{159}Tb were carried out at ARRONAX in the 35–62 MeV range using stacked-foil techniques. Measured excitation functions for ^{153}Dy, ^{155}Dy, ^{157}Dy, and ^{159}Dy show good agreement with literature data and confirm the reliability of the indirect production pathway. Simulations based on these data indicate that, under typical irradiation conditions (30 h, 40 h decay), thick targets can yield up to **1.6 GBq μA^{-1}** of ^{155}Tb [1].
A complete **separation protocol** for the indirect production route has been designed and validated. The method, based on extraction chromatography using LN resin, allows the selective recovery of terbium from a dysprosium matrix after decay of ^{155}Dy. The process was **tested under hot conditions**, confirming the chemical and radiological robustness of the method. Analytical quality controls were performed via γ-spectrometry and ICP-based techniques to assess purity and recovery yields.

Results and Discussion

The integrated nuclear and chemical approach demonstrated the feasibility of producing high-purity ^{155}Tb through the indirect route **^{159}Tb(p,x)→^{155}Dy→^{155}Tb**. The measured cross-sections enable realistic production planning, while the optimized separation protocol provides efficient terbium recovery with radiochemical purity exceeding medical-grade requirements. The successful small-scale hot tests confirm that the process can be extended to higher-activity targets, paving the way for reproducible and scalable isotope production.

Conclusions

The UNIMI unit, in collaboration with ARRONAX, has established a validated workflow that bridges **nuclear data, process modeling, and radiochemical purification** for ^{155}Tb. The indirect production method, combined with the optimized separation protocol, represents a reliable and scalable solution for the supply of terbium isotopes for medical applications. Future work will focus on full-scale irradiations and separation campaigns under routine and automated radiochemical conditions.

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THEORETICAL PERSPECTIVE ON THE PRODUCTION OF MEDICALLY PROMISING ^{110M}IN AND ^{193M}PT BY CHARGED PARTICLE INDUCED REACTIONS

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Introduction

The recent advancements in the field of nuclear medicine can be fairly attributed to the efficient methods for the production of the promising radionuclides in sufficient amounts and with high purity. This work covers the theoretical aspects related to production of two radionuclides; ^{110m}In ($T_{½}$ = 69.1 min, ε = 38.74%, β^+ = 61.26%, $E_{\beta+}$ = 1011 keV) and ^{193m}Pt ($T_{½}$ = 4.33 d, IT = 100 %). The potential of ^{110m}In has been explored for diagnostic studies via PET [1], whereas ^{193m}Pt is a candidate for Auger electron therapy [2]. In this work a comparison of measured and theoretical excitation functions is presented for the (p,*x*n), (d,*x*n) and (α,*x*n) reactions with relevance to the high purity production of ^{110m}In and ^{193m}Pt.

Description of the Work

Analysis of the excitation functions is imperative to assess the suitability of a nuclear reaction for the production of a radioisotope. The available experimental data were thoroughly analyzed for consistency and adjusted in accordance with the standard monitor reactions and the new decay data, if necessary. The evaluated reactions for ^{110m}In include proton induced reactions on cadmium isotopes (*i.e.* ^{110,111,112}Cd(p,*x*n)^{110m}In) and α–particle induced reactions on silver (*i.e.* ^{107,109}Ag(α,*x*n)^{110m}In). In case of ^{193m}Pt, deuteron and α–particle induced reactions on iridium and osmium targets, respectively, were envisaged. The role of theoretically calculated excitation functions has become integral part in nuclear data evaluations. The selected nuclear reactions were simulated by the three nuclear model codes EMPIRE, TALYS and ALICE-IPPE. The relevant nuclear model parameters were varied to obtain the agreement among theoretical and measured cross sections for these isomeric radionuclides. The suggested data were employed to derive the integral yields. A critical comparison of the various production routes of ^{110m}In alongwith the assessment of some important impurities ^{110g,111}In is presented. Similarly, amounts of radioimpurities ^{195m,191}Pt are estimated during ^{193m}Pt production.

Conclusions

This work presents the optimized conditions for the production of medically interesting ^{110m}In and ^{193m}Pt at the small and intermediate energy cyclotrons by the proton, deuteron and α–particle induced reactions. Furthermore, the role of parameterization in nuclear model codes for isomeric excitation functions is also emphasized.

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LONG-LIVED CONTAMINANTS IN CU-61 LABELED BIOMOLECULES PRODUCED BY PROTON BOMBARDMENT OF NI-61 ENRICHED TARGETS

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Introduction

Cu-61 ($t_{1/2}$=3.33 Hr, 61% β+, E_{max} = 1.216 MeV) is being studied as a possible alternative to ^{68}Ga for PET imaging of tumor-seeking biomolecules. As compared to ^{68}Ga, ^{61}Cu has the advantage of lower maximum positron energy (E_{max} = 1.216 MeV vs 1.899 MeV for ^{68}Ga), and a longer half-life (3.33 hr vs 68 min for ^{68}Ga) that allows for efficient production, labeling, and delivery to the imaging center. The production of chelation-based ^{61}Cu radiopharmaceuticals has been demonstrated in several centers [1].

Production

Various routes of production of ^{61}Cu with medical cyclotrons have been presented[1,2], but, for the high Mbq quantities at a high specific activity needed for routine imaging, proton bombardment of ^{61}Ni enriched targets using the ^{61}Ni(p,n)^{61}Cu reaction, offers several advantages to include higher activity and better radionuclidic purity.

All production methods of ^{61}Cu result in the formation of long-lived contaminants which must be separated from the ^{61}Cu prior to labeling with the biomolecule of interest [3].

Analysis

This work reports on the quantification of long-lived contaminants from ^{61}Cu produced from a 99.42% enriched ^{61}Ni target on a Niobium backing. Samples of ^{61}Cu labeled biomolecules were collected at the End of Synthesis (EOS), and the initial ^{61}Cu activity was determined with a medical dose calibrator. The ^{61}Cu was allowed to decay for two days, and the samples were counted on a high-resolution gamma spectrometer which was provided with the library of isotopes shown below (Ortec Gammavision). The printout was carefully scrutinized to ensure there were no unidentified peaks that could represent additional isotopes were present and to eliminate incorrect associations of observed lines with contaminants (e.g. 511 keV). The contaminant load in Bq contaminant/MBq ^{61}Cu at EOS, and at expiry were then determined and reported. Finally, the total contaminant load (sum of the individual contaminants) was reported.

Conclusion

The following panel of long-lived contaminants have been identified in cyclotron-produced ^{61}Cu: ^{57}Co, ^{58}Co, ^{60}Cu, ^{64}Cu, and ^{48}Sc. Of these, ^{58}Co is the dominant contaminant observed. ^{61}Cu appears to be a viable PET imaging isotope for labeled biomolecules.

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PRODUCTION OF HIGH RADIOISOTOPIC PURITY ^{73}SE FOR IN VIVO APPLICATION AT A 30 MeV CYCLOTRON

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Introduction

^{73}Se is an underutilized radionuclide for positron emission tomography (PET) with favorable chemical and physical properties. Its advantageous decay characteristics − high positron intensity, moderate positron energy, absence of high-energy photons and an intermediate half-life of 7.2 hours − make it an ideal alternative to commonly applied radiometals. The main challenge, however, arises from its production. Previously ^{73}Se was typically produced via the ^{75}As(p,3n)^{73}Se nuclear reaction in the energy range of 40→30 MeV to minimize the coproduction of the impurities ^{75}Se and ^{72}Se[1]. Our recently developed radiolabeling strategy based on selenadiazole formation and the commissioning of the IBA cyclone 30 XP in Jülich motivated us to investigate the feasibility of the production of ^{73}Se with high radioisotopic purity suitable for in vivo applications by irradiation with 30 MeV protons.

Description of the Work or Project

To facilitate the development of high-current targetry, elemental arsenic was finely ground and then pressed into a disk with a 20 mm outer diameter under a pressure of 15 tons. The disk was then pressed into a 7 mm thick 26 mm diameter AlMg4 backing with a central 2 mm depth/20 mm diameter depression at 6 t. The backing was covered with a 40 µm thick graphite foil and tightly closed with a screw cap. The calculated beamstop is within the backing close to the cooling water interface for an efficient cooling. Arsenic discs of 190 – 448 mg/cm² (0.33 – 0.77 mm) were each irradiated at 90° incident angle with 30 MeV protons, corresponding to calculated energy range between 30→27,8 MeV and 30→24,5 MeV, depending on the thickness. Radioactivity was quantified by HPGe γ-ray spectroscopy of the irradiated targets after a sufficient cooling period.

Table 1: Results for the irradiation of targets with varying thickness

Areal Density [mg/cm²]	190	224	250	313	448
Production yield [MBq/µAh]	128	131	146	145	170
^{75}Se/^{73}Se [%]	0.011	0.034	0.035	0.060	0.057

As expected from the excitation functions[1], the production yield increased together with the impurity of ^{75}Se reaching a value up to 170 MBq/µAh for thicker targets. To our delight, even for the thickest target the impurity of ^{75}Se was significantly below 0.1% at EOB and can be further reduced to values of 0.011 % for thin targets while still achieving a fair production yield of ^{73}Se of 128 MBq/µAh. So far, irradiations with beam currents up to 15 µA have shown no visible damage of the target. The inevitable coproduction of ^{74}As amounted to 3 – 4%. This is however of no concern as it can be chemically separated during the following labeling chemistry. No other radionuclidic impurities besides traces of ^{24}Na were observed, presumably from backing activation.

Conclusions

In this preliminary study we demonstrated the feasibility of producing ^{73}Se suitable for in vivo imaging from thin arsenic targets using 30 MeV protons. Achievable production rates exceeding 2 GBq/h suffice for tracer development and (pre)clinical in vivo applications.

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A COMPARISON OF COMPTON SUPPRESSION AND GAMMA-GAMMA COINCIDENCE IN NEUTRON ACTIVATION ANALYSIS: A REVIEW

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Compton suppression and gamma-gamma coincidence techniques have been in existence for many decades primarily used in nuclear structure studies. Although there were a couple of original papers on Compton suppression neutron activation analysis (NAA) it was not till the early 1990's that this technique was employed in a more systematic approach. While gamma-gamma coincidence was more frequently used the method was also not fully exploited in routine NAA. Both these methods have unique capabilities that can greatly improve the analysis of radionuclides from NAA either by reducing the background significantly and/or eliminating spectral interferences. A succinct comparison of these two methods will be made including their advantages and disadvantages, and how a simultaneous integration of both methods can be very advantageous in the competitive world of trace element analysis.

MACHINA, THE MOVABLE ACCELERATOR FOR CULTURAL HERITAGE IN-SITU NON-DESTRUCTIVE ANALYSIS: FIRST RESULTS AND CASE STUDIES

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Introduction

Nuclear analytical techniques using particle accelerators have helped answer important questions concerning the materials composing artworks for several decades. However, bringing an object of Cultural Heritage importance to an accelerator laboratory can be difficult due to logistics and insurance, or impossible due to physical constraints such as frescoes. The MACHINA project was created to build an accelerator that can be easier installed closer to where artworks are, such as museums and restoration centers, or even transported to where it might be needed. The first results concerning beam characterization and application to cultural heritage objects were performed.

Description of the Project

MACHINA was built within a collaboration between INFN and CERN to be placed inside Opificio delle Pietre Dure of Florence, a renowned center for art conservation in Italy [1]. Based on CERN's patented 750 Mhz HF-RFQ cavities, MACHINA produces a 2 MeV pulsed proton beam, with a repetition rate of 200 Hz, and a pulse length of 125 μs. Made to perform PIXE analysis, its control system is open-source and user-friendly. MACHINA's proton beam has been characterized in terms of current and energy, with a focus on their dependence on HF-RFQ power, using the RBS (Rutherford Backscattering) technique. The data acquisition system was tested with measurements made on a replica of fresco's artwork.

Conclusions

Experimental results from beam characterization are in agreement to simulation data. Beam energy changes with different HF-RFQ power: at 90% of the nominal power the beam is multienergetic, while at the nominal power it has one component at 2 MeV. Moreoever, first tests of PIXE imaging show no deformation or artefacts in the elemental distribution maps, and above all no material damage was revealed.

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CHNET_MAXI: OPTIMIZING MUONIC ATOM X-RAY AND PROMPT GAMMA SPECTROSCOPY FOR NON-DESTRUCTIVE LEAD ISOTOPIC RATIO ANALYSIS IN CULTURAL HERITAGE

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Introduction

The determination of isotopic ratios, particularly of lead, is a powerful tool for provenance studies in archaeology and cultural heritage. Conventional techniques (TIMS, ICP-MS) are highly precise but destructive, making them unsuitable for unique and valuable artifacts. The CHNET_MAXI project, a collaboration between ISIS and INFN (CHNet and commission 5) explores a novel non-destructive methodology based on muonic atom X-ray spectroscopy (μXES) and prompt gamma emission following muon capture. While pioneering studies, have already demonstrated the feasibility of such measurements, CHNET_MAXI aims to advance the technique by optimizing detection systems and data acquisition for improved sensitivity and accuracy.

Description of the Work or Project

CHNET_MAXI proposes to exploit both muonic X-rays and prompt gammas emitted after negative muon capture in lead isotopes (^{204}Pb, ^{206}Pb, ^{207}Pb, ^{208}Pb). These observables provide isotope-sensitive figures of merit, including isomeric shifts in μX lines and isotope-dependent prompt gamma cascades. The project will implement an innovative detection setup featuring a 64-channel scintillating fiber hodoscope for beam monitoring, a compact 16-channel GAGG-HR scintillator array for small samples, two CLLB crystals to assess the potential of high-resolution scintillators, and an array of nine HPGe detectors to ensure high energy resolution and efficiency. Monte Carlo simulations (mu-ARBY, based on GEANT4) are being developed to model the full setup, including muon transport, X-ray emission, and prompt gamma cascades. Experimental validation will be carried out at the ISIS-RAL facility with enriched lead samples. The objective is to benchmark and optimize the technique against conventional mass spectrometry methods using certified standards.

Conclusions

CHNET_MAXI will establish a unique non-destructive approach for lead isotopic ratio analysis in cultural heritage, combining muonic X-ray and prompt gamma spectroscopy. Although not the first attempt at such measurements, this project focuses on significantly improving sensitivity, precision, and applicability through a new generation of detection systems and DAQ. Results will have direct impact in archaeology, heritage science, and fundamental muonic atom physics.

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PRODUCTION OF ^{26}AL AND ^{10}BE VIA NEUTRON REACTIONS IN SiO_2-ROCKS: IMPLICATIONS FOR BURIAL DATING RELATED TO THE CRADLE OF HUMANKIND--UNESCO WORLD HERITAGE SITE

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Introduction

The Cradle of Humankind World Heritage Site (COHWHS) in South Africa hosts one of the highest concentrations of hominin fossils globally, including Australopithecus, Paranthropus, and Homo naledi. These fossils are embedded within complex dolomitic cave systems whose formation history and chronology are central to reconstructing early human evolution in the region. Accurately reconstructing the exposure history of these sediments is not only a scientific objective, but also a crucial step in preserving and correctly interpreting the paleoanthropological cultural heritage preserved within the COHWHS.

The Project

Cosmogenic isotope dating (or geo-dating) relies on measuring the concentration of long-lived isotopes such as ^{26}Al and ^{10}Be in SiO_2-rich rocks, as their ratio provides an estimate of the sample's age.

Accurate burial dating requires a precise understanding of the production rates of ^{26}Al and ^{10}Be. These nuclides are produced by cosmic-ray interactions: fast neutrons inducing spallation at the surface, and fast and negative muons contributing at depth. While muon-induced production is relatively well constrained, significant uncertainties remain in the neutron-induced component due to limited experimental nuclear cross-section data. These uncertainties propagate directly into dating errors for fossil-bearing sediments.

To address this gap, we performed the first direct measurement campaign of ^{26}Al and ^{10}Be production in quartz exposed to a high-intensity neutron spectrum at the n_TOF facility at CERN. The n_TOF source provides a white neutron spectrum closely resembling that of cosmic rays but at intensities several orders of magnitude higher, enabling statistically meaningful activation of quartz samples collected from COHWHS. Following irradiation, the resulting nuclide concentrations will be quantified via Accelerator Mass Spectrometry at CIRCE.

Conclusions

Geodating offers a unique opportunity to understand the formation and chronology of the complex chambers systems in the COHWHS, that is essential to reconstruct early human history, likely rooted in this region. This contribution will present the project and the theoretical motivations for measuring the production rate. In addition, the preliminary results from the measurement campaign carried out at n_TOF will be discussed.

BUILDING A RELIABLE STABLE ISOTOPES SUPPLY CHAIN FOR YB-176

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Introduction

Orano is a world-leader in nuclear fuel cycle activities from mining to recycling of used fuel and has been leveraging since 2020 on its unique competencies and technologies for the enrichment of uranium to develop new way of producing stable isotopes especially Yb-176 for medical uses.

Description of the Work or Project

Orano Stable Isotopes is an extensive project which one of the ambitions is to increase the supply of stable isotopes in the OECD area. The first step was the commissioning of a cascade of centrifuges in October 2023. The second step is using its knowhow of isotopic separation to enrich elements which can't be enriched by centrifuge.

CEA has developed a laser enrichment technology, Atomic Vapor Laser Isotope Separation technology (AVLIS), with Orano as a stakeholder. In 2003, the efficiency of AVLIS was proven on a large scale on uranium isotopes by separating more than 200kg of enriched uranium from two tons of natural uranium. The principle of this technology could be successfully applied for the separation of lanthanides among which Ytterbium. We believe that it will be the cheapest and the most efficient way for industrially enriched Ytterbium in the future as a timely answer to the growing OECD needs.

In 2023, Orano completed a feasibility study to adapt the Uranium AVLIS on Ytterbium. This study validated by simulation the technical feasibility of an enrichment of 99.5% for Yb-176. It also confirmed the achievable volumes and the economic model of an implementation into our Stable Isotopes Laboratory. In our test bench, the behavior of Ytterbium without isotopic separation was validated in 2023 and early 2024. Since mid-2024, the isotopic separation parts of test bench have been adapted to Ytterbium. The test bench was tested in 2025 during the summer. A first sample with a low enrichment grade was produced in fall 2025. A second sample at the industrial enrichment grade will have been produced early 2026. Time will then come to gather an ecosystem to fund the next steps including the irradiation of the sample, the confirmation of the cost of the equipment, and the construction of the equipment. In this plan and subject to a Orano's board approval, the industrial production could start at the end of the decade and, thanks to the modularity of the equipment, could be increased according to the demand.

Conclusions

After the commissioning of a centrifugation production line to enrich stable isotopes, Orano is addressing the major stakes that isotopically modified Ytterbium supply for medical application is encountering. We have already demonstrated with centrifugation that we can come to the market on time in full with a new reliable supply chain and we will make it again with our project based AVLIS to serve the rising demand on Yb-176.

ULTRACENTRIFUGATION TO BUILD A RELIABLE STABLE ISOTOPES SUPPLY CHAIN FOR QUANTUM AND HEALTHCARE

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Introduction

Orano is a world-leader in nuclear fuel cycle activities from mining to recycling of used fuel and has been leveraging since 2020 on its unique competencies and technologies for the enrichment of uranium and fluorine chemistry to produce stable isotopes for the research, medical and industrial communities.

Description of the Work or Project

Orano Stable Isotopes is an extensive project which one of the ambitions is to increase the supply of stable isotopes in the OECD area. The commissioning of our first cascade of centrifuges was successfully completed, after a test phase, in October 2023, on time and on budget with our initial commitments, and we gave a memorable opening ceremony on October 18th, 2023, to celebrate it.

Production of stable isotopes such as Xenon, Molybdenum, Silicon and Germanium based on centrifugation technology is now on-going and since April 2024, Orano has delivered, among others, isotopically modified Silicon compounds to a dozen of players of the quantum ecosystem, on time and even over the expected isotopic grade. Today we are operating an isotopic separation capacity that is enough to serve quantum and pulmonary MRI needs in the coming years. We are ready to follow the increase of the demand for precursors for cutting-edge theranostics such as [^{64}Cu ;^{67}Cu] by extending our capacities, and to achieve this goal, we need a 3-year vision to anticipate such extension and be ready when the demand will be there. With our production unit located in France, we are addressing the major stakes that stable isotopes supply is encountering. We have already demonstrated that we can reach the highest levels of isotopic purity that could only be purchased in Russia a couple of years ago.

We are ready to stand by our customers while barriers are lifted worldwide in the framework of the Wassenaar Arrangement: since 2024, isotopically modified Silicon and Germanium have been concerned by the export control regulations, in most of the countries of OECD. In such context, operating a stable isotopes production unit in France ensures to the final users the reliability of their supply chain, a simpler logistics path, and smooth export exchanges between like-minded countries.

Conclusions

With its production unit located in France, Orano is addressing the major stakes that isotopically compounds supply for quantum and nuclear medicine is encountering. We have already demonstrated that we can reach the highest levels of isotopic purity while barriers are lifted worldwide in the framework of the Wassenaar Arrangement. In such context, operating a stable isotopes production unit in France, in the OECD area, ensures to the final users the reliability of their supply chain and smooth export exchanges between like-minded countries.

A Look at the Problems of Radionuclide Raw Material Supply for Isotope Production from the Perspective of a Sealed Source Manufacturer

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Introduction

An uninterrupted supply of high-quality raw materials for sealed radioactive sources production is a cornerstone of business success.

Description of the Work or Project

There are a several aspects which are to be considered as core risks for radioisotope industry:
- an extremely narrow market of raw material producers sometimes leads to shortages and irregular supplies due to periodic overloads;
- the non-commercial nature of most raw material producers and dependent on other parallel tasks conflict with the interests of raw material production.;
- In many cases, the perishable nature of products imposes limitations on maintaining warehouse stocks.
- Technical issues related to the specific nature of the product, such as packaging, storage, and transportation;

Therefore, we are faced with the reality that even a perfectly structured, disciplined production of radionuclide sources will experience interruptions and periodic failures to customers, including key sectors of industry and nuclear medicine.

Conclusions

Therefore, to maintain the presence and development of isotope technologies in modern industry and support of a positive image of our isotope industry, we must consider increasing the stability of radionuclide raw material production, which can be achieved through coordination of all participants or other means that unite and manage market participants.

Radioanalytical determinations and radioactivity measurements in the field of Radiation Protection: the experience of the Integrated Laboratory of Radioactivity Measurement and Monitoring of the ENEA Radiation Protection Institute

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Introduction

Since many years ENEA has been working in the field of radioactivity measurement especially for environmental and internal dosimetry monitoring purposes. This activity represents a great heritage of competence and experience, now collected in the Integrated Laboratory of Radioactivity Measurement and Monitoring of the ENEA Institute of Radiation Protection (IRP-MIR), which acts in three different units located respectively in the ENEA Centers of Saluggia, Casaccia and Trisaia. Thanks to their favorable geographic positions (placed respectively in the North, Center and South of Italy), these units work as one service, able to intervene all over the country.

Description of the Work or Project

The large set of measurement systems and equipment available at IRP-MIR, together with the knowhow for the application of specific techniques of physical-chemical and radiochemical preparation, allow to carry out analyses on a wide spread of different samples biological, environmental and samples coming from plant decomissioning for the determination of a huge number of radionuclides, such as actinides, uranium, ^{90}Sr, ^{210}Po, ^{226}Ra, ^{3}H and natural and anthropogenic gamma emitters. Different techniques are used to determine activity in samples, such as alpha spectrometry, gross alpha/beta counting by proportional counter, liquid scintillation counting and ICP-MS spectrometry. IRP-MIR labs are continuously subjected to internal verification through intercalibration tests and the quality of their performances are supported by regular participation to qualifying exercises and proficiency tests proposed by the most accredited national and international organizations, such as PROCORAD (Association for the Promotion of Quality Control in Radiotoxicological Analysis) to which our Institute has been participating since many years, and ALMERA (Analytical Laboratories for the Measurement of Environmental Radioactivity), the international network of Laboratories established by the IAEA with the aim to give radioanalytical sustain to the Agency, for measurements on samples coming from contaminated areas, because of accidental or intentional release of radioactivity. On behalf of the Italian Government the Institute of Radiation Protection of ENEA is active member of ALMERA network since 2005.

Conclusions

The aim of this work is to present an overview of the performances provided by IRP-MIR Laboratory in the field of environmental monitoring, radiotoxicology and “special matrices” radioactivity analyses, while giving particular emphasis on the types of analyses where the chemical and radiochemical procedures assume a role of greater significance.

CAPACITY BUILDING FOR ISIN NUCLEAR EMERGENCY CENTRE: CONVEX-3 2025 EXERCISE EXPERIENCE

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Introduction

Legislative Decree 45/2014 [1], which established National Inspectorate for Nuclear Safety and Radiation Protection (ISIN), assigns the Inspectorate, among other tasks, the responsibility of providing technical support to Civil Protection Authorities in planning and response to nuclear and radiological emergencies. Moreover, in accordance with Article 184 of Legislative Decree 101/2020 [2], ISIN hosts the Data Elaboration and Evaluation Centre (CEVaD), the technical structure of the Civil Protection Department, ensuring a common technical reference for the management of such emergencies. In order to fulfil ISIN's advisory role, the Nuclear Emergency Centre (CEN) was established. Its role is explicitly highlighted in the National Plan for the Management of Nuclear and Radiological Emergencies.

Description of the Work

CEN is equipped with systems, tools, and expertise enabling the technical management of emergencies, ranging from the initial assessment of the incidental situation to the radiological characterization of affected areas. These resources include atmospheric dispersion models early warning radiological monitoring networks, data collection and analysis platforms, communication procedures with national and international institutions, and a 24/7 on-call service with experts in nuclear safety, radiation protection, and atmospheric dispersion modelling.

CEN staff members receive continuous training on operational systems, internal procedures, and the fundamentals of emergency management. Moreover, the CEN regularly takes part in national and international exercises, which are crucial to consolidating operational capacities and enhancing the professional development of recently recruited staff.

In June 2025, the entire CEN staff participated in the international CONVEX-3 exercise, organized by the IAEA and based on a severe accident scenario at the Cernavoda nuclear power plant in Romania. The 36-hour continuous exercise provided Italy with the opportunity to test its National Plan for Nuclear and Radiological Emergencies and to assess coordination among the various institutions involved.

Conclusions

Participation in CONVEX-3 represented a crucial capacity building opportunity for the CEN: experts were able to apply established procedures, strengthen analytical and communication skills, and reinforce cooperation with other institutions. For newly recruited staff, the exercise served as a practical test to apply the knowledge gained through training.

The experience confirmed the central role of the CEN as a technical advisor in nuclear and radiological emergencies, while highlighting the importance of continued investment in training, tools, and human resources to ensure the country's operational readiness.

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ACTIVITY STANDARDIZATION OF YB-175 TO STUDY ITS DECAY PROPERTIES

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Introduction

Ytterbium-175 is an emerging radionuclide in the field of nuclear medicine, since it is a promising candidate for developing therapeutic agents. Despite this interest, there are still open questions about its decay properties (e.g. photon emission intensities, half-life). Furthermore, the metrological traceability to measure the activity of ^{175}Yb accurately is yet to be established.

Description

In this work, a successful activity standardization of ^{175}Yb is reported. The ^{175}Yb was obtained via the PRISMAP medical radionuclides program with the aim to derive its absolute photon emission probabilities and study its half-life. The material was produced at Institut Laue-Langevin (ILL) by neutron irradiation and went through radiochemical purification at the Paul Scherer Institute (PSI). An ampule of the received ^{175}Yb solution was also sent to the Bureau International des Poids et Mesures (BIPM) in Paris to establish a link to the International Reference System (SIR).

Our primary choice for the activity determination method was 4πβ-γ coincidence counting, because this measurement technique has only minimal dependence on the underlying nuclear data. The measurements were realized in three different, custom-built experimental setups, taking advantage of a digitizer-based measurement approach and off-line data analysis. The activity was derived by the efficiency extrapolation method.

The activity of the solution was also measured with four liquid scintillation (LS) counters, employing the CIEMAT/NIST efficiency tracing and TDCR methods to derive its activity. Using the most recent decay data from the literature, the derived activity was consistent with the value obtained from coincidence counting. The overall standard uncertainty of the activity determination combining all results was less than 0.4%. Using the long-term LS counting data, it was possible to extract the half-life of ^{175}Yb.

Finally, a series measurements using calibrated high purity Germanium detectors were performed in order to study the gamma spectrum of ^{175}Yb in detail. In combination with the precisely known activity and half-life, these measurements will be used to investigate the decay scheme of ^{175}Yb allowed and to derive absolute gamma emission probabilities in the future.

Conclusions

With the present work, the standardization of the novel therapeutic agent ^{175}Yb was successfully carried out and an international traceability link was established. The half-life obtained from the long-term measurement was found to be in excellent agreement with other recent determinations. In the next analysis step, these results will be used to derive gamma emission probabilities with high precision.

METHOD OPTIMIZATION APPROACH APPLIED TO THE DETERMINATION OF ^{241}Am IN URINE IN EMERGENCY SITUATIONS

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Introduction

During nuclear or radiological emergency, the need to quickly monitor a very large number of people is actual, so there is a need for fast and robust methods to determine radionuclides in bioassay samples. A simple method to project and adapt routinary measurement techniques for a mass monitoring of internal contamination based on the concept of "minimum detectable dose" has been developed and applied to Americium and Curium isotopes.

Description of the Work

Rapid column extraction methods have been used in the Integrated laboratory of Monitoring and measurement of Radioactivity of the ENEA Radiation Protection Institute (IRP-MIR) from several years, applied to biological samples, for the routinary occupational exposure monitoring of alpha emitting radionuclides, such ^{241}Am. A slightly modified procedure was reported by the ENEA Casaccia IRP-MIR laboratory for rapid analysis of Am and Cm in small urine samples, suitable for emergency situation. This method was designed by adopting an original criterion founded on the concept of "minimum detectable dose" defined as the dose corresponding to a measured activity equal to the minimum detectable activity (MDA). In radiation protection, MDA is the parameter that summarizes and defines more than any other the potential of a specific measurement technique in relation to specific needs. This parameter[1] constitutes the basis for the definition of appropriate monitoring programs to guarantee that a predefined effective dose value assumed as a Reference Level (RL) is not exceeded, according to the ICRP indications for emergency situations[2].

Conclusions

This optimization approach can be extended to all types of internal contamination measurements. Moreover it is specifically studied for the prior identification of the operating parameters that most affect the optimization of an analysis procedure so that it could be able both to detect all contaminations which lead the exceedance of a predetermined RL and to calculate the useful samples collection time. The procedure here presented has also been successfully validated with spiked urine samples at two different levels of contamination. The technique is specific for ^{241}Am, but Cm isotopes may also be determined in the same purified fraction, using ^{243}Am tracer as a yield monitor, since curium tracks closely with americium in this method and this is a typical laboratory practice[3].

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VALIDATION OF A QUALITATIVE METHOD FOR TOTAL BETA EMITTERS DETERMINATION IN URINE SAMPLES USING LIQUID SCINTILLATION COUNTING AND GAMMA SPECTROMETRY

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Introduction

In the domain of radiotoxicology, the determination of beta emitting radionuclides in urine samples is a valuable tool in occupational radiation protection and in emergency situations, in that it enables to obtain relevant data for accurate calculation of committed effective dose to workers or other potentially contaminated people, e.g. in a mass accident.
With the aim of eliminating the need of time-consuming and complex radiochemical separation procedures used in quantitative determinations of virtually every pure beta emitting radionuclide of common interest (e.g. Sr-90), in this work we present an original and simple analytical method which exploits simultaneously Liquid Scintillation Counting (LSC) and gamma spectrometry for the qualitative determination of total beta emitting radionuclides in urine samples.
This method may be a useful and relatively simple tool for screening purposes both in occupational radiation protection and in emergency situations.

Description of the Work or Project

500 mL or 1 L urine aliquots taken from a large set of 24-hour urine samples featuring baseline radioactivity level (natural or fallout activity) have been submitted to gamma spectrometry using three different HPGe detectors to determine their K-40 activity concentration c_A(K-40). In parallel, decolourized 3.1 mL aliquots of the same samples, mixed with 15 mL UltimaGold LLT® scintillating cocktail, have been submitted to LSC to measure their counting rates in the 5 keV-1700 keV energy window, in ultra-low level mode.
For these baseline samples, the relationship between counts per minute (CPM) in LSC and c_A(K-40) obtain by gamma spectrometry is approximately linear and a statistical prediction band (CPM_{min}, CPM_{max}) *vs.* c_A(K-40) is then calculated in order to discriminate positive results from negative results when unknown samples are analyzed.
Moreover, to check the selectivity/specificity and the sensitivity of the method, a large set of samples spiked with H-3, Sr/Y-90 and natural uranium (the latter as simulant of alpha emitters, which might in principle affect LSC measurements) have been analyzed: the results confirm the fitness of the proposed analytical method for the intended purposes.

Conclusions

In this paper the authors present a novel analytical method for the qualitative determination of total beta emitting radionuclides in urine. The method exploits a quantitative and statistically significant correlation between the activity concentration of K-40 determined by gamma spectrometry c_A(K-40) and the counting rate (CPM) in a selected energy window in LSC. A prediction band (CPM_{min}, CPM_{max}) vs cA(K-40) is calculated based on the specific laboratory measurement equipment and experimental conditions and it is then used to discriminate positive results from negative results.

THE TRANSPORT OF RADIOISOTOPES FOR MEDICAL USE: CRITICAL ISSUES AND INITIATIVES

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Introduction

The presentation concerns the transport of radioactive material for medical use, providing a description of the critical issues and the initiatives implemented by Italy through the National inspectorate for nuclear safety and radiation protection (ISIN) in order to prevent and to mitigate them.

Description of the Work or Project

The transport of radioactive material in the Italian territory is mostly related with medical and research (90%) and most of transported packages for the medical use contains Fluorine-18.
During the transport of radiopharmaceuticals both economic and radiation protection aspects have to be optimized in the definition of the routes because these materials need to be delivered in the shortest time and the dose to workers and the involvement of population have to be minimized according to the "As Low As Reasonably Achievable" criteria (ALARA).
One of the critical issues in the transport of radiopharmaceuticals and, more generally, of radioactive material is the delay in and denial of shipment, defined by the IAEA as “Denial of Shipment” (DoS), i.e. an explicit or implicit refusal to carry or accept a shipment of radioactive material at any point during transport though it conforms to all applicable regulatory requirements, or a policy decision not to accept such material by one of the parties involved in a route along the shipment.
DoS has a significant impact in the transport of radiopharmaceuticals due to the nature of these materials, which decay rapidly; consequently, even a short delay in the delivery of these products can result in the loss of several doses for diagnosis and treatment of patients.
In order to implement the IAEA relevant forum recommendations on the facilitation of the transport of radioactive material, Italy, through ISIN, has adopted the following initiatives:

- the designation of a National Focal Point (NFP) for DoS;
- the establishment of a National Committee on the facilitation of safe and secure transport of radioactive material (FATRAM), which brings together all the public administrations, companies and associations involved in the transport of radioactive material.

The NFP main objectives are to share knowledge on DoS and to prevent DoS by proposing solutions and collecting data about existing situations.
The main objectives of the FATRAM Committee are:

- planning and coordination for the prevention and tackling of DoS instances, supporting all interested parties;
- identification of any regulatory obstacles or discrepancies between national and international legislation for the transport of radioactive material;
- promoting harmonization of procedures to facilitate the arrival of radiopharmaceuticals on national territory;
- promoting training and communication activities on the transport of radioactive material.

Conclusions

The NFP and FATRAM Committee activities will be essential to prepare proposals for possible interventions, including regulatory and normative ones, to reduce cases of DoS that affect, in particular the provision of medical treatment and diagnosis, the selection and reliability of transport routes for all kinds of radioactive material and the predictability of transport.

Keywords

Radiopharmaceuticals, transport, denial of shipment, FATRAM.

CHARACTERISATION OF ENVIRONMENTAL REFERENCE MATERIALS SPIKED WITH RADIONUCLIDES BY MASS SPECTROMETRY

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Introduction

The critical challenge in the field of trace or ultra-trace analysis of radionuclides in environmental matrices lies in the lack of reference materials. This is a major need in many fields, including environmental monitoring, the nuclear industry and nuclear forensics. One of the aims of the European MetroPOEM [1] project is to produce two reference materials (RM): a liquid seawater-based material and a solid synthetic silicate material. These two materials have been doped with different radionuclides including U, Pu, Am and Np.

Description of the Work or Project

This work presents the analytical strategy to characterize with high precision the isotopic compositions and concentrations of the mother U, Pu, Am and Np solutions used for doping RM by multicollection mass spectrometric techniques. These spikes were alone solutions which are first characterized by Thermal Ionisation Mass Spectrometry (TIMS) and by Multi-collector Inductively Coupled Plasma Mass Spectrometry (MC ICP-MS) associated with the technique of isotope dilution for their concentrations. The uncertainties obtained for U and Pu isotope ratios are on per mill level and concentrations lower than 1%. We will present the methodology used for uncertainty evaluation and the uncertainty budget for each measurement. The independent spike solutions were mixed by weight and the mixture were characterized using the same techniques and after chemical separation using UTEVA-type extracting resin [2]. The results are compared with those obtained on the alone solutions and the differences are discussed. Finally, the spike mixtures were added to the liquid seawater-based material and to the solid silicate material to produce two RM. The homogeneity, between-bottles and within bottles, of both RMs was assessed using gamma-ray spectrometry and mass spectrometry. The results obtained by mass spectrometry on these two reference materials are presented and discussed.

Conclusions

The two environmental reference materials are well characterized on isotopic and elemental compositions by mass spectrometric techniques and for Am by gamma-ray spectrometry and could be used to develop and validate methods of measurements by mass spectrometry in laboratories in charge of environmental monitoring or nuclear forensics.

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OPERATIONALIZING A NUCLEAR DIGITAL TWIN FOR MEDICAL ISOTOPE IRRADIATION PLANNING TO MEET CLINICAL DEMAND

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Introduction

The United States is a global leader in nuclear technology, yet access to key medical isotopes remain fragile due to limited global production capacity, reliance on foreign reactors, and short isotopes half-lives. To address this, we have developed the first ML-driven Medical Isotope Planning Digital Twin (MIP-DT) to optimize nuclear reactor-based production of medical isotopes. Our goal is to increase isotope yield and throughput directly, supporting access to lifesaving diagnostics and therapies for cancer, cardiovascular, and neurological diseases. This work evaluates a series of irradiation scenarios for ^{152}Sm at UT Austin's TRIGA Mk-II reactor. The objective was to ensure safe reactor operations while producing the target activity of ^{153}Sm required for a 150 mCi patent dose.

Description of the Work

A series of irradiation scenarios for ^{152}Sm were evaluated using a DT varying with reactor operations (see Figure 1), to assess the tradeoffs between maximizing medical isotope yield while maintaining safe reactor operations. Additionally, the MPACT code is used to model the same reactor operations to provide confirmatory analysis of the digital twin predictions.

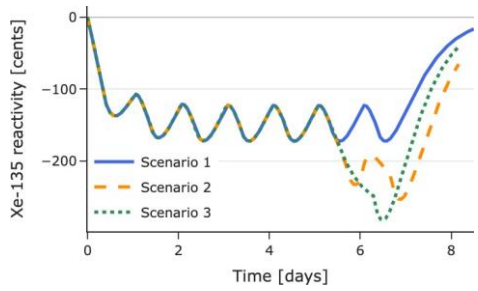

Figure 1: Xenon Reactivity Worth Predictions

Peak at	DT Reactivity (cents)	MPACT Reactivity (cents)	Difference (cents)
1 day	-137	-124.7	-12.3
2 days	-167.7	-157.5	-10.2
3 days	-171.8	-162.9	-8.9
4 days	-172.3	-164.4	-7.9

Table 1: Reactivity Comparison During Operation

For both calculations, the model was started a week prior to the irradiation campaign, and the operating schedule was assumed to be 8 hours at full power followed by a 16-hour shutdown. Three scenarios were examined by irradiating the sample with: **(1)** 8 hours-on/16-off reactor operation for 3 days, **(2)** 16 hours-on/8-off for 2 days, and **(3)** 31 hours irradiation. Comparison between the DT predictions and MPACT reference results (Table 1) demonstrate strong agreement with respect to the overall ^{135}Xe reactivity worth, which is a key operational concern during extended irradiation campaigns. We concluded that the similar ^{135}Xe reactivity would be experienced during the 16-on/8-off irradiation campaign as the 31-hour straight irradiation.

Conclusions

This project demonstrates the viability of using modeling and simulation capabilities to help inform irradiation campaigns for the production of medical isotopes. Three irradiation scenarios were evaluated to determine the best operational plan to produce the sample with accurate activity and most efficiently. Overall, the operators chose two 16-hour irradiations with an 8-hour shutdown period. Ultimately, the sample was delivered to the patient on time and with sufficient dose.

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THE ISOLPHARM RADIONUCLIDE IMPLANTATION STATION FOR MEDICAL APPLICATIONS AT SPES

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Introduction

The ISOLPHARM project investigates the production of medical radionuclides using the Isotope Separation On-Line (ISOL) technique. This production method is designed for the SPES facility at the INFN Legnaro National Laboratories. To supply users with the desired radionuclides, a dedicated experimental station, named IRIS, was designed. This work presents the setup and functionality of the IRIS system.

Description of the Work or Project

The ISOLPHARM Radionuclide Implantation Station (IRIS) has recently been installed in the SPES low-energy experimental hall. IRIS consists of two main sections: the first handles the collection of the Radioactive Ion Beam (RIB) delivered from the SPES beamline, while the second measures the collected activity. The RIB is implanted into tablets made of pharmaceutical-grade cellulose or dextrates. Once the collection is complete, the chamber is vented, and the tablets are transferred to the detection site. Two gamma-ray detectors were characterized to estimate the collected activity by analyzing the measured energy spectra. After characterization, the tablets are dropped into a shielded container, making them available for subsequent use. Custom software and GUI enable users to control the collection and perform the activity quantification.

Conclusions

The ISOLPHARM Radionuclide Implantation Station (IRIS) was successfully installed and characterized offline at the SPES facility, covering the entire process from radionuclide collection to activity measurement and storage. Future online tests are planned with both stable and radioactive ion beams to validate the system under operational conditions.

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DATA-DRIVEN OPTIMIZATION OF TERBIUM PRODUCTION VIA ^{nat}EU(α,x) REACTIONS: FROM EXPERIMENTS TO NSGA-II MODELLING

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Introduction

The Health Physics group at LASA laboratory in Milan has a long-standing tradition in the study and optimization of accelerator-based radionuclide production for medical and environmental applications. In the last decade, research efforts have focused on theranostic radionuclides, with special emphasis on terbium, whose four isotopes (^{149,152,155,161}Tb) offer complementary emissions suitable for therapy and imaging. A wide range of experimental campaigns has been carried out within this framework, exploring light-ion-induced reactions on various rare-earth targets to assess alternative production routes for terbium isotopes. Among these studies, the α-induced reactions on natural europium (^{nat}Eu(α,x)) represent a cornerstone. This work presents the results of that investigation and their subsequent use in multi-objective optimization of production parameters through NSGA-II modelling.

Description of the Work or Project

We measured excitation functions for ^{nat}Eu(α,x) up to 65 MeV using blade-coated Eu_2O_3 targets on Al and the IBA-C70XP cyclotron at GIP ARRONAX [1]. Beam monitoring employed ^{nat}Al(α,x)^{24}Na and ^{nat}Cu(α,x)^{66,67}Ga against IAEA recommendations; activities were quantified by short-term HPGe measurements at ARRONAX and long-term γ-spectrometry at LASA. The dataset covers $^{149\text{-}161}$Tb and co-produced Gd/Eu nuclides (e.g., ^{153}Gd, ^{151}Gd, ^{148}Eu). TALYS 1.96 describes trends but shows a systematic ≈ 5 MeV energy shift, indicating the need for improved level density and α-optical model parameters.
On this experimental basis, we formulated a multi-objective optimization for ^{155}Tb on enriched ^{153}Eu using NSGA-II. Decision variables include incident energy window, target thickness, irradiation and cooling times. Objectives jointly maximize ^{155}Tb yield (driven by ^{153}Eu(α,2n)) and radionuclidic purity, while minimizing long-lived co-production and target-material usage. The resulting Pareto front quantifies trade-offs between productivity and purity, providing experimentally anchored operating regions where the desired channel dominates while (α, xn) side-channels are suppressed.

Conclusions

By coupling a full α-induced europium dataset with NSGA-II, LASA delivers a predictive, data-driven framework for ^{155}Tb production design on ^{153}Eu: excitation functions constrain the physics, while optimization yields actionable operating envelopes balancing yield, purity, and resources. This approach complements radiochemical development and accelerates translation from nuclear data to clinically relevant terbium supply.

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RADIOLANTHANIDE PRODUCTION IN CORE (RAPIC): USING COMMERCIAL NUCLEAR REACTORS FOR RADIONUCLIDE PRODUCTION

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Introduction

Radiolanthanides such as ^{177}Lu and, more recently, ^{161}Tb are among the most promising radionuclides for targeted radionuclide therapy. The RAPIC project explores novel target designs to irradiate enriched lanthanide materials (i.e., ^{176}Yb and ^{160}Gd) directly within the core of the Nuclear Power Plant Gösgen, Switzerland.

Description of the Work or Project

While these radionuclides are produced almost exclusively in nuclear research reactors, RAPIC aims to enable production within a commercial power reactor. To achieve this, the project proposes to exploit the Aeroball core monitoring system (AMS), which is used for routine measurements of the neutron flux inside the reactor core, as an insertion pathway for specially designed target spheres. These are fabricated in the form of intermetallic compounds (IMCs) of the selected lanthanide elements with a platinoid metal. They are synthesized through the hydrogen-mediated coupled reduction process [1] and must comply with the dimensional and mechanical specifications required by the AMS. Optimization efforts focus on the lanthanide-to-platinoid ratio, processing temperature, holding time, and annealing conditions, with the goal of improving both mechanical integrity and irradiation stability. The characterization of produced materials involves iteratively X-ray diffraction for phase identification and scanning electron microscopy combined with energy-dispersive X-ray spectroscopy for microstructural and compositional analysis. The mechanical behavior is assessed through indentation and punch tests, simulating the stress encountered during AMS insertion. The most promising IMCs will then undergo neutron irradiation tests at the Swiss Spallation Neutron Source SINQ at PSI to evaluate the irradiation stability and quantify radionuclide yields. In a final step, a suitable chemical separation and purification strategy will be devised in order to obtain high-purity, non-carrier-added ^{177}Lu and ^{161}Tb suitable for radiopharmaceutical applications.

Conclusions

To date, Gd–Pd and Gd–Pt IMCs have been successfully synthesized under optimized conditions. These were mechanically tested, revealing promising performance. The activation impurities of the pure Pd and Pt matrix materials have been characterized, and irradiation experiments on the treated samples are scheduled to evaluate radiation-induced embrittlement of the IMCs. Ultimately, RAPIC could establish a scalable production pathway for key radiolanthanides in a commercial nuclear power plant, thereby enhancing their availability for radiopharmaceutical applicatons in Switzerland and abroad.

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Feasibility study on Ac-225 production using BWR

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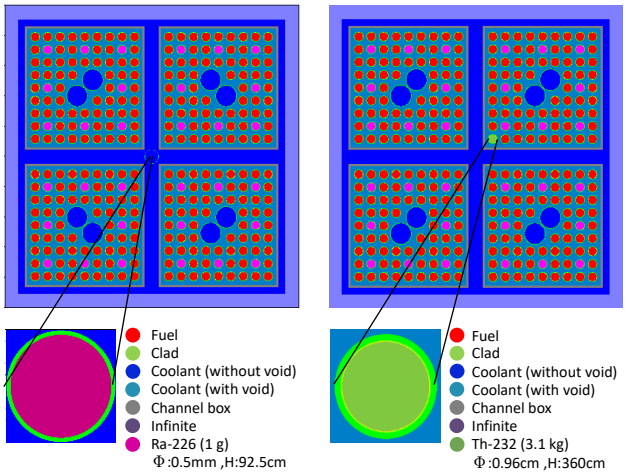
Introduction

Ac-225 is a promising medical radioisotope for cancer therapy, but its global supply is limited, and it is not produced in Japan. Considering potential future demand, domestic production is necessary. Commercial light water reactors, with large irradiation areas and long neutron exposure times, may enable efficient production. This study investigates the feasibility of producing Ac-225 using a commercial boiling water reactor (BWR).

Description of the Work

Ra-226 and Th-232 were selected as target materials. The analysis employed a four-assemblies BWR model ~~using the Monte Carlo code~~ with MVP-BURN, with fuel enrichment assumed to vary only axially. The power per assembly was set at 4.3 MW which was same value as typical BWR. For the Ra method, 1 g of metallic Ra-226 was loaded into the startup neutron source holder at the center. For the Th method, one UO_2 fuel rod in every four assemblies was replaced with a natural thorium metal rod, corresponding to 3.1 kg per assembly and 592 kg (191 pins) for the full core; a case with ThO_2 was also examined for comparison. ~~For the Th method, one UO_2 fuel rod per assembly was replaced with a natural thorium metal rod (compared with ThO_2), corresponding to 3.1 kg per assembly and 592 kg (191 pin) for the full core.~~ In both cases, irradiation was assumed for four cycles (390 days ~~of~~ operation and 90 days ~~of~~ cooling eachper ~~cycle~~). Target loading configurations are shown in Figure 1.



(a)Ra-226 method (startup neutron source holder) (b)Th-232 method (one fuel rod replaced with natural Th)

Figure1 BWR 9×9 four fuel assemblies and target material loading

Results

(1) Ra-226 method: After four irradiation cycles, 0.35 GBq of Th-229 was produced. The Ac-225 obtainable through subsequent milking was estimated to be approximately 3.5 GBq. By increasing the Ra-226 loading to about 18 g, it would be possible to achieve the annual global supply level of approximately 60 GBq. (2) Th-232 method: Following four irradiation cycles, 44 g of U-233 was generated ~~(Fig. 2)~~. Assuming that one pin per four assemblies~~y~~ is replaced with Th-232 across the entire core (191 pin), 8.4 kg of U-233 could be produced. After 20 years of cooling, this would yield 6.1 GBq of Th-229, corresponding to an Ac-225 yield of approximately 61 GBq per year via~~through~~ milking.

Conclusions

Two production pathways for producing Ac-225 in a BWR were investigated. The required loading amount to achieve the global supply level of approximately 60 GBq of Ac-225 was estimated, implying that future domestic production in Japan could be achievable.

References *(style example)*

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PRELIMINARY EVALUATION OF AC-225 PRODUCTION IN THE RSG-GAS REACTOR USING LEU ELECTROPLATING CAPSULE

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Introduction

Targeted radionuclide therapy (TRT) has recently shown a lot of interest in α-emitting radionuclides. Actinium-225 (Ac-225) is one of the most promising alpha emitters because of the decent half-life of 9.92 days. However, there are not enough Ac-225 produced to meet demand. The natural decay of Thorium-229 (Th-229), which originated from the old Uranium-233 (U-233) stockpiles, is the first source of Ac-225. Ac-225 production by (n,2n) reaction in fast experimental reactor JOYO previously had been studied[1]. This research aims to investigate the potential production of Ac-225 by (n,2n) reaction using Indonesia's research reactor (RSG-GAS) and a newly suggested modified low enriched uranium (LEU) electroplating capsule with an implanted Ra-226 target.

Description

The RSG-GAS multipurpose research reactor (15 MWt pool-type, light water-cooled) was modeled in OpenMC using ENDF/B-VIII.0 nuclear data to evaluate Ac-225 production by the standard operation cycle of RSG-GAS, which is 26-days irradiation and 7-days cooling time. The main idea was placing 1 gram Ra-226 targets in the center of low-enrichment uranium (LEU) electroplating capsules typically used for Mo-99 production within the reactor's central irradiation position, which feature three irradiation holes. The configuration of LEU electroplating capsule is depicted in Figure 1. This design would produce fast neutrons from LEU fission to increase Ra-226(n,2n) reactions. The evaluation showed that with the thin LEU layer, Ra-225 production increased by ~52%, reached 11 GBq at the end of irradiation time. With only one cycle and five times separation, a total of 120 days, the total production of Ac-225 reached 6.2 GBq.

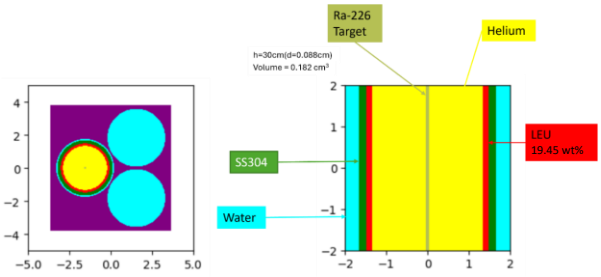

Figure 1 Modified LEU electroplating capsule configuration

Conclusions

The new design of Ra-226 target irradiation capsule by modifying LEU electroplating capsule, originally for producing Mo-99 shows that production of Ra-225 was observed higher with the thin LEU layer, increased by ~52%. After 5 times milking in every 17.5 days, the total production of Ac-225 with thin LEU layer reached 6.2 GBq. This result was promising to produce Ac-225 in the future.

Keywords: Actinium-225, Low Enriched Uranium Electroplating Capsule, RSG-GAS, Targeted Radionuclide Therapy

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CYCLOTRON PRODUCTION OF MEDICAL RADIONUCLIDES WHICH DRIVE TODAY'S RESEARCH AT FORSCHUNGSZENTRUM JÜLICH

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Introduction

The production of proton rich radioisotopes is the supreme discipline of cyclotrons, making their application essential for the development and production of the positron emitters used in medical imaging. With increasing interest in the development of theranostic radionuclides, the cyclotron-based production of radiometals is becoming of increasing relevance and with the commissioning of the Cyclone 30XP cyclotron our institute at FZJ is now expanding its research field accordingly. Recently, new projects have been initiated focusing on non-standard radionuclides focusing on ^{45}Ti, ^{72}As, ^{193m}Pt, ^{203}Pb and ^{211}At. A report of the current work in our institute will be given.

Experimental work and projects

After commissioning of the Cyclone 30XP cyclotron, proton-, deuteron-, and alpha-particle–induced nuclear reactions can be employed at energies up to 30 MeV.
The positron emitter ^{45}Ti is a promising candidate for novel PET tracers and is also under consideration for application in multi-tracer imaging. Its production with 14 MeV protons and its purification have previously been established in Jülich and syntheses of *in-vivo* stable complexes for radiolabelling are underway. For the production of the therapeutic Auger electron emitter ^{193m}Pt via the ^{nat}Os(a,xn)-reaction on osmium an optimised targetry and radiochemical separation procedure is being developed. Concurrent, an efficient process for the routine production of ^{211}At has been established.
Using the experimental beam line of the Cyclone 30XP extensive cross section measurements were done on the direct production of the non-standard positron emitter ^{72}As via protons on enriched ^{72}Ge and alpha-particles on ^{69}Ga. Additional experiments in collaboration with PSI, Switzerland, are scheduled to investigate the production of ^{72}As via the ^{72}Se generator route.

Conclusions

With the commissioning of the new cyclotron a significant extension of the experimental scope could be achieved to meet the increasing interest in non-standard radionuclides. Taking into consideration the complete creation chain of the radiotracers significant progress in the preparation of several non-standard radionuclides, i.e. ^{45}Ti, ^{72}As, ^{193m}Pt, ^{203}Pb and ^{211}At was achieved.

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PRODUCTION OF RADIOISOTOPES FOR APPLICATION STUDIES AT RIKEN RI BEAM FACTORY: EXPLORING NEW ELEMENTS THROUGH CANCER THERAPY

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At the RIKEN RI Beam Factory, Wako, Japan, we have been developing production technologies of radioisotopes (RIs) and conducting RI application studies in the fields of physics, chemistry, biology, engineering, medicine, pharmaceutical and environmental sciences [1]. With light- to heavy-ion beams from the RIKEN AVF cyclotron, we produce more than 100 RIs from ^{7}Be (atomic number Z = 4) to ^{262}Db (Z = 105). In chemistry of superheavy elements (SHEs), the chemical properties of Rf (Z = 104) and Db in aqueous solutions were investigated using novel automated rapid chemical analysis apparatuses for single atoms in collaboration with University of Osaka, Kanazawa University, Niigata University, and Japan Atomic Energy Agency. In the field of nuclear medicine, we have been developing production technologies for ^{211}At and ^{225}Ac through the ^{209}Bi(α,2n)^{211}At and ^{226}Ra(p,2n)^{225}Ac reactions, respectively, for targeted α-particle therapy (TAT). Currently, we supply ^{211}At to 25 research groups across Japan to support the developments of novel nuclear medicines.

RIs of a large number of elements (multitracer) are simultaneously produced from metallic targets such as ^{nat}Ti, ^{nat}Ag, ^{nat}Hf, and ^{197}Au irradiated with a 135-MeV/nucleon ^{14}N beam from the RIKEN Ring Cyclotron (RRC). The multitracer is useful to trace the behavior of many elements simultaneously under an identical experimental condition. Recently, we developed a large-scale ^{211}At production system equipped with a rotating liquid ^{209}Bi target and an on-line dry distillation unit on the RRC beamline. ^{225}Ac can also be produced in the ^{232}Th(^{14}N,$xnyp$)^{225}Ac reaction for TAT.

An isotope of element 113 was synthesized in the cold fusion reaction of ^{209}Bi(^{70}Zn,n)^{278}113 using the RIKEN gas-filled recoil ion separator (GARIS) at the RIKEN linear accelerator (RILAC) facility. The name nihonium and symbol Nh were approved for the new element to complete the 7th period of the periodic table. A synthesis experiment of new element 119 is ongoing in the ^{248}Cm(^{51}V,xn)$^{299-x}$119 reaction using GARIS-III at the upgraded superconducting RILAC facility (SRILAC). We installed a gas-jet transport system to GARIS as a novel technique for SHE chemistry. Long-lived SHE RIs of ^{261}Rf, ^{262}Db, ^{265}Sg (Z = 106), and ^{266}Bh (Z = 107) useful for chemistry experiments were produced in the heavy ion induced reactions on a ^{248}Cm target and their decay properties were investigated in detail using a rotating wheel apparatus for α and spontaneous fission spectrometry. After the successful chemical synthesis of $Sg(CO)_6$ led by the Univ. Mainz and GSI Helmholtzzentrum für Schwerionenforschung groups, a detailed experiment to investigate the stability of the metal carbon bond in $Sg(CO)_6$ is in progress with a thermal decomposition setup by the Paul Scherrer Institute group. Also, syntheses and properties of Tc, Ru, Rh, and Re carbonyls were studied with the ^{252}Cf fission source at Institute of Modern Physics and GARIS for future studies on Bh, Hs (Z = 108), and Mt (Z = 109) carbonyls.

Reference

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PRODUCTION OF NOVEL AUGER ELECTRON EMITTING RADIONUCLIDES AT THE HEVESY LABORATORY

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Introduction

Auger electron (AE) emitters hold great potential for applications in targeted radiotherapy (TRT) due to the very short range of the emitted electrons and the associated high energy deposition. If brought to specific cell constituents by a suitable targeting vector, such radionuclides could in principle kill only the cancerous cells while sparing healthy neighboring tissues. For enabling preclinical experiments, the desired radionuclides need to be made available in sufficient activity, and good chemical and radiochemical purity.

Description of the Work or Project

Lanthanum-135 (^{135}La), erbium-165 (^{165}Er) and palladium-103 (^{103}Pd) are three novel AE emitting radionuclides which have favorable properties for TRT. We here describe the production of these radionuclides on a GE PETtrace 16.5 MeV cyclotron and their purification on extraction resins. To obtain ^{135}La in high yield and purity, enriched barium-135 is needed, which is available in the carbonate form. This material does not have ideal properties as target material; it was mixed with Al powder to increase the thermal conductivity and make it possible to press into a silver target backing carved in the center.[1] ^{165}Er can be produced from natural holmium. A common impurity in metallic Ho is Er, which limits the molar activity. As it is easily available in high purity, Ho_2O_3 was therefore used as target material mixed with Al powder to improve the tolerance of the target. Non-carrier-added ^{103}Pd can be produced from natural Rh which can be electroplated. Metallic Rh has ideal properties as target material but is challenging to dissolve. We electroplated Rh on a graphite target backing and performed the dissolution electrochemically. After the target development, efficient purification procedures were developed for the three radionuclides.

Table 1: Details for the production and purification of ^{135}La, ^{165}Er and ^{103}Pd.

	Target material	Target mass (mg)	Production yield (MBq/µAh)	Separation factor
^{135}La	[^{135}Ba]$BaCO_3$/Al	200	20.3 ± 2.3	$6\cdot10^7 \pm 5\cdot10^7$
^{165}Er	Ho_2O_3/Al	180	12.5 ± 1.6	$4.9\cdot10^4 \pm 3.2\cdot10^4$
^{103}Pd	Rh	23-47	2.0 ± 0.6	$1.0 \cdot 10^6$

Conclusions

^{135}La, ^{165}Er, and ^{103}Pd were obtained in activity and purity suitable for radiolabeling and preclinical studies.

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Keywords: Auger electron emitters, radionuclide production, separation

ACCELERATOR PRODUCTION OF THULIUM-166 AND THULIUM-167 RADIOISOTOPES FROM ALPHA-PARTICLES INDUCED REACTIONS ON HOLMIUM

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Introduction

Accelerator-based production of radioisotopes for medical applications are recently taking a centre stage relative to reactor production route. In particular, there are several promising radioisotopes, such as ^{167}Tm, produced via cyclotrons which have decay characteristics suitable for diagnosis and or targeted radioisotopes therapy (TRT). Specifically, the ^{67}Tm was proposed as an important radioisotope for studying bone and tumor and as skeletal imaging agent. Furthermore, the emission of Auger electrons, low energy γ- and X-rays by the ^{167}Tm and its moderate long half-life (9.25 days) are fitting characteristics for radiotherapy, making it suitable for the treatment of small tumors weighing 1 mg or less.

Description of the Work or Project

In the present work, 50 MeV α-particles beam was used to induce reactions on ^{165}Ho target for the production cross section of ^{166}Tm and ^{167}Tm radioisotopes. The reaction cross sections were measured in the energy range of 49.6 MeV down to the threshold of production of these radioisotopes. The stacked-foil activation technique was used for the irradiation of the target whereas the gamma-ray spectrometry was perfumed using a Ge detector. The measured excitation functions for the radioisotopes were compared with previous measurements as well as the theoretical evaluations from TALYS nuclear reaction code via its library, the TENDL-2017. We also calculated the thick target yields for the radioisotopes.

Conclusions

The results agree with some of the previous experimental measurements, though the theoretical predictions could not accurately reproduce the present measurements. These results could be useful for medical applications, astrophysical studies, and for the improvements of the nuclear reaction models codes.

Keywords: ^{166}Tm, ^{167}Tm, Holmium, (α,x) reactions and excitation functions.

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THE TARGET-ION SOURCE UNIT FOR THE COMMISSIONING OF THE SPES ISOL FACILITY

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Introduction

The Target-Ion Source (TIS) unit represents the core of the Radioactive Ion Beam (RIB) production process in an ISOL system, and is constituted by the target, the ion source and the vacuum vessel that contains the former two items. The TIS unit adopted for the commissioning of SPES, the ISOL facility at INFN-LNL, included a target composed by a set of silicon carbide (SiC) disks, and the Forced Electron Beam Induced Arc Discharge (FEBIAD) ion source.

Description of the Work or Project

The TIS reliable and efficient operation is of paramount importance to ensure the delivery of RIBs to experimental users, therefore each component was carefully studied and tested to identify its operational conditions. In the case of the SiC target, a multistep simulation procedure, including MonteCarlo and Multiphysics simulations, was developed to study the effects of the target irradiation with a proton beam, whereas the material thermal and mechanical properties were deeply investigated at high temperature. Regarding the adopted FEBIAD ion source, the new possibilities provided by additive manufacturing of ISOL-grade materials were exploited, aiming at increasing the ion source repeatability and reliability. Indeed, the Laser Powder Bed Fusion (LPBF) technique proved to be suitable for producing tantalum components capable of operating in vacuum at high temperature. Benefitting of the know-how accumulated with the INFN HISOL and HISOL_NEXT experiments, FEBIAD Ta cathodes and anodes were produced by LPBF and extensively tested, resulting in a better geometrical accuracy and an increased ion source reliability.

Conclusions

The first RIB at SPES was achieved with a SiC target coupled with a FEBIAD ion source proved including a LPBF Ta cathode. The positive outcome of such experience paved the way for further explorations of the new degrees of freedom provided by additive manufacturing.

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Thin Layer Activation of non-metallic material by using the $^{nat}C(^3He,x)^7Be$ nuclear reaction based on the carbon content

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Introduction

Thin Layer Activation (TLA) is a versatile tool for measuring wear, corrosion and erosion rate on the surface of different machine parts by using the charged particle activation. It is easy to accomplish when the surface to be investigated contains iron or elements from the iron group, because the cross sections, yields and penetration properties are well-known and well-documented. It is not the case by plastic materials and others, e.g. DLC (diamond-like carbon) that do not contain these metallic elements. Thanks to the relatively high cross section of the $^{nat}C(^3He,x)^7Be$ nuclear reaction and the nuclear properties (half-life, gamma-radiation, …) of the ^7Be labelling radioisotope, the problem can be easily solved [1,2].

Description of the Work or Project

In the case of plastic materials, the beam intensity should be low not to damage the surface with heat load, and in the case of DLC the penetration depth should be low because the low expected wear rate. That's why we used a relatively low beam current (< 500 nA) and declined irradiation (15°), where the penetration depth is a quarter of that of perpendicular irradiation. In special cases, the counterpart (mainly an iron-containing material) had to be radio-labelled with ^{57}Co or ^{56}Co to measure the wear of both parts simultaneously.

Fig. 1 Calculation of necessary irradiation time, irradiation angle and the resulting activity

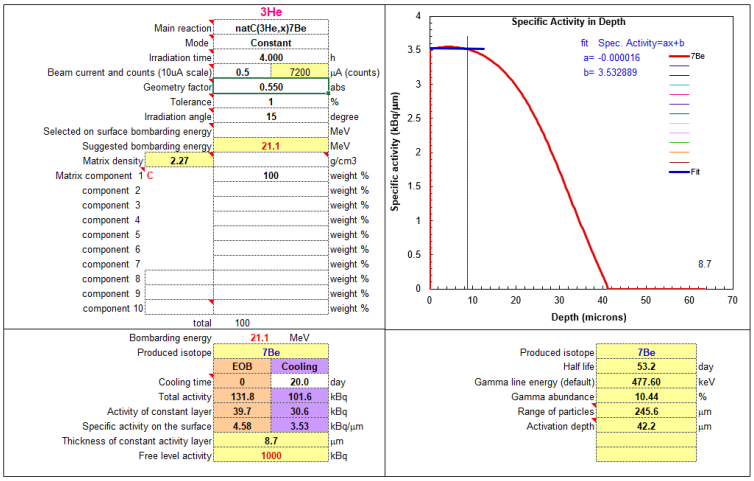

Fig. 1 shows the calculation based on the TLA code, which is also available at the IAEA [3] Nuclear Data section. It shows the activation of carbon with ^3He beam under 15° angle, which produces 8.7 µm constant depth profile and 40 µm total penetration depth. The activity in the constant layer is 30 kBq, even after 20 days after the end of the irradiation, and the corresponding total activity is 130 kBq. It requires 4 hours irradiation time with 0.5 µA beam current. This is far below the Free Handling Limit (FHL) of the ^7Be isotope, and so can be delivered and used without a radioactivity license.

Conclusions

The feasibility of using ^3He induced nuclear reaction to produce a reasonable amount of ^7Be for wear measurement has been proven. In the case of DLC coating the thickness of the DLC layer can be much less than the penetration depth or the penetration depth down to the

reaction threshold. So the matrix of the material can also be activated, which produces a surplus activity but makes possible to monitor breakage through the coating.

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CHALLENGES IN MEASUREMENTS OF ENRICHMENT OF ^{28}SI AS SILANE BY USING TOF-MS

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Introduction

Based on silane, SiH_4, the lightest gaseous silicon compound, Isosilicon AS has developed chromatographic methods for enrichment of the lightest silicon isotope[1,2], ^{28}Si. By using packed columns, the separation factor between neighboring theoretical plates is very small, but the number of plates can be extremely high. Thus, the accurate analysis of the isotope variation is imperative although very demanding.

Description of the Work or Project

In order to determine the separation factors for $^{28}SiH_4$ versus the two heavier isotopes, $^{29}SiH_4$ and $^{30}SiH_4$, the output from the separation unit was coupled directly to a Time-Of-Flight Mass-spectrometer, TOF-MS equipment at IC2MP (CNRS, University of Poitiers, France). However, the large difference in natural abundancies between ^{28}Si and the others, 92.223 vs. 4.685 and 3.092 % respectively[3], made the signals from $^{28}SiH_4$ override the others even for the non-enriched samples. This report will give an assessment of how to analyse the spectra and also the possible faults one might experience using TOF-MS.

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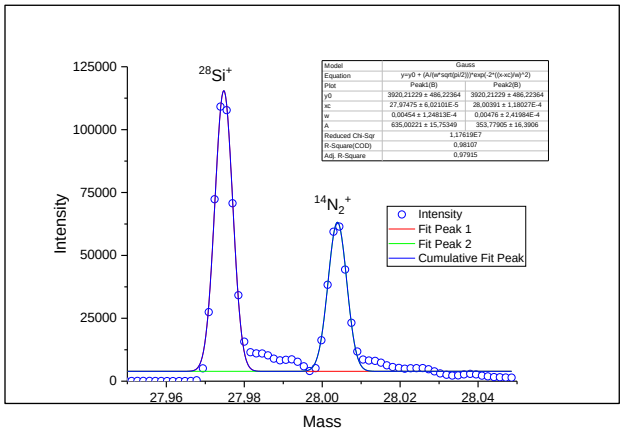

Figure 1. Example of TOF-MS mass resolution
The graph shows that for mass 28 it is possible to distinguish between $^{28}Si^+$ and $^{14}N_2^+$

Conclusions

Despite the high mass resolution of TOF-MS it is not sufficient for good measurements of enrichment of ^{28}Si as silane.

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Recent Developments in Neutron Beam Characterization at the RAON NDPS

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Introduction

The Nuclear Data Production System (NDPS) at the Rare Isotope Accelerator complex for ON-line experiments (RAON) is a new facility designed to generate fast neutrons for various applications, including nuclear data measurements, material science, and semiconductor testing. Neutrons are produced via nuclear reactions by bombarding a target with high-energy ion beams delivered from the RAON heavy-ion accelerator. Following the successful first beam commissioning in September 2024, which confirmed the overall system integration and performance, we proceeded with initial experiments and facility upgrades.

Experimental Progress and Results

System Upgrades

Prior to new measurements, the facility underwent upgrades, notably to the Beam Profile Monitoring (BPM) system. This system, which utilizes a phosphor screen and a high-resolution camera, was improved to allow for more precise and stable beam targeting on the neutron production target.

Machine Study and Characterization

The initial experimental campaign used a 16.3 MeV/nucleon $^{40}Ar^{18+}$ ion beam impinging on a thick carbon target to produce a white-spectrum neutron beam. A detailed machine study was performed to characterize the neutron beam. We measured the neutron energy spectrum and flux using various detectors, including a Liquid Scintillation Counter (LSC), CLYC-6, and He-3 detectors. Furthermore, experiments were conducted to investigate the effects of different moderators and a stainless steel (SUS) shadow bar on the resulting neutron beam profile and energy distribution.

Conclusions

The recent upgrades and initial experiments have successfully characterized and significantly improved the fast neutron beam capabilities at NDPS. The results confirm the enhanced performance of the facility, providing valuable data on beam moderation techniques and the response of various neutron detectors. This work represents an essential step in preparing the NDPS for future high-precision experiments and diverse applications in neutron science at RAON.

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DIGITAL 4πβ(TDCR)–γ COINCIDENCE COUNTING AT THE BIPM USING A MODIFIED TDCR SYSTEM

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Introduction

The 4πβ(TDCR)–γ coincidence method is a key technique for the primary standardization of radionuclides. It requires only three experimental quantities, the beta count rate from double or triple coincidences, the gamma count rate, and the coincidence count rate, and does not rely on nuclear decay data or efficiency models. Originally based on proportional counters, 4πβ–γ coincidence counting is now increasingly implemented with liquid scintillation systems, offering greater flexibility in sample preparation.

Description of the Work or Project

At the BIPM, one of the Triple-to-Double Coincidence Ratio (TDCR) systems has been adapted to perform 4πβ(TDCR)–γ digital coincidence counting by adding a NaI(Tl) detector as a fourth channel. The system operates with a CAEN DT5730S digitizer and DPP-PSD firmware, recording data in list mode.

The data are analyzed using the Digital Coincidence Counting (DigiCoinc-2025) software, developed jointly with the National Institute of Metrology (NIM, China). The software constructs beta–gamma time difference distributions to optimize coincidence windows and relative delay between channels, applies an extended dead-time correction to suppress after-pulses, and implements a digital adaptation of the **modified Müller formula**, which corrects coincidence count rates using digitally estimated transmission factors, rather than relying on the independent Poisson process assumption of the original formula. Activity values are determined via efficiency extrapolation by varying beta-channel thresholds, with final results obtained through linear fits to zero inefficiency.

Validation experiments were carried out with ^{60}Co and ^{166m}Ho sources using the modified 4πβ(TDCR)–γ system. Results showed excellent agreement with those from a conventional TDCR system, confirming the reliability of the new approach.

Conclusions

The modified BIPM TDCR system successfully integrates 4πβ(TDCR)–γ digital coincidence counting, combining flexibility, robustness, and high accuracy. The approach provides an efficient tool for primary radionuclide standardization and has been validated against established methods.

Based on these first results, a new system 4πβ(TDCR)–γ digital coincidence counting with optimized detection features will be developed at BIPM.

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RAPID DETECTION OF THORIUM, RADIUM, AND ACTINIUM IMPURITIES IN ^{228}Th DECAY SERIES ISOTOPE PRODUCTS

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Introduction

Radionuclides in the decay chain of ^{228}Th, specifically ^{212}Pb and ^{212}Bi, have shown increasing interest for targeted alpha therapy. The purity of these daughter products from longer-lived parent isotopes is an important metric that will impact the final drug product quality and may also have implications related to site licensing if the impurity is present in significant quantities. Analytical methods must be rapid and capable of measuring trace quantities of impurities in relatively high amounts of other radionuclides with a range of half-lives and decay emissions that can interfere with detection techniques.

Description of the Work or Project

Separation by extraction chromatography and analysis by alpha spectrometry has shown promise for isolating Th, Ra, and/or Ac impurities from ^{228}Th, ^{224}Ra, and ^{212}Pb/Bi sources with low limits of detection and rapid analysis times. Contamination of ^{229}Th(^{225}Ac) and ^{227}Ac(^{227}Th) in ^{228}Th sources can be quantified by an actinium-thorium separation on UTEVA and DGA-Normal resins. The amount of ^{228}Th impurity in ^{224}Ra, used for ^{212}Pb and ^{212}Bi generators, can be quantified after separation on TEVA and TRU resins. The amount of ^{224}Ra and ^{228}Th in in ^{212}Pb or ^{212}Bi can be determined after separation on a combination TEVA, TRU, and SR resins. The Ac and Th samples may be prepared for alpha spectrometry analysis by CeF_3 microprecipitation onto filter membranes, while Ra samples precipitated with $BaSO_4$. These methods have been designed to rapidly detect impurities on the order of < 0.01% total activity and have been demonstrated successfully on several ~0.1-1 mCi samples.

Conclusions

Quantitative analysis of trace radionuclide impurities in nuclear medicine drug products is an important step in the quality control of radiopharmaceuticals. Methods have been developed for the quality control of ^{228}Th, ^{224}Ra, and ^{212}Pb/Bi products which employ extraction chromatography resins to isolate radionuclidic impurities for analysis by microprecipitation alpha spectrometry. These methods have successfully quantified impurities of < 0.01% in both ^{224}Ra and ^{212}Pb products.

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IMPLEMENTATION OF A QUALITY MANAGEMENT SYSTEM IN A CYCLOTRON-PET/CT RADIOPHARMACEUTICAL PRODUCTION LABORATORY

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Introduction

Laboratories dedicated to the production of radiopharmaceuticals for positron emission tomography (PET) play a critical role in modern nuclear medicine by providing essential inputs for the early detection and monitoring of various pathologies. Given the highly specialized and sensitive nature of these processes which involve the handling of radioactive materials and chemical synthesis under controlled conditions it is imperative to implement a robust and regulatory-aligned quality management system. In this context, the ISO/IEC 17025 standard offers a fundamental framework to ensure technical competence, result traceability, patient safety, and continuous improvement.

Description of the Work or Project

The implementation of a Quality Management System (QMS) was carried out in our laboratory dedicated to the production of radiopharmaceuticals for PET, in accordance with the guidelines of the ISO/IEC 17025 standard. The aim is to ensure the reliability of results, patient safety, and regulatory compliance through the standardization of critical processes. A key pillar of the laboratory was the development of work protocols aligned with Good Manufacturing Practices, radiological protection regulations, and the requirements established by the national regulatory authority. These protocols encompass everything from the synthesis and quality control of radiopharmaceuticals to the safe operation of radiation-emitting equipment and the proper management of radioactive waste. In addition, the qualification and metrological verification of the equipment used in production were conducted to ensure performance in accordance with technical specifications and radiopharmaceutical manufacturing requirements. Simultaneously, training and professional development programs were created for technical staff to strengthen operational competence, promote a culture of quality, and ensure the correct application of established procedures.

Conclusions

The implementation of a QMS in a PET radiopharmaceutical production laboratory represents a fundamental framework to ensure technical competence, result traceability, patient safety, and continuous improvement. The process enabled the standardization fostered a culture of continuous improvement among technical and professional staff. Furthermore, alignment with international standards facilitates regulatory compliance and paves the way for future accreditations, scientific collaborations, and service expansion. Overall, the Laboratory demonstrates that quality is not merely a regulatory requirement, but a strategic tool for operational excellence in the field of radiopharmaceutical production.

Keywords: Radiopharmaceuticals, Quality Management System, Process Standardization, Operational Excellence.

VALIDATION OF A SIMPLIFIED METHOD FOR THE DETERMINATION OF AMINOPOLYETHER AS PART OF THE QUALITY CONTROL OF ^{18}F-FDG

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Introduction

During the ^{18}F-FDG production, it is essential to perform pharmacopeial quality control tests to ensure the safety, efficacy, and stability of the radiopharmaceutical, as well as to comply with regulatory requirements. However, the analytical test designed to identify Related Compound A (RCA), corresponding to aminopolyether, requires specialized materials that are often difficult to obtain. Therefore, the aim of this work was to validate a simplified procedure for this test, adapted to the conditions of a PET radiopharmaceutical production centers in Latin America.

Description of the Work or Project

A methodology based on a colorimetric assay was validated to detect residual RCA in ^{18}F-FDG samples using aluminum silica gel plates and iodine chamber visualization. The approach adopted considers the pharmacopeia specifications for the use of aluminum oxide plates, which are difficult to acquire and maintain in stock in our country. For the validation, aluminum silica gel TLC plates were optimized to enable rapid and visual detection of RCA at the pharmacopeial limit (50 μg/mL). Three tests were conducted: specificity, detection limit, and robustness. The specificity assay demonstrated that the proposed method is selective for RCA at a concentration of 0.05 mg/mL; the detection limit was determined to be 0.006 mg/mL of RCA, and robustness was confirmed through triplicate testing.

Conclusions

Implementing simplified methodologies with readily available materials for routine quality control of ^{18}F-FDG provides cost-effective and reliable alternatives to optimize analytical processes in the laboratory located in Costa Rica. Our approach increases accessibility to locally available materials and reduces dependency on hard-to-import supplies for performing radiopharmaceutical quality control tests.

Keywords

Quality Control, aminopolyether, TLC, validation

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COMPACT LINEAR ACCELERATORS FOR RADIOISOTOPE PRODUCTION

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Introduction

While cyclotrons are currently the predominant type of accelerator used for radioisotope production, there is growing interest in using linear accelerators (linacs) for this application. Linacs can achieve higher beam currents with lower loss and minimal activation. They are economically competitive with cyclotrons, in particular for production of radioisotopes at low energy or when using particles heavier than protons. In recent years, significant efforts have been devoted to developing new compact linac designs, potentially opening new avenues for the production of radioisotopes used in medical imaging and treatment.

Description of the Work or Project

In recent years, CERN has built Linac4, a large linear accelerator operating at 352 MHz, designed to provide protons for the LHC injection chain. This experience was subsequently applied to the design and construction of a series of more compact low-energy accelerators operating at 750 MHz frequency, used for applications such as proton therapy and ion beam analysis.

As a next step, the 352 MHz design has been adapted for acceleration of helium ions (4He2+) to produce Astatine-211 (211-At), the most promising theragnostics isotope for targeted alpha therapy of cancer. The resulting linac is less than 12 meters long, and consists of an alpha particle source, a compact Radio Frequency Quadrupole (RFQ), and a Quasi-Alvarez Drift Tube Linac (QA-DTL) of new design. This set-up accelerates the beam to 28.4 MeV, the energy required for efficient production of 211-At from a 209-Bi target. To maximise efficiency, the linac operates in pulsed mode with a 10% duty cycle. An AISHa-type ion source as used for carbon ion therapy [1] delivers a 5 mA helium beam, corresponding to an average current of 0.5 mA on target, well beyond the capabilities of present cyclotrons. Development is also underway on a new ion source optimized for light ion production, aiming to increase the peak current to 20 mA. Further extension of the linac with additional DTL tanks could increase the final energy to 50-80 MeV, enabling the production of several other medically relevant radioisotopes.

The design of a more compact version of this linac, operating at 750 MHz, has recently begun. It will use the same ion source, coupled with the RFQ design recently developed for fully stripped carbon ions.

Conclusions

An innovative linac design for the production of 211-At and other medically relevant isotopes has been developed, offering dimensions and costs comparable to those of existing cyclotrons but with higher production rates thanks to the increased beam current. Development efforts are now focused on even more compact versions operating at higher frequency, along with associated components such as the ion source and the target systems.

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α-PARTICLE-EMITTING MEDICAL-ISOTOPE PRODUCTION FACILITY BASED ON A HIGH INTENSITY PROTON SUPERCONDUCTING LINAC ACCELERATOR

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Introduction

Targeted radionuclide therapy has been an important clinic breakthrough, particularly targeted α-therapy with α-particle-emitting isotopes such as ^{225}Ac, ^{223}Ra, ^{213}Bi, ^{212}Pb, has demonstrated a successful clinic trial effect. Significant efforts are being made worldwide to develop stable radiopharmaceuticals with α-emitting isotopes. However, the major bottleneck for conducting translational research and future extensive clinical treatments is the limited availability of those α-emitting isotopes. ^{225}Ac isotope can be produced by the spallation reaction ^{232}Th(p,x) ^{225}Ac on thorium targets with proton energies ranging from 100 to 1,000 MeV at beam currents hundreds eμA (1-2). An α-particle-emitting medical -isotope production facility named as IP-SAFE based on a high-intensity proton superconducting linac is being built by IMP in Lanzhou. This talk will present technical design and challenges as well as construction progress of IP-SAFE facility.

Description of the Project

IP-SAFE facility is dedicated to demonstration of high-yields production of ^{225}Ac and ^{223}Ra medical isotopes with proton beam energy 115 MeV and beam current 0.5-1.0 mA. IP-SAFE facility consists of a 115 MeV superconducting proton linac accelerator, two irradiation thorium-target stations, two lines of chemical-separation dedicated to high-purity ^{225}Ac and ^{223}Ra isotopes simultaneous-separation, radioactive waste collection and treatment system, and other auxiliary sub-systems. The unique feature of the IP-SAFE facility is high-intensity proton beam operation and multiple thorium-targets in order to achieve high yields production of the ^{225}Ac and ^{223}Ra isotopes. There are two irradiation target-stations, one for low intensity beam 250-300 eμA with single-target of three cassettes, the other one for high-intensity beam 500-1000 eμA with 16-targets of three cassettes by beam scanning irradiation. The presentation will focus on detailed technical design of the IP-SAFE facility and construction status.

Status and Time-schedule of the Project

The 115 MeV superconducting proton linac will start beam commissioning in March-April 2026. The target stations and isotope separation systems with the hot cells will be ready for beam tests in May 2026. It is expected to start ^{225}Ac isotope production at low beam intensity in June-July 2026.

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RESONANT IONIZATION LASER ION SOURCE FOR HIGH-PURITY RADIOACTIVE ION BEAMS AT SPES, INFN-LNL

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Introduction

The Resonant Ionization Laser Ion Source (RILIS) is a powerful technique employed in many Isotope Separation On-Line (ISOL) facilities around the world for the selective production of isotopes [1]. The step-wise photo-ionization method serves as the foundation for RILIS. It allows the ionization of the desired elements with high chemical selectivity. When combined with mass separation techniques, high-purity isotopic beams can be delivered.
Selective Production of Exotic Species (SPES) is a second-generation ISOL facility in INFN-LNL. The project employs the RILIS technique to deliver high-purity radioactive ion beams [2], by selectively ionizing the isotopes produced by impinging a UC_x target with a proton beam @40 MeV.

Description of the Work or Project

The SPES Laser Ion Source (SPES-LIS) has a tubular structure comprising of two sections: the hot cavity and the transfer line. Resonant laser beams, precisely tuned to the resonant frequency(s) of atomic transition(s) of the desired elements, are injected into the volume of the source. The ion beam is extracted in the opposite direction using an extraction electrode at 30 keV.
The source has been characterized in two independent experimental campaigns carried out at ISOLDE Offline 2, CERN. Experimental tests on the measurement of the chemical selectivity of the source were performed at different operational temperature of the source, and with varying contaminant ion density. The effect of the high ion density on the local production of laser ions inside the source will be discussed. Results on the overall efficiency of the laser ion source will also be presented.

Conclusions

We present the results from the comprehensive characterization of the SPES-LIS, carried out at the ISOLDE Offline 2 facility. This work demonstrates the capability and importance of the source for ion production at ISOL facilities, taking into consideration both its chemical selectivity and overall efficiency. Ongoing efforts toward further optimization of the source will also be discussed.

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RADIOISOTOPE PRODUCTION WITH HIGH-POWER LASERS: HOW TO APPROACH

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Introduction

Successful demonstration of laser-driven nuclear reactions, resulting in synthesis of medical radioisotopes has been repeatedly reported, for a review see Ref. [1]. Most recently, the synthesis of ^{11}C was reported, claiming that the production of preclinical dose is achievable [2]. However, for radioisotope production an important parameter is the specific activity which is generated in the production target.

Description of the Work or Project

Recently, at ELI-NP a project, named “Dr. Laser”, was initiated related to medical applications of high-power lasers. One of the pillars of the project is demonstration of the production of medical radioisotopes with laser-driven proton and/or deuteron beams, and in photonuclear reactions. In particular, one of the deliverables of the project is the production and characterization of pre-clinical doses of 11C. Within this talk, I will discuss the planned experimental set-ups for the realization of the project and the simulation chain which is been carried out for optimization of the isotope production. The following chain of simulations is considered: hydrodynamic laser-target simulations, PIC simulations for generation of the secondary beams, magnetooptical calculations for focusing of the secondary beam, Monte Carlo simulations for the interaction of the secondary beam with the production target considering different target materials, and radiochemical estimates for the extraction of the produced activity. The proposed experiments for optimization of the secondary beams will be reported. In particular, a water-leaf target has been developed, for proton/deuteron acceleration with high-rep rate lasers. The diagnostics used for characterization of the generated particle beam pulses will be described, too.

The work is supported by the European Union, the Romanian Government and the Health Program, within the project "Medical applications of high-power lasers - Dr. LASER"; SMIS Code: 326475

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ADVANCING THERANOSTIC RADIOISOTOPE PRODUCTION THROUGH ION LINEAR ACCELERATOR BASED TECHNOLOGIES

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Introduction

Theranostic α- and β-emitting radioisotopes are increasingly important in precision oncology, while many promising candidates lie beyond the production capabilities of commercial medical cyclotrons. Ion LINACs operating in the 10–30 MeV range provide a complementary production route by enabling higher threshold reaction channels. Within the IFIGENEIA project we investigate the feasibility of LINAC-based isotope production by optimizing beam parameters, target design, and yields to support European radiopharmaceutical landscape.

Description of the Work or Project

A feasibility study was performed for ^{177}Lu production via ^{176}Yb(d,p)/(d,n) reactions using Geant4 simulations. Enriched Yb_2O_3 targets (97%, 0.01–3 mm) were irradiated with 15–20 MeV deuterons. Reaction yields and isotope inventories were calculated for 5- and 12-day irradiations. Results were benchmarked against published computational data, demonstrating consistent predictions and confirming the viability of accelerator-based ^{177}Lu production. In parallel, a wider simulation campaign using Geant4 and FISPACT explores LINAC-accessible theranostic isotopes, including ^{64,67}Cu, ^{43,44g,47}Sc, and ^{152,155,161}Tb, while α-emitters such as ^{225}Ac, and ^{211}At have been identified for further study.

Conclusions

The simulations indicate that an incident deuteron energy of ~18 MeV and a target thickness of 0.36 mm maximize ^{177}Lu production yield. Results demonstrate that ion-LINAC production can deliver clinically relevant radioisotopes, dimimishing thus the dependence on nuclear reactors. The modelling framework, validated with the ^{177}Lu, is now applied to the broader isotope portfolio, enabling systematic evaluation of Cu, Sc, Tb, Ac, and At production routes. A LINAC-based production of theranostic isotopes is a promising scheme under investigation within the IFIGENEIA project.

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Powering the Future of Nuclear Medicine: Scalable Solutions for Global Isotope Demand

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Introduction

The global demand for isotopes is growing at a pace greater than the world's current cyclotron and research reactor infrastructure can supply, driven by a surge in medical innovation, clinical trials, advanced diagnostics, and the rise of personalized medicine. As new therapeutic applications emerge and nuclear medicine becomes a cornerstone of modern oncology, the isotope sector is poised for exponential growth in the coming years.

Despite this demand, today's global isotope supply relies heavily on aging research reactors and limited cyclotron infrastructure. These systems were not built to support commercial-scale production and are increasingly challenged by capacity constraints, maintenance downtime, and geopolitical uncertainties.

Description of the Work or Project

By leveraging decades of nuclear experience and expertise, Laurentis Energy Partners (LEP) is transforming isotope production with advanced reactor-based solutions designed to meet global medical isotope demand. Laurentis and BWXT Medical Ltd. co-designed and commissioned a patented target delivery system (TDS) to produce large quantities of medical isotopes inside a working nuclear reactor at Ontario Power Generation's (OPG) Darlington Nuclear Generating Station while the reactor seamlessly generates clean electricity for millions of homes and businesses. This first-of-its-kind technology is the world's largest capacity isotope irradiation system, representing a significant breakthrough in high-efficiency, high-volume medical isotope production.

Conclusions

CANDU reactors are well suited for large-scale isotope production due to their high thermal neutron flux and minimal downtime compared to small-capacity research reactors. LEP's TDS is designed to leverage these advantages in CANDU reactors to enable scalable, reliable access to lifesaving and high-impact isotopes, including molybdenum-99 (Mo-99), yttrium-90 (Y-90), and lutetium-177 (Lu-177).

FIRST MEASUREMENT OF ^{210,211}AT CROSS SECTIONS USING THE GANIL SPIRAL2 LINAC

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Introduction

Targeted Alpha Therapy (TAT) is a promising cancer treatment exploiting the short range and high linear energy transfer of alpha particles. ^{211}At ($T_{1/2}$ = 7.2 h) is especially attractive because it emits a single alpha particle per decay and has chemical properties similar to iodine, enabling theranostic strategies with halogens. However, its production through the ^{209}Bi(α,2n)^{211}At reaction is challenged by the competing ^{209}Bi(α,3n)^{210}At channel above 28.6 MeV. ^{210}At decays to ^{210}Po, a long-lived (with a half-life of 138 years) and highly radiotoxic isotope that cannot be chemically separated. Accurate cross-section data for ^{210}At and ^{211}At are therefore essential to define optimal irradiation conditions for medical-grade ^{211}At.

Description of the Work

We report the precise measurements of ^{210}At and ^{211}At cross sections performed with the SPIRAL2 superconducting linear accelerator at the Grand Accélérateur National d'Ions Lourds (GANIL, Caen, France). Mono-energetic alpha beams in the 28–31 MeV range were delivered onto Bi targets at the Neutrons For Science (NFS) facility. The accelerator's energy precision (<0.1%) combined with an instrumented Faraday cup for beam monitoring and a pneumatic transfer system allowed accurate and reproducible irradiations. Gamma-ray spectroscopy was conducted using the high-efficiency EXOGAM clover detector array.

Cross sections for ^{211}At were obtained via its 687 keV γ-line, while ^{210}At was quantified through the 245, 1181, 143 and 1483 keV γ-lines. The results show good agreement with IAEA-recommended data for ^{211}At and provide new measurements of ^{210}At between 28.6 and 31 MeV which align well with the findings of Lambrecht et al. (Lambrecht & Mirzadeh, 1985). The rise in ^{210}At production was clearly observed near threshold, confirming that operating around 29 MeV yields optimal ^{211}At production with limited ^{210}At contamination.

Conclusions

This study demonstrates the unique capability of SPIRAL2 to provide high-precision nuclear data for radionuclide production. The dataset will contribute to the optimization of ^{211}At production, supporting its development as a key radionuclide for Targeted Alpha Therapy. These results also highlight the potential of SPIRAL2 for systematic studies of other isotopes relevant to nuclear medicine and other fields.

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Environmental radioactivity mapping in Italy: insight from the ITALRAD project

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Within the national ITALRAD project, the University of Ferrara and INFN, in partnership with public and private stakeholders, developed an integrated approach combining airborne gamma spectroscopy and ground surveys to map natural and anthropogenic radionuclides and assess environmental dose.

The project employed complementary airborne platforms: a dedicated aircraft for regional-scale coverage (RadGyro) and UAV-based systems (RadHawk) for targeted surveys over critical or inaccessible areas. Equipped with high-efficiency scintillators (NaI(Tl), $CeBr_3$), digital multichannel analyzers, and GNSS-IMU navigation sensors, these platforms enabled real-time gamma-ray spectra acquisition, yielding spatial distributions of K, eU, eTh, and ^{137}Cs. Between 2010 and 2024, approximately 10000 km² of the Italian territory were surveyed. Field sampling of over 4500 rock and soil sampled anchored airborne data to local geology. Advanced geostatistical methods, such as Collocated CoKriging, produced high-resolution maps of radionuclide concentrations and derived effective dose. The resulting datasets serve multiple purposes: regional geology and soil studies, mineral exploration, sustainable management of building materials, environmental protection of contaminated sites, and emergency planning for artificial fallout events. UAV-based rapid-response operations proved especially valuable for detailed assessments in industrial NORM sites and critical areas.

This presentation will outline key results and technical innovations, including examples of radiometric maps at different scales, integration with geological and geomorphological data, and case studies on emergency management and site characterization. Combining light aircraft, UAVs, advanced detectors, and multidisciplinary expertise, Italy's ITALRAD experience exemplifies a mature airborne radiological-survey framework that bridges fundamental research, environmental applications, and technology transfer to society.

ASSESSMENT OF RADON AND RADIUM IN DRINKING SPRING WATER IN THE REGION OF BEIRA INTERIOR, PORTUGAL

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Introduction

In the Beiras region of central Portugal, geological pattern is characterized by granitic bedrock enclosed in metamorphic formations, enriched in lithogenic radionuclides and their progeny. Spring water, of underground origin, can dissolve some radioelements. This water is commonly drunk by the population. Therefore, the radiological risk of ingesting radionuclides, such as radon and radium through the consumption of this water, must be carefully evaluated.

The radioprotection hazard is assessed after measuring these radionuclides in water, following ICRP recommendations. The potential influence of geological characteristics at the sampling sites, together with the physicochemical properties of the samples, is investigated. Moreover, radon and radium contents are compared for understanding the origin of the dissolved radon in water.

Description of the Work or Project

Spring water is sampled at different locations in the region of Beira Interior. Each sample is characterized by its physicochemical properties (sampling temperature, pH, conductivity, total dissolved matter) and by its geological location. Radon was measured using Rad7 equipment (Durridge) which analyses the alpha emissions of its progeny (^{218}Po and ^{214}Po). Radium was assessed by alpha spectrometry after adsorption onto a MnO_2 substrate.

Our analyses show values ranging from 20 ± 6 to 816 ± 33 Bq/L for radon and from 29 ± 4 to 304 ± 23 mBq/L for radium. Those values are consistent with previous works (Inácio, 2017). No clear correlation was observed between the activity of ^{226}Ra and the activity of ^{222}Rn; however higher ^{226}Ra concentrations were associated with lower ^{222}Rn levels. The concentration of ^{222}Rn increased with temperature, suggesting mechanisms more complex than simple solubility.

Proxies such as bedrocks composition, water-rock interaction, water flow rate, and air transfer processes must be considered to interpret our results. The annual effective dose due to ingestion can be higher than the recommended reference dose level by ICRP.

Conclusions

Our study contributes to understanding the behavior of Rn and Ra in water, their transfer through human exposure pathways, and the associated increase in radiological risk for the population of the Beira Interior region.

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TIME-RESOLVED GAMMA SPECTROMETRY FOR DISENTANGLING NATURAL AND ANTHROPOGENIC AIRBORNE RADIONUCLIDES

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Abstract

Monitoring airborne radioactivity associated with total suspended particulate matter involves both natural and anthropogenic radionuclides and poses a challenge that is not primarily driven by instrumental sensitivity. The key issue is the separation of overlapping isotopic contributions characterized by markedly different temporal behaviours. Shortly after sampling, gamma spectra are dominated by short-lived radon progeny, which mask the signals of radionuclides of environmental relevance. In this framework, the limitation is conceptual rather than instrumental.

This work presents the implementation of the EyeRAD protocol at the Italian National Institute of Nuclear Physics (INFN) Ferrara site. EyeRAD is a national INFN initiative aimed at atmospheric radioactivity monitoring based on high-resolution gamma spectrometry of particulate matter. Here, time is treated not as an operational constraint but as an analytical variable. Sequential gamma acquisitions become part of the measurement method, allowing the physical discrimination of isotopic contributions through their temporal evolution.

Atmospheric particulate matter is collected using high-volume samplers operating at 1000 L min^{-1} on glass-fiber filters over standard 23-hour sampling cycles, corresponding to a total sampled air volume of $\sim 1.4 \times 10^3$ m^3 per session. After collection, filters are folded to preserve particle retention and measured at fixed time intervals, typically 2, 5, 24, 48, and 72 hours after sampling, enabling the experimental tracking of radon progeny decay and the progressive isolation of longer-lived radionuclides.

Such a time-resolved approach requires a measurement system capable of sustaining this complexity. Gamma-ray measurements are performed using the MCA_RAD system, consisting of two coaxial p-type HPGe detectors with 64% relative efficiency and an energy resolution of about 1.9 keV at 1.33 MeV, operated in a lead- and copper-shielded configuration that reduces background by approximately two orders of magnitude. Efficiency calibration reproduces the actual folded-filter geometry using certified reference materials of natural origin, avoiding geometry-dependent ex-post corrections.

For a sample measured 24 hours after collection with a 19-hour live time , minimum detectable activities of 7.4×10^{-5} Bq m^{-3} for ^{131}I and 6.5×10^{-5} Bq m^{-3} for ^{137}Cs are achieved, while ^{7}Be is routinely quantified at activity levels of $(4.1 \pm 0.3) \times 10^{-3}$ Bq m^{-3}. The resulting measurement is not merely an activity value, but a physically informed description of atmospheric radioactivity.

FROM SOIL TO TREE: ELEMENTAL DRIVERS FOR TIMBER TRACEABILITY

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Introduction

Elemental analysis has emerged as a powerful tool to trace wood origin. Since soil composition strongly influences wood chemistry, establishing soil–wood linkages are crucial to identify elemental drivers that can support law enforcement and environmental monitoring in the Amazon biome based on scientific evidence.

Description of the Work

Fifty-six paired samples of wood and soil were collected in the Jamari National Forest (n = 28, Rondônia state) and in the Amapá National Forest (n = 28, Amapá state), both located in the Brazilian Amazon rainforest. The chemical elements Ce, Co, Cr, Cs, Eu, Fe, La, Sc, Sm, Ta and Tb were determined in wood and soil samples by triple quadrupole inductively coupled plasma mass spectrometry (ICP-MS/MS) and neutron activation analysis (NAA).
Although Spearman's correlation indicated a significant direct relationship only for Ce, canonical correlation analysis (CCA) revealed strong multivariate relationships, mainly driven by Ce, Cs, Eu, La, Sm and Tb (Figure 1).

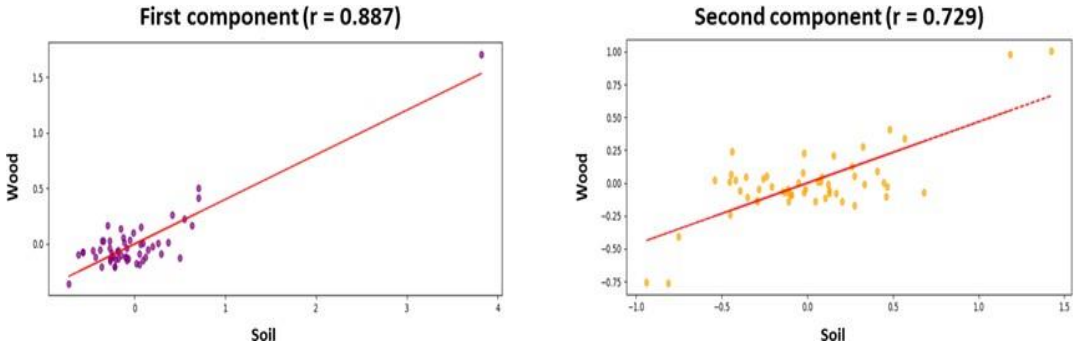

Figure 1: Canonical correlations between soil (n=56) and wood (n=56) samples in the first two components

The first canonical component showed a correlation of 0.887, accounting for 78.7% of the shared variance and was mainly driven by soil Tb, Cs and La, which corresponded to higher levels of La, Eu, Sm and Tb in wood. The second canonical component showed a correlation of 0.729, explaining 53.2% of the shared variance and reflected the influence of Ta, Tb and Ce in soil, with Ce increasing in wood. These results demonstrate that soil–wood relationships are structured by common drivers.

Conclusions

The rare earth elements Ce, Eu, La, Sm and Tb together with Cs in soil and wood are influenced by the same latent factors, so variations in soil composition are reflected in variations in wood despite the absence of direct correlations. These systematic relationships indicate that the most influential elements, being exclusively soil-derived and metabolically inert, make elemental composition a robust and reliable approach for timber traceability and provenance.

RADIOXEON MEASUREMENTS AND SOURCES IN ATLANTA, GEORGIA, USA

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Introduction

A measurement campaign of radioxenon was initiated in Atlanta, GA, USA in 2025 using a SAUNA Q_b [Ringbom *et al.*, 2023] system deployed on the campus of the Georgia Institute of Technology. Initial results have confirmed the detection of both ^{133}Xe and ^{131m}Xe. Radioxenon isotopes are critical for monitoring anthropogenic radionuclide emissions, particularly in the context of the Comprehensive Nuclear-Test-Ban Treaty (CTBT). While the primary objective of CTBT monitoring is to identify nuclear weapon explosions, accurate interpretation requires a robust understanding of background levels arising from civilian nuclear power generation and medical isotope production [Bowyer, 2021]. Establishing baseline measurements in urban areas such as Atlanta is therefore essential to distinguish anomalous signatures from routine industrial or medical activities.

Description of the Work or Project

The dataset demonstrates distinct temporal and isotopic patterns. Detections of ^{133}Xe frequently appear as multi-day plumes, consistent with long-range transport from the west, suggesting either distant reactor sources or extended-duration releases. In contrast, ^{131m}Xe has been observed both concurrently with ^{133}Xe and independently. When detected alongside ^{133}Xe, the signal persists for several days, consistent with regional-scale atmospheric transport. However, several isolated detections of ^{131m}Xe occurred without accompanying ^{133}Xe. One such event, confined to a 12-hour interval, strongly indicates a local source. This highlights the role of medical isotope production and application in shaping urban radioxenon signatures, even in the absence of local nuclear facilities.

Conclusions

The Atlanta monitoring campaign provides new insights into radioxenon background behavior in an urban environment with no proximate reactor sources. Multi-day plumes of ^{133}Xe are most consistent with long-range transport from distant reactors, while short-duration, isolated detections of ^{131m}Xe point to localized contributions from medical isotope usage. Establishing detailed baseline measurements such as those presented here will enhance the ability to differentiate legitimate treaty-relevant events from routine civilian releases.

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^{161}Tb-LABELED GASTRIN ANALOGUE AS A NOVEL TOOL FOR PRECISION TREATMENT OF ADVANCED MEDULLARY THYROID CANCER – STUDY DESIGN OF A PROSPECTIVE PHASE I/II CLINICAL TRIAL (ACRONYM: MTC-Tb)

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Introduction

Medullary thyroid carcinoma (MTC) is a rare malignancy, accounting for approximately 5% of all thyroid cancers and 13% of thyroid cancer–related deaths. At present, approved multikinase inhibitors (cabozantinib, vandetanib) for advanced MTC provide only temporary disease control without a significant survival benefit. The newer agent, selpercatinib, effective in MTC with RET mutations (≈25% of cases), offers a targeted treatment option for only a limited subset of patients. More than 90% of MTCs overexpress cholecystokinin-2 receptors (CCK2R), making them a promising target for radioligand therapy (RLT). The indium-111 labelled CCK2R-targeted gastrin analogue CP04 has demonstrated high uptake in MTC cells [1]. CP04 labelled with terbium-161 (Tb-161), which emits β^- particles as well as conversion and Auger electrons, gives a promise of therapeutic efficacy by enabling elimination of both macroscopic and microscopic lesions.

Description of the Work

This work aims to develop a personalized RLT for advanced, unresectable MTC using a CCK2R-targeting analog, [^{161}Tb]Tb-CP04, and to evaluate its efficacy and safety in a first-in-human study. Thirty adults with advanced, unresectable, histopathologically confirmed MTC will be enrolled. All participants will undergo [^{111}In]In-CP04 imaging to confirm CCK2R expression before therapy. Eligible patients will receive four [^{161}Tb]Tb-CP04 cycles every 8–16 weeks (initial dose 7.4 GBq, adjusted by dosimetry for bone marrow, stomach, and kidneys). Treatment efficacy and safety will be assessed by clinical, biochemical, and imaging evaluations during a 3-year follow-up. PFS, OS, and response rates will be determined according to RECIST 1.1 criteria.

Conclusions

RLT with [^{161}Tb]Tb-CP04 is anticipated to offer an effective and low-toxicity treatment option for patients with advanced, inoperable MTC.

Acknowledgement

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ADVANTAGES OF COBALT 60 IN BRAIN RADIOSURGERY

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Introduction

Cobalt-60 is arguably the single radioisotope with the greatest impact on global healthcare, as 30–40 percent of all single-use medical devices worldwide are sterilized by its irradiation. First produced by Seaborg and Livingood in 1938, large-scale production became possible only after World War II, when research nuclear reactors enabled consistent isotope generation. In 1951, the first patient was treated with a high-intensity Cobalt-60 therapy unit designed at the University of Saskatchewan in Canada, marking the beginning of modern radiotherapy. While its use for sterilization became predominant during the 1960s, Cobalt-60 found many other applications, from calibration and brachytherapy to specialized uses such as the Soyuz capsule altimeter. Although LINAC systems have replaced Cobalt-60 in most external-beam radiotherapy, there remain specific applications in radiation therapy and radiosurgery where its physical characteristics make it unmatched by accelerator-based photon sources.

Description of the Work or Project

This presentation will provide an overview of the broad use of Cobalt-60 in healthcare beyond sterilization, including its role in the calibration of dosimetry systems, external-beam radiotherapy, brachytherapy, and breast cancer treatment. The focus will then turn to stereotactic radiosurgery (SRS) with the Leksell Gamma Knife, where Cobalt-60 remains the source of election for precision brain treatments. The discussion will compare Cobalt-60 with LINAC-based technologies, showing that while technological gaps can often be bridged, the physics gap remains intrinsic to nature itself.

This analysis will address three key aspects of SRS with Cobalt-60. The first concerns the design enabled by the use of multiple compact Cobalt-60 sources allowing dose delivery through a three-dimensional array, producing a cumulative effect with sharp dose fall-off, minimal geometrical penumbra, and precise energy delivery at the isocentre. The second concerns lateral-electron equilibrium and the condition of kerma = 1. The low, discrete photon energies of Cobalt-60 ensure stable lateral-electron equilibrium and dose-delivery conditions where the energy released in a volume equals the energy absorbed in the same volume. This enables the treatment of smaller volumes than is achievable with LINACs, whose broader, higher-energy spectra compromise equilibrium at small field sizes. The third aspect concerns the minimisation of extracranial dose: the intrinsic design and lower photon energy of Cobalt-60 sources result in the lowest extracranial and peripheral doses by design. Finally, the presentation will discuss how recent studies on low-dose effects on cognitive function and lifetime cancer risk from diagnostic imaging relate to the choice of Cobalt-60 as the radiation source for SRS, emphasizing how essential it is to minimise the dose outside the target.

Conclusions

Cobalt-60 remains essential, not as a legacy technology, but as the technology of election for treating the brain. Its advantages are not the result of engineering constraints, but of fundamental physical principles that cannot be replicated by LINAC photon beams. Our conclusion is that Cobalt-60 remains essential in brain radiosurgery and continues to shape both the science and business of nuclear technology in medicine.

RADIOBIOLOGY EXPERIMENTS WITH AG-111 FOR THE ISOLPHARM PROJECT

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Introduction

The ISOLPHARM project has the main objective of producing innovative radiopharmaceuticals using the SPES facility at the INFN-LNL laboratories. The project focuses on the study of ^{111}Ag, a β^--emitting radionuclide which shows interesting characteristics for theranostic applications. This work presents a series of *in vitro* experiments conducted to assess ^{111}Ag effects on cells.

Description of the Work or Project

Clonogenic assays have been conducted on different cell lines, specifically UMR-106 (rat osteosarcoma), MDA-MB-231 (human breast adenocarcinoma), and LNCaP (human prostate carcinoma), to evaluate both the uptake and the cell survival following the administration of free ^{111}Ag at different doses and dose rates. In September, additional experiments with the mentioned radionuclide were conducted using cells inserted in 3D bioprinted scaffolds made of GelMA, with the objective of better mimicking the *in vivo* tumor environment and measure the radionuclide uptake using a β-detector.

Conclusions

The described experiments confirm the potentialities of ^{111}Ag as a candidate for the development of TRT radiopharmaceuticals. Further preclinical studies, including experiments with targeting agents, are already planned in order to validate the predicted efficacy in more clinically relevant models.

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FROM ISOTOPES TO PRECISION ONCOLOGY: INNOVATION AND HUMAN RESOURCE DEVELOPMENT IN BNCT

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Introduction

The Okayama University Neutron Therapy Research Center (NTRC) was established in April 2017 as a hub for research and education in Boron Neutron Capture Therapy (BNCT). Its primary focus is on the development of BNCT, including the improvement of boron agents, the advancement of irradiation technologies and neutron sources, and the refinement of treatment planning systems. Through activities ranging from basic research to clinical applications, the center aims to establish innovative radiation therapies. Internationally, NTRC has signed a cooperation agreement with the International Atomic Energy Agency (IAEA), and in 2022, Okayama University was designated as an IAEA Collaborating Centre in the field of BNCT, contributing to education, human resource development, and research standardization. In addition, by strengthening partnerships with universities and research institutes in Japan and abroad, the NTRC plays a key role as an international hub for BNCT research.

Project

Isotopes are widely used in medicine for both diagnosis and treatment, and BNCT is a representative example. In BNCT, the stable isotope boron-10 (^{10}B) is selectively delivered to cancer cells. When irradiated with neutrons, a nuclear reaction occurs, producing short-range alpha particles and lithium nuclei that selectively destroy cancer cells while sparing surrounding healthy tissue. For diagnosis, the radioactive isotope fluorine-18 (^{18}F) is used in PET imaging (^{18}F-BPA PET) to confirm boron drug accumulation in tumors prior to treatment. Through this combination of isotopes, BNCT enables a highly precise and selective approach to cancer therapy and is regarded as a promising next-generation radiation treatment.

Our research highlights include the development of innovative BNCT modalities such as transurethral BPA delivery for refractory bladder cancer and boron neutron capture immunotherapy for melanoma in combination with immune checkpoint inhibitors. In parallel, we are synthesizing next-generation boron agents—targeting brain, breast, pancreatic, and gastrointestinal tumors—through strategic collaboration with pharmaceutical sciences. These isotopic agents demonstrate enhanced tumor selectivity and therapeutic efficacy, accelerating the transition from bench to bedside. To strengthen translational predictivity, we have established patient-derived 3D culture models that reproduce the tumor microenvironment with high fidelity. These models not only improve the biological reproducibility of radiation evaluation but also contribute to global efforts to reduce animal testing, aligning with emerging regulatory frameworks on alternative preclinical models.

Beyond research, NTRC emphasizes human resource development and international networking. The NTRC has hosted IAEA-supported training workshops, welcoming participants from multiple countries, and will organize the 2nd Training Workshop on Advances in BNCT in 2025.

Conclusions

By linking isotope-based science, translational research, and education, NTRC is shaping BNCT as a paradigm of next-generation precision radiotherapy, contributing both to scientific innovation and to the sustainable development of global healthcare capacity.

ADVANCING GLOBAL COMPETENCE IN DIAGNOSTIC AND THERAPEUTIC RADIOISOTOPES AND RADIOPHARMACEUTICALS THROUGH E-LEARNING AND LAB-TRAINING: COLLABORATION BETWEEN WCI, IAEA AND KAERI

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Introduction

The **World Council on Isotopes (WCI),** in partnership with the **International Atomic Energy Agency (IAEA)** and the **Korea Atomic Energy Research Institute (KAERI),** has established a dual-structured training initiative for radioisotope professionals and related experts from countries with limited training resources in the peaceful use of radioisotopes. The program integrates two complementary components: (1) an e-learning course and (2) a hands-on laboratory training course.

Description of the Program

E-learning Course: Launched in 2016, the course is conducted in two parts. Part 1 offers flexible, self-paced online modules on critical topics such as Good Manufacturing Practices (GMP), quality control, and regulatory processes. Part 2 focuses on the clinical and therapeutic applications of radioisotopes and radiopharmaceuticals. Each year, approximately 120 participants from more than 30 countries engage in the program, showcasing its global reach and accessibility. Key topics covered throughout the course include radionuclide production techniques (both reactor- and cyclotron-based), basic and advanced radiochemistry, radiopharmaceutical preparation, regulatory landscapes in various regions, and guidance on establishing optimal radiopharmaceutical regulations. The program emphasizes interactive learning through Google Classroom, with live Q&A sessions, and graded assignments to reinforce understanding. To date, about 550 participants have been trained in the program.

Laboratory Training: To complement the theoretical foundation, a two-week laboratory training course has been offered since 2023.The training takes place at two hospitals and one research institute, covering topics such as radioisotope production, GMP experience, antibody preconditioning, radioisotope labeling, and quality control experiments. These experiments involve the use of suitable antibodies for ^{89}Zr, peptides for ^{68}Ga and ^{177}Lu, as well as automatic synthesis and quality control (QC) experiments with ^{18}F-fluoride. The course lasts for two weeks and employs a trainee-centered approach to learning. This methodology prioritizes learner autonomy and independence by placing responsibility for the learning path in the hands of the trainees. By imparting skills and foundational knowledge relevant to specific subjects, along with the schemata needed to meet performance requirements, this approach enables trainees to develop self-sufficient problem-solving abilities. The acceptance rate for this training course is over one in ten.

Conclusion

This program highlights the capacity of international cooperation, ensuring equitable access to specialized knowledge, particularly in view of growing number of medical cyclotrons worldwide. By integrating e-learning with laboratory-based instruction, the WCI–IAEA–KAERI program demonstrates a sustainable model for building global technical competence in nuclear medicine.

CHERNE, 20 YEARS OF AN INTENATIONAL NETWORK FOCUSED ON STUDENTS

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Introduction

The paper presents an overview of the activities of the informal network "**C**ollaboration for **H**igher **E**ducation and **R**esearch in **N**uclear **E**ngineering & Radiological Protection" (CHERNE). It is an open network bringing together academic institutions involved in Nuclear Engineering and Radioprotection (https://irisib.be/cherne/) and composed now of 19 partners representing 8 countries.

History

The network creation in 2005 was initiated from the observation that large experimental systems were expensive to buy and maintain and so the access for students and young researchers began difficult for educational purposes. A group of academic partners decided to join their resources to allow the sharing of such experimental devices and specific competences of teaching staff as well as personal professional network. Different learning/research activities were settled with low fee for students. CHERNE also took benefit from European Lifelong learning program possibilities like Intensive Programs (IP) to develop teaching activities mainly focused on technical skills on early days.

An adaptative network to the benefit of students

Since 2015, the importance of new types of teaching methods and learning practices (like distance learning) or generic skills (communication, management, durability, ethics, SDGs…) increase The network proposed European program projects like Erasmus+ Strategic Partnerships (KA2 action) to develop new tools mainly for students but also for people already on the work market (continuous education) or future students (high schools).
The latest development concerned the use of virtual tools (escape room, Virtual Reality) to create a link between pure theoretical lecture and the "on field work" and Collaborative Online International Learning platform (COIL) to facilitate the sharing of information about tools and techniques. New challenges like AI in nuclear education and durability competences are already the future ideas to deal with.

Conclusion

CHERNE has the tradition to be strongly involved with industrial, research and regulatory organisation to embed the interdisciplinarity of nuclear sciences and applications. Networking is an important goal of all activities between our master students (the next generation engineers).

PARTICLE THERAPY MASTERCLASS AS MEANS OF CAPACITY BUILDING

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During the past century, particle accelerators played an essential role on advancing scientific knowledge and on improving standards of living. Today, they are being increasingly used not only in research laboratories but also in hospitals and industry. As accelerator technology develops, the potential for new applications expands especially since such developments are systematically supported by EU funded projects. In particular, the potential of accelerator-reliant therapy and diagnostic techniques increased considerably over past decades, playing an increasingly important role in identifying and curing otherwise difficult to treat cancers.

With the aim to highlight benefits from fundamental research for medical applications and cancer treatment, a new MasterClass on Particle Therapy was developed based on the matRad treatment planning open source software. Initially addressing high-school students it was also adapted for university students and professionals. In a very intuitive way, it makes evident the importance of proper diagnostics and the role of radio-isotopes for diagnosis and therapy.

DEVELOPING THE NEXT GENERATION OF ISOTOPE SCIENTISTS: A MIDPOINT REVIEW

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Introduction

The US Department of Energy (DOE) recognized the need to train more scientists[1,2] at the bachelor's, master's, and doctoral levels with the broad knowledge and skill set to perform isotope R&D and production work. To address this need, in October 2023, DOE allocated $5 million USD spread over 5 years to train students in all aspects of isotope science, including radiation modeling, radiochemistry, and materials assay.

Description of the Work or Project

To meet this demand, a consortium of three universities in the Richmond, Virginia, area in the USA was formed in collaboration with Oak Ridge National Laboratory (ORNL). The goal of this consortium is to educate and train 70 students, establish a new radiochemistry laboratory, and strengthen cooperation between these organizations. This initiative includes an 8-week isotope science summer course, a 2-week workshop at ORNL, and year-round individual research projects for every student. At the approximate midpoint of this grant, 29 students spanning multiple STEM majors have joined and produced 18 conference papers. Two summer courses and workshops have been offered, and a radiochemistry laboratory has been created. Additionally, multiple students received best paper awards and national scholarships, highlighting the quality of this educational program.

Conclusions

DOE is correct in identifying the need for more scientists who can do isotope R&D and production work; they have made a significant financial investment. The consortium has made considerable progress and is on track to meet its goals. This approach of training students year-round in all aspects of isotopes, using a combined classroom and research method, is a model that appears successful and can be adopted by others.

Acknowledgements

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THE CINCH HUB PLATFORM FOR SUSTAINABLE E&T IN NUCLEAR AND RADIOCHEMISTRY

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Introduction

The four European projects **CINCH I**, **CINCH II**, **MEET-CINCH**, and **A-CINCH** have formed a coordinated effort to strengthen education and training in the field of nuclear and radiochemistry (NRC) across Europe, aiming to mitigate the skill-based deficits within the academic nuclear area at all levels, to counteract the loss of young generation's interest for the topic and to assure the maintenance of the needed nuclear expertise in the perspective of a possible nuclear renaissance.

Description of the Project

By identifying educational needs, harmonizing curricula, and developing innovative teaching tools, the CINCH projects established the foundation for a common approach and expanded the training offer through Hands-on Training courses, e-learning materials and Massive Open Online Courses for both students (BSc, MSc and PhD students) and professionals, as well as by introducing interactive tools such as Interactive Screen Experiments, Virtual Reality, Remote Controlled Experiments, and Augmented Reality. A*d hoc* educational resources aimed at raising public awareness of the relevance of nuclear and radiochemistry in areas such as energy, safety, medicine, and environmental protection were prepared for citizens, high school students and their teachers.
Aiming for the widest accessibility, the CINCH Hub platform (available at this link: https://hub.cinch-project.eu/) was specifically developed to wrap up outcomes of the series of CINCH projects into a user-friendly and easy-to-navigate single page interface and to facilitate access to all the developed education and training tools.
The experience gained and the feedback collected are presented and discussed.

Conclusions

The work done in the last fifteen years within the CINCH framework aimed to define a long-term sustainable strategy for E&T in nuclear science and have substantially contributed to building a sustainable, innovative, and well-coordinated European training infrastructure in NRC, enhancing both NRC excellence and attractiveness for new generations and sector professionals.

Keywords: Nuclear and Radiochemistry, E&T, Nuclear awareness, Hands-on Training, interactive educational tools, Sustainability

NORWEGIAN NUCLEAR RESEARCH CENTRE

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The goal of the Norwegian Nuclear Research Centre is to increase Norway's competence in nuclear physics and nuclear chemistry and is a cross-disciplinary collaboration between Norway's leading institutions these areas of research: University of Oslo, Norwegian University of Life Sciences, and Institute for Energy Technology. We address major research questions within the nuclear field spanning topics in 5 research themes (RT) and have launched new Bachelor and Master programs with significant investments and new hires to support the RTs. This presentation will focus on the work within each RT.

RT 1: Nuclear Properties Fundamental nuclear properties are key to many applications of nuclear science, including nuclear theory, nuclear astrophysics, and nuclear energy and are not yet fully understood, especially for exotic nuclei far from stability. These points will be studied at the Oslo Cyclotron Laboratory and with collaborators at larger accelerator facilities abroad.

RT 2: Nuclear Fission It is impossible to directly measure the state of the fission fragments right after fission. We therefore focus on measuring the γ-rays emitted from the fission fragments; these carry away excitation energy and angular momentum from the fragments, so measurement informs about their initial states through measurement of average γ-ray properties, as well as discrete γ-rays from specific fragments. This will provide benchmarks for fission simulation codes and verify the underlying physics theories.

RT3: Nuclear Simulation Within RT3, the primary focus is nuclear physics models essential for nuclear decommissioning, waste management, operational safety, and advancement of new reactor designs. This involves simulations of nuclear reactors across their entire lifecycle, with a particular emphasis on physics modelling. Additionally, there is a dedicated focus on radiological modelling, particularly of nuclear and radiation physics concerning worker exposure. Integration of physics and AI-powered Digital Twins serves to amplify these efforts, facilitating more effective research and analysis in these critical areas.

RT 4: Radionuclide production and Speciation Several scientific disciplines are engaged to identify and study emerging radionuclides which may be critical for medical and industrial applications. Radionuclides are pivotal in many cutting-edge methods to diagnose and treat cancer, and so, one of the main goals of this research theme is to facilitate the upscaling and industrial-scale production of these emerging radionuclides. Radionuclide therapy enables a highly personalised form of cancer therapy which can be tailored to minimise the damage to healthy tissue. In RT4, the focus is on radionuclides which are suitable for theranostics, which enables the simultaneous diagnosis and treatment of cancer. There is also a focus on α-emitting radionuclides which are amenable for Targeted Alpha Therapy (TAT).

RT 5: Environmental Radiochemistry and Source Characterisation Environmental Radiochemistry involves the study of the transport and fate of radioactive isotopes in the environment and supports decision makers with a scientific basis for environmental risk assessment and management. Applications include topics such as radon exposures to the public, nuclear decommissioning and waste disposal, nuclear preparedness, and nuclear security, and cover a multitude of potential sources, including nuclear power reactors, research reactors, medical and industrial sources, fuel cycle facilities, as well as nuclear weapon stockpiles.

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MODERN INSTRUMENTATION FOR PHYSICS EDUCATION: A FOCUS ON RADIOACTIVITY

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Introduction

CAEN educational tools aim to engage students in the exploration of physics phenomena through hands-on experiments using advanced instrumentation. Among these, a key application is the investigation of environmental radioactivity — a naturally occurring but often misunderstood phenomenon. To promote awareness and familiarity, CAEN has developed dedicated kits that allow students to detect and analyze natural radiation using modern technologies.

Description of the Work or Project

CAEN S.p.A., an industrial spin-off of the Italian National Institute for Nuclear Physics (INFN) since 1979, leverages over 45 years of experience in high-energy and nuclear physics to develop advanced educational tools. The company offers modular Educational Kits designed to bring modern technologies and instrumentation into physics teaching laboratories.

These kits, equipped with dedicated control software, provide a flexible platform for introducing students to key concepts such as statistics, pulse processing, particle detection, and nuclear imaging. Among the various applications, the study of environmental radioactivity stands out as a particularly effective educational topic.

To support this, CAEN has developed specialized kits that include all the necessary components: scintillating detectors (e.g., LYSO and CsI), a detection system based on Silicon Photomultipliers (SiPMs) with integrated preamplifier, bias power supply, signal shaper, and a fully featured Multi-Channel Analyzer (MCA). The kits may also include small samples of common radioactive materials, source holders, and shielding materials such as aluminum and lead.

Students can acquire and calibrate energy spectra, analyze the composition of various samples, and perform experiments such as gamma spectroscopy, absorption measurements, and passive radon detection. These activities combine theoretical background with hands-on experimental practice, data analysis, and critical interpretation of results, providing a comprehensive and engaging approach to modern physics education.

Conclusions

CAEN Training Courses and Educational Kits are designed to provide a clear understanding of nuclear physics phenomena. With step-by-step guidance, even non-expert users can carry out meaningful measurements. By combining theoretical concepts with practical setup, data analysis, and critical interpretation, these tools offer a complete and accessible training experience in modern physics.

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https://www.caen.it/products/sp5630en-plus/

ISOTOPE ISOLATION FROM MASSIVE PROTON-IRRADIATED TARGETS AT LOS ALAMOS NATIONAL LABORATORY

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Introduction

This contribution is a mini overview of isotope production from a radiochemist's perspective at Los Alamos National Laboratory.

Description of the Work or Project

Los Alamos National Laboratory (LANL) Isotope Program has a rich history of supplying isotopes for medical, industrial, environmental and research and development applications for more than 40 years. Production of a diverse suite of isotopes from the LANL Isotope Program has worldwide impact within the medical field and throughout the scientific community. We continue to develop new capabilities and explore novel production routes to make available a greater variety of isotopes.

In this contribution, challenges associated with isolating radioisotopes from large, irradiated targets - tens to hundreds of grams of material and approaches to overcome these challenges will be discussed. Furthermore, overview of several new processes developed more recently will be outlined including production and isolation of Bi-207, Tb-155 and Zr-88 [1]. Advanced instrumentation has been utilized for these processes such as implementation of peristaltic pumps, high performance liquid chromatography and custom dispensing unit to dispense microliter volumes of highly radioactive material within the hot cells will be covered.

Conclusions

Advances in radiochemical processing are enabling rapid development, production and purification of new isotopes and providing radioisotopes in new form factors.

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FROM ACCELERATOR WASTE TO RESEARCH: ISOLATION AND USE OF LONG-LIVED RADIONUCLIDES AT THE PAUL SCHERRER INSTITUTE

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Introduction

The dedicated production of rare long-lived radionuclides is both costly and time-intensive. In some cases, it would require extremely long irradiation periods dedicated exclusively to this purpose, making the production of sufficient quantities nearly impossible. Nevertheless, several of these radionuclides are of great importance for a wide range of research fields, including astrophysics, nuclear medicine, geophysics, fundamental nuclear physics, and nuclear waste management.

Description of the Work or Project

The Paul Scherrer Institute (PSI) operates the Spallation Neutron Source (SINQ), powered by one of the world's most intense high-energy proton accelerators, the High-Intensity Proton Accelerator HIPA (590 MeV, up to 2.4 mA). Within the framework of the ERAWAST initiative (Exotic Radionuclides from Accelerator Waste for Science and Technology)[1], a comprehensive program has been established over the past two decades to recover rare long-lived radionuclides from different PSI accelerator waste matrices.

In many cases, nuclear data for these radionuclides, such as half-lives, branching ratios, and cross sections, remain incomplete, uncertain, or inconsistent. The primary challenge was the scarcity of available sample material. To address this, sources of several radionuclides ($^{7/10}$Be, ^{32}Si, ^{44}Ti, ^{53}Mn, ^{60}Fe, ^{90}Mo, ^{137}La, ^{146}Sm, ^{148}Gd, ^{154}Dy, ^{157}Tb) were identified, chemical separation methods were developed, and dedicated source or target materials were prepared and characterized.

Conclusions

This contribution will provide an overview of past and ongoing efforts at PSI to recover long-lived radionuclides from accelerator wastes for use in scientific purposes. These efforts enabled new half-life determinations[2], cross-section measurements, and the provision of these radionuclides for experiments of broad scientific relevance. Looking ahead, exploiting accelerator by-products as an isotope resource offers a sustainable and cost-effective approach to improving nuclear data and advancing both fundamental and applied science.

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Towards reliable supply of radioisotopically pure terbium: Can molecular extraction combined with mass separation bring us closer to the clinics?

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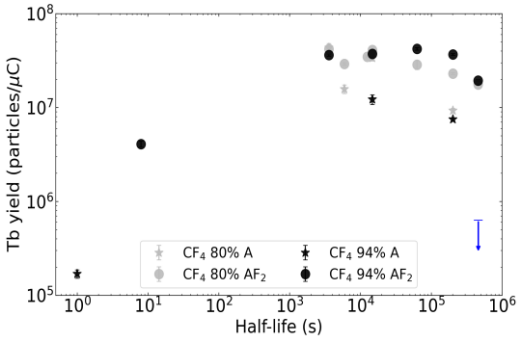
Introduction

Four terbium isotopes, ^{149}Tb, ^{152}Tb, ^{155}Tb and ^{161}Tb, show particular promise for molecular imagining and targeted cancer therapies, enabling a true theragnostic approach [1]. This includes the attractive but hard to access α-emitter ^{149}Tb. With the exception of reactor-produced ^{161}Tb, large-scale production of radioisotopically pure Tb isotopes remains challenging, and current methods cannot yet sustain the needs of preclinical research [2].

Description of the Work or Project

The Isotope Separation On-Line (ISOL) technique is currently the only approach capable of providing radioisotopically pure $^{149, 152, 155}$Tb for radiopharmaceutical development, typically via Dy precursor extraction. Direct extraction of Tb from irradiated Ta targets is hindered by its low volatility and strong chemical interaction with the target material. This work explores molecular extraction as a strategy to enhance Tb volatility and improve release.

Figure 1: Yields of Tb extracted from a fluorinated Ta target.



A series of online and offline studies was performed at CERN-ISOLDE facilities to investigate molecular beams of Tb using available compounds and irradiated Ta targets in combination with a FEBIAD ion source and CF_4 injection. Ion beam composition was studied as a function of target, ion source, and gas injection conditions to optimise the delivery of Tb beams. The isotopic chain (A=144-168) was investigated under online conditions to gain insight into physical processes governing terbium fluoride formation and release.

Conclusions

This work demonstrates the feasibility of extracting Tb as molecular sidebands, clarifying the mechanisms that currently limit Tb release in both online and offline mass separation. Beyond the answers obtained, new questions arise on the best way to scale production at emerging facilities such as ISOL@MYRRHA and TATTOOS@PSI, with the hope of bringing Tb closer to the clinics.

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Keywords: Mass separation, Radionuclide production, Terbium

INDIRECT PRODUCTION OF ^{155}TB USING NATURAL TERBIUM TARGETS: A TWO-STEP RADIOCHEMICAL SEPARATION APPROACH

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Introduction

Terbium radionuclides show promise for theragnostics, where what you see is what you treat. ^{155}Tb ($T_{1/2}$ = 5.32 d, ε) appears to be one of the most prospective diagnostic radionuclides to accompany therapeutic lanthanides in the next decade due to the wide range of available production methods for ^{155}Tb and its similar chemical properties. However, current cyclotron-produced ^{155}Tb has suboptimal radionuclidic purity[1]. To improve it, most of the production methods either rely on highly enriched materials (for direct production methods) or α-particle accelerators (for the previously proposed indirect method[2]). In this work, the possibility of producing high-purity ^{155}Tb from the monoisotopic, and therefore readily available, terbium via ^{159}Tb(p,5n)^{155}Dy→^{155}Tb nuclear reaction was investigated: from irradiation of terbium targets, through separation of ^{155}Dy, to obtaining the final ^{155}Tb product from ^{155}Dy decay via radiochemical separation, ready for preclinical studies.

Description of the Work

Natural terbium oxide targets were pressed (40 mg, 0.5 mm thick, 6 mm in diameter) and encapsulated in aluminium. Irradiations were performed at PSI's IP2 irradiation station, fed by the Injector 2 cyclotron with protons at 50 µA. The optimal irradiation conditions were determined to be at ~53 MeV energy beam on target.

A two-stage separation method for ^{155}Tb production was developed with the use of cation exchange and extraction resins. At first, chemical separation of the dysprosium fraction from the irradiated terbium target was simulated using cation exchange chromatography. After time elapsed to allow ^{155}Dy to decay to ^{155}Tb, the daughter fraction was separated using an extraction resin. A third column was utilized for the concentration of product. The process was first validated by means of "cold" (nonradioactive) bench experiments, and the collected fractions were analyzed using ICP-OES. A panel with three columns was designed and implemented into a hot cell for the following irradiation experiments.

Conclusions

The concept of obtaining ^{155}Tb by means of the indirect nuclear reaction ^{159}Tb(p,5n)^{155}Dy→^{155}Tb has been confirmed by test irradiations and bench experiments. More than 1 GBq of ^{155}Tb is being produced by irradiating targets of 40 mg terbium oxide for 8 hours. The radiochemical separation method provides a separation factor between terbium and dysprosium of >10^5, allowing the production of a radionuclidically pure product ready for subsequent biological studies.

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OPTIMIZATION OF ^{68}GA SEPARATION FROM SOLID TARGETS IRRADIATED AT A MEDICAL CYCLOTRON

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Introduction

Gallium-68 is well established as a diagnostic radionuclide for PET imaging. It can be obtained from generators loaded with its parent, ^{68}Ge, and eluted regularly. However, the supply of such generators and the activity which can be eluted are a limitation. The cross section of ^{68}Zn for the nuclear reaction ^{68}Zn(p,n)^{68}Ga is suitably high (0.8 barn at 11.5 MeV)[1] to produce high activities (>> 1GBq) with the relatively widely available 18 MeV medical cyclotrons.
The aim of this work was to develop a rapid purification method to isolate high purity ^{68}Ga from metallic ^{68}Zn targets, in a form to readily allow labelling of vector molecules at high molar activity.

Experiments and results

Based on the cross sections for the production of ^{68}Ga, ^{67}Ga and ^{66}Ga that have been accurately measured at the Bern medical cyclotron,[1] the irradiation process was optimized and metallic ^{68}Zn was pressed into 40 mg targets (ø 6 mm) which were irradiated either at the Bern medical cyclotron or at the PSI's IP2 irradiation station, supplied with 72 MeV protons from the Injector 2 cyclotron, degraded to ~11 MeV. After retrieval from the irradiation capsule, the target was dissolved in concentrated HCl, $TiCl_3$ added as reductant to convert Fe^{3+} to the Fe^{2+} form[2] and the solution passed through an Amberchrom CG161M (DuPont) absorption resin column. The ^{68}Ga was retained, whereas ^{68}Zn and impurities (incl. Fe) were eluted. Using less concentrated HCl, ^{68}Ga was then eluted and directly loaded onto a column packed with TK200 extraction resin (TrisKem Int.). The final product was eluted from this column with a minimal volume of 0.1 M HCl. The whole separation procedure was performed in 30 minutes. Typically, a 20 min irradiation (16 μAh) yielded 2 GBq at end of separation. Radionuclidic purity was assessed by γ-spectrometry: ^{68}Ga >99.5%. The pH was adjusted to 4-4.5 with an adequate amount of Na acetate to radiolabel to DOTATOC and NODAGA. A labelling yield >95% at an apparent molar activity (AMA) up to 50 MBq/nmol was achieved and determined by HPLC. Cold impurities (Fe, Zn, Pb, Cu) were <10 μg/GBq (ICP-OES). The same purification procedure was also applied successfully to ^{67}Ga obtained commercially but unfortunately with a purity insufficient to achieve good labeling yields at the high AMAs required for in-vivo preclinical studies.[3] The ^{68}Zn separated during the purification procedure can easily be recycled by electrowinning from the initial HCl eluate when neutralizing it with ammonia. The ^{68}Zn dendrites obtained in this way can be easily pressed to new target disks.

Conclusions

This method ensures production of radionuclidically and radiochemically pure ^{68}Ga at much higher activities, than available from a generator. The separation can be finalized in a short time with a simple two-column system, which can be implemented in a hot cell.

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DEVELOPMENT OF A ROBUST METHOD FOR ISOLATION OF ^{124}I PRODUCED VIA ^{124}Te (p, n) ^{124}I REACTION FOR RADIOPHARMACEUTICAL PREPARATION

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Introduction

^{124}I is an emerging long-lived PET radionuclide attracting tremendous interest for long-term clinical PET studies. Particularly, the long half-life (4.2 d) of ^{124}I is especially suited for prolonged time in vivo studies of high molecular weight compounds uptake. The low energy biomedical cyclotrons abundantly available all over the world can be conveniently used for production of ^{124}I via ^{124}Te (p, n) ^{124}I reaction. In this study, we report the production of ^{124}I and development of a facile method for isolation of the radionuclide in a form suitable for preparation of radiopharmaceuticals.

Description of work

To validate the optimal proton energy for irradiation, natural TeO_2 pellets wrapped in aluminium foil were irradiated at various beam energies, viz., 10, 12, 14, 16 and 18 MeV for 1 h each. Later, a pellet of TeO_2 were irradiated at 14 MeV for 66 h at 110 nA current to get the maximum activity of ^{124}I. After irradiation, the TeO_2 target was dissolved in 4 M NaOH solution and then pH of the solution was adjusted to ~ 7 using HCl solution, which resulted in white precipitation of tellurium oxide/hydroxide. That precipitate was separated from the supernatant iodine solution by filtration. In the supernatant solution containing ^{124}I, alkaline sodium sulphite solution (1 mg/mL) was added to make [^{124}I]I-NaI. [^{124}I]I -mIBG was prepared by well-established nucleophilic isotope exchange reaction to demonstrate the suitability of the separated product for preparation of radiopharmaceuticals.

Results

The optimization study carried out at different proton beam energies indicated that 14 MeV was the most suitable energy for production of ^{124}I with maximum yield under the conditions of our irradiation. The batch yield of ^{124}I under this condition was 0.52 ± 0.06 MBq μA^{-1} h^{-1} (n = 3). The overall radiochemical separation yield in different batches was found to be 86.6 ± 3.6 %. In addition to ^{124}I, few extraneous radioisotopes ($^{123/126/130}$I) were also produced while using natural TeO_2 target. However, use of enriched ^{124}Te target would minimize the co-production of these radioisotopes. The radiochemical purity of the separated product was found to be > 98% in the form of [^{124}I]I-NaI. [^{124}I]I-mIBG could be prepared with 98.7 ± 1.1 % radiolabeling yield, demonstrating the potential of the radiochemically separated product for preparation of radiopharmaceuticals. The radiolabeled product maintained its radiochemical purity and integrity under physiological conditions (PBS at 37 °C) over a period of 1 week.

Conclusions

The optimization of radioisotope production conditions and development of a facile radiochemical methods are the key issues in maximizing the production yield of ^{124}I and minimizing the associated costs. The present study would widen the clinical use of ^{124}I and also expand the capability of radioisotope production based on small biomedical cyclotrons.

Keywords: ^{124}I, biomedical cyclotron, MIBG, PET, precipitation, radiochemical separation, radiopharmaceuticals

Invited
Sonja Schreurs

THE APPROPRIATE ENVIRONMENTAL SAMPLE TO EDUCATE NOVICE STUDENTS IN ENVIRONMENTAL RADIOACTIVITY MEASUREMENTS USING GAMMA RAY SPECTROSCOPY

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Proper implementation of gamma ray spectroscopy for environmental radioactivity measurements can often be challenging when trying to achieve high accuracy and high precision results. Phenomena such as gamma-ray self-attenuation can potentially add to the overall uncertainty in measurements, especially for samples that are large (100–500 g) and contain high-Z materials in significant quantities. As well, most environmental measurements need extended periods of time for measurements typically between 12 and 36 h per sample, depending on sample size and radioactivity concentration levels. For more than one decade we have been involved in radioactivity measurements in the oil and gas exploration sector, primarily in analyzing scale, soil and sludges. Our experience has revealed that scale is an environmental sample that can easily be analyzed for ^{226}Ra, ^{228}Ra and ^{210}Pb in a relatively short period of time for only 20 g of material due to the unusually high concentrations of these radionuclides. All the daughter products that decay with gamma rays can also be readily measured. Because of the higher Z elements such as iron, barium and strontium in elevated concentrations, gamma ray self-attenuation is of paramount importance to elucidate, particularly for the 46.4 keV gamma ray belonging to ^{210}Pb. And finally, there is a clear major disequilibrium in the ^{238}U and ^{232}Th chains. All these radiological and chemical characteristics for oil scale make this an ideal candidate to quickly teach novice researchers about the challenges in natural occurring radioactive materials (NORM) in gamma ray spectroscopy measurements. In addition, the number of researchers involved in environmental radioactivity measurements is decreasing and the need for an education template such as the one presented in this work is a very good tool for novice researchers in NORM.

MANAGEMENT OF TECHNOLOGICALLY ENHANCED RADIOACTIVE MATERIAL (TENORM) IN THE OIL & GAS COMPANIES ACTIVITIES, THE ENI EXPERIENCE

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Introduction

The presentation aims to show the best practices that Eni has developed since the early 1990s for the safe management of TENORM matrices, in relation to the operational activities of the plants, waste treatment, disposal and dismantling of installations.

The accumulation of Naturally Occurring Radioactive Materials is a well-known phenomenon in the Oil&Gas industry for a long time: production water flowing into the well pipes before and then into the production and treatment plants together with crude oil and gas usually transports natural radionuclides from the reservoir to the surface. Chemical and physical mechanisms during the process can then produce their deposition inside production equipment giving rise to the formation of radioactive residues usually referred to as sludge and scale.

These deposits contain radionuclides of the natural radioactive series of ^{238}U and ^{232}Th with different levels of radioactivity concentration, mainly ^{226}Ra, ^{228}Ra and their daughter products.

Some of the results obtained by performing numerous measurements of radioactivity levels in produced water, sludge, and scale at Eni's facilities in Italy and abroad have been and continue to be carried out; some of the results will be presented to provide an overview of the impact that TENORM can have on workers during typical offshore and onshore operations involving the operation and handling of contaminated equipment, as well as on the environment.

The monitoring carried out also highlighted that the presence of TENORM in components can vary substantially from one plant to another, depending on physical and chemical parameters such as temperatures, pressure variations, flow geometries, water cut and of course also from the geology properties of the reservoir.

Moreover, frequent maintenance interventions allow the prevention of the formation of scale or sludge in the plant components, reducing in this way the presence of TENORM in the plant.

To manage TENORM in Eni production plants, a procedure based essentially on two phases has been developed and adopted:

• a preliminary radiometric investigation on site, based on the knowledge of the process, allows the identification of the radiometric anomalies associated with the presence of TENORM in the various components of the plant;

• then, collection of samples with potentially content of natural radionuclide and the characterization of these through gamma spectrometry analysis.

For residues it is necessary to identify the disposal chain, to carry out adequate dose assessments for representative individuals and for the worker potentially involved.

The contaminated parts of the plant intended for cleaning or disposal activities are stored in areas equipped in a way to avoid potential soil contamination and ensuring also that no accidental release of contaminated material could happen.

Eni is committed to identify methods for managing TENORM matrices in order to guarantee safe and adequate removal of residues, valorizing, when possible, materials which, once decontaminated, can be reused, or recycled.

Machine Learning algorithms for soil texture prediction from airborne radiometric surveys

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Abstract

Soil texture is a key parameter influencing soil functioning, agricultural productivity, and sustainable land management. Accurate texture maps are essential for cultivation planning, soil conservation, and environmental assessment, but traditional surveys often lack the resolution to capture fine-scale variability. To address this gap, we evaluate the use of Airborne Gamma-Ray Spectroscopy (AGRS) combined with machine learning technique as a framework for soil texture mapping.

The study was conducted in the Mezzano Lowland (Emilia-Romagna, Italy), a 189 km² reclaimed agricultural plain investigated through a dedicated AGRS survey. Potassium (K) and equivalent thorium (eTh) abundances derived from the radiometric data were correlated with soil texture information from the regional 1:50,000 soil texture map. A multi-approach methodology was adopted, including Simple Linear Regression (SLR), Multiple Linear Regression (MLR), and Non-Linear Machine Learning (NLML) algorithms based on deep neural networks. Models were trained and validated to test their ability to predict clay and sand fractions.

The results confirmed negative correlations between sand content and K and Th abundances and positive correlations between clay and both elements. While regression approaches reproduced large-scale patterns, the NLML model provided higher predictive accuracy, enabling the generation of high-resolution maps of clay and sand distribution. These maps also revealed geomorphological features absent from existing soil maps, such as paleo-channels that as reported by historical hydrographic records, shaped the Mezzano Lowland during the Etruscan and Roman periods.

This study demonstrates that AGRS, particularly when combined with machine learning technique, is an effective tool for digital soil mapping. The proposed framework enhances the resolution of soil texture information, supports the reconstruction of paleo-hydrography, and provides valuable insights for precision agriculture and sustainable soil management.

RADIOTRACERS FOR THE STUDY OF MARINE AND OCEANIC ESCOSYSTEM: THE CLIMOCEAN PROJECT

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Introduction

The CLIMOCEAN project aims to the development of a methodology based on radiotracers to monitor the adaptation of marine species to Climate Change. The goal is to study the influence of the acidification of the seas and oceans on the growth of various species of coral, bivalves and echinoderms, as they are organisms that build their skeleton or their shell through the production of calcium carbonate. The uptake of isotopes of Ca (^{41}Ca, ^{45}Ca) into the exoskeleton is used to determine the growth of those species, exposed to present and time projected (50-100 years) climatic conditions [1]. Isotopic composition is determined by direct determination of the emitted radiation (^{45}Ca) or with accelerator mass spectrometry (^{41}Ca)[2].

Description of the Project and results

The study is conducted through differential analysis between controlled mesocosms, where the animal colonies are cultivated. This is achieved by using two twin marine tank systems. Each system consists of a main water tank, where the corals and mollusks are cultivated at present pH condition (8.11) and future one (7.8), and an auxiliary tank specifically designed for experiments requiring short-term exposure to ^{45}Ca/^{41}Ca.

In the framework of the ^{45}Ca studies (IFIC-CSIC and Oceanographic, Valencia, Spain), several experimental campaigns have been initiated on two coral species (Stylophora pistillata and Pocillopora damicornis). After the exposure, the skeletons were dried and subsequently dissolved and mixed with Ultima Gold AB liquid scintillator for a high-sensitivity beta spectrometry. In the framework of the ^{41}Ca studies (Hydrobiological Station of Chioggia, Italy) experiments have been performed using three species (Ruditapes phillipinarum, Chamelea galina and Paracentrotus lividus). Animals were maintained in tanks at two different pH conditions for 1, 2 and 3 months. The samples have been recently sent to VERA laboratory (Vienna, Austria) for AMS analysis.

Conclusion

This cross-disciplinary project is possible due to the joint efforts of expertise from the Valencia Oceanogràfic (E), the Hydro-biological station of the University of Padova (I), the Instituto de Física Corpuscular (E) and the INFN-LNL (I). The status of the project and the results of the first measurements performed at the Oceanogràfic and Hydro-biological station will be presented.

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CONDITIONS FOR SYNTHESIS OF ^{203}[HG]METHYL MERCURY IN BUFFERED SOLUTIONS: INVESTIGATING MECHANISMS OF MERCURY LOSS AND CHEMICAL STABILITY

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Introduction

Neurotoxin and environmental contaminant methylmercury ($HgCH_3$) poses significant risks to marine ecosystems and human health as it can bioaccumulate and biomagnify in aquatic food chains [1].[^{203}Hg]$HgCH_3$, is a crucial radiotracer for surveying potential impacts of the neurotoxin on marine life, however, the synthesis and storage of [^{203}Hg]$HgCH_3$ is limited by low conversion efficiencies, losses of mercury from solution, and difficulty in quantification and safe handling. These limitations undermine the reliability of tracer studies and hinder progress in environmental monitoring and remediation efforts [2]. This study addresses these issues by presenting an improved synthesis and investigation of the mechanisms of mercury loss from solution, providing a reliable and high-quality product for environmental tracer applications.

Description of the Work or Project

[^{Nat}Hg]HgO was irradiated in the OPAL reactor at a neutron flux of 1 x 10^{14} cm^{-2} s^{-1} for 10 days. To ensure decay of coproduced [^{197}Hg]HgO ($T_{1/2}$ =64.14 h), a 40-day decay period was imposed. [^{203}Hg]HgO was converted to a solution of [^{203}Hg]$HgCl_2$ in 1M HCl. [^{203}Hg]$HgCH_3$was synthesised by reacting neutralised [^{203}Hg]$HgCl_2$ with excess methylcobalamin B in sodium acetate buffer (pH 5) (minimum volume) at room temperature for 24 hours. The reaction mixture was treated with 3M HCl and extracted with CH_3Cl_2, followed by back extraction with Milli-Q water to remove residual aquocobalamin. The CH_3Cl_2 layer was stirred with Milli-Q water or 0.05M Na_2CO_3 and the CH_3Cl_2 layer was evaporated under nitrogen. Radiochemical purity was determined via TLC autoradiography. Methylation efficiency and mercury recovery were quantified and compared to replicated synthesis methods. An enhanced methylation protocol was devised by adjusting reagent equivalences and reaction and extraction volumes**.** The optimized protocol yielded an average chemical conversion of 96.1 ±1.9%, surpassing results achieved by replicating literature methods (70 ± 15.1%). Quantification was accomplished through TLC autoradiography. Intriguingly, in instances of incomplete methylation, where end of process monitoring indicated conversion rates between 54% and 70%, monitoring of combined CH_3Cl_2 layers indicated that 100% of mercury in solution was in the methylated form. The discovery of this discrepancy underscores the critical importance of performing rigorous quality control at the final stage of synthesis, rather than exclusively post-extraction (as done in literature). Furthermore, an investigation into loss of mercury from solution during storage revealed that volatilization was the predominant mechanism of mercury loss. In PTFE vessels, loss of mercury from solution was consistent amongst storage conditions (basic, acidic and at -4˚C) at 11-15%, and by halving the headspace, total losses were reduced to less than 5%.

Conclusions

This work provides a significant advancement in the synthesis of [^{203}Hg]$HgCH_3$, achieving up to 98% methylation and minimizing inorganic mercury concentrations in environmental tracers. These improvements offer a more reliable and efficient method for producing [^{203}Hg]$HgCH_3$. This work is poised to have wide reach implications in the field of ecotoxicology, specifically about studies employing the [^{203}Hg]$HgCH_3$ tracer.

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NANOMEDICINE APPROACHES FOR TARGETED ALPHA THERAPY AND THERANOSTICS

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Introduction

Nanoparticles (NPs) are an attractive platform for radionuclide delivery that have the potential to overcome the limitations of radionuclide self-targeting and chelation. For α-emitting radionuclides, such as ^{225}Ac, ^{212}Pb/^{212}Bi, or ^{223}Ra, the α-particle bond-breaking recoil energy and subsequent relocation of decay daughters may result in increased off-target effects. Encapsulation and retention of α-emitting radionuclides and their decay daughters has been demonstrated in vitro, but further development is required to optimize their efficacy and delivery.

Description of the Work

We have synthesized and evaluated different approaches to radio-NPs using both inorganic and organic platforms. In particular, we have evaluated poly(lactic-*co*-glycolic acid) (PLGA) organic NPs as biodegradable and biocompatible delivery vehicles for radionuclide retention and targeted delivery. These have been fully characterized using a variety of mass spectrometry techniques, cryogenic electron microscopy, and cell-based assays. Similarly, we have employed lanthanide-based inorganic NPs to encapsulate different surrogate isotopes and radionuclides. Understanding the interaction of radionuclides with lanthanide-based NPs is critical to optimize their encapsulation and retention. Improving colloidal stability, biocompatibility, and targeting NPs represents a key step toward the development of radionanomedicines.

Conclusions

Our application of nanotechnology and advanced characterization techniques to design and understand radionuclide doped nanomedicines offers a unique approach for theranostics and future combination therapies. Recent research in this area will be discussed.

HUMAN SERUM ALBUMIN COATED DYSPROSIUM OXIDE NANOPARTICLES AS IN VIVO GENERATOR OF ^{166}Dy/^{166}Ho

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Introduction

The dysprosium-166/holmium-166 (^{166}Dy/^{166}Ho) in vivo generator holds significant promise for the treatment of large malignancies, due to the long half-life of the parent nuclide ^{166}Dy ($T_{½}$ = 81.5 h) and the emission of high-energy β^- particles from the daughter nuclide ^{166}Ho ($T_{½}$ = 26.6 h). Since, ^{166}Dy/^{166}Ho exists in radioactive equilibrium state, better therapeutic efficacy could be expected by using ^{166}Dy/^{166}Ho in vivo generator instead of lone administration of ^{166}Ho. However, a critical challenge arises due to internal conversion of ^{166}Dy, which can release up to 72% of ^{166}Ho when conventional chelators are used, thus reducing therapeutic efficacy and in vivo stability. To address this issue, we have developed human serum albumin (HSA) encapsulated dysprosium oxide nanoparticles ([^{166}Dy/^{166}Ho]Dy_2O_3@HSA NPs) to enhance the stability and retention of ^{166}Ho.

Description of Work

For production of ^{166}Dy/^{166}Ho, natural Dy_2O_3 target was irradiated in the Dhruva reactor at BARC and the irradiated target was radiochemically processed. The radiolabeled NPs was synthesized by incorporating ^{166}Dy into $DyCl_3$ and HSA solution, followed by pH adjustment to ~11. Magnetic resonance imaging (MRI) contrast and computed contrast (CT) property of the NPs was also evaluated. In silico studies was conducted to the asses the stability of the in vivo generator. In vivo stability of the radiolabeled NPs was also confirmed by the SPECT imaging and ex vivo biodistribution studies in healthy Wistar rats by injecting activity via tail vein. For in vivo sentinel lymph node mapping (SLN) the radiolabeled NPs were subcutaneously injected into the left footpad of the Wister rat, and a SPECT scan was recorded at 2 h post injection.

Results

The [^{166}Dy/^{166}Ho]Dy_2O_3@HSA NPs, measuring 12.5 ± 2.4 nm, demonstrated excellent colloidal and radiochemical stability. The synthesized NPs showed decent T_2 MR imaging and CT contrast properties. Molecular docking studies predicted enhanced radiochemical stability, which was confirmed by in vivo SPECT imaging and biodistribution studies in healthy Wistar rats. The NPs demonstrated predominant hepatobiliary clearance, indicating high in vivo stability. Furthermore, localized injection into the footpad facilitated clear imaging of the popliteal lymph node, demonstrating its capability for noninvasive sentinel lymph node mapping and potential radiotherapeutic ablation of metastatic lymph nodes.

Conclusions

[^{166}Dy/^{166}Ho]Dy_2O_3@HSA NPs act as an efficient in vivo generator system, combining stable radioisotope retention, multimodal (SPECT/MRI/CT) imaging capability, and therapeutic potential.

Keywords: ^{166}Dy/^{166}Ho; Dy_2O_3 nanoparticles; in vivo generator; multimodality imaging

RADIOLABELLING OF AN OCTADENTATE BISPIDINE LIGAND WITH THERANOSTIC PAIR OF SCANDIUM

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Introduction

Scandium (Sc) isotopes are attractive theranostic radiometals with potential uses in personalized medicine. Positron emitter ^{44}Sc (β^+, 94%, $E_{\beta+av}$ = 630 keV, $t_{1/2}$ = 4.04hrs), with its longer half-life, provide a better versatility for PET imaging uses than commonly used radioisotopes such as ^{18}F and ^{68}Ga. β^- emitter ^{47}Sc (β^-, 100%, $E_{\beta\text{-av}}$ = 162keV, $t_{1/2}$ = 3.35d) has the potential to reduce radiation exposure to heathy tissues during radiotherapy applications. While several ligands have been evaluated, and among them DOTA is the gold standard, there is still an unmet need to have ligands that bind scandium without elevated temperatures (> 70°C) which are able to be functionalized to targeting vectors such as peptides or antibodies. In the present study, the complexation of scandium with Lp, a pyridyl moiety functionalized by two amino(methyl)bis(methylphosphonic) acid has been evaluated.

Description of the Work or Project

Sc-Lp complexation data have been obtained through free-ion selective radiotracer extraction (FISRE) method, displaying the formation of a mononuclear Sc-Lp complex. Sc-Lp complexes were fully characterized by ^{45}Sc NMR, ^{1}H NMR and ^{31}P NMR spectroscopy at different pH. Radiolabeling was performed at various temperatures in ammonium acetate buffer at pH 4.5, either with ^{44}Sc eluted from a ^{44}Ti generator, or with ^{47}Sc produced from a cyclotron. The radiolabeling yields were > 98% even at room temperature and for 5 minutes of contact. The resulting [^{44,47}Sc] Sc-Lp complexes exhibited good stability in serum and against hydroxyapatite over 48hrs. The [^{47}Sc] Sc-Lp complex was injected in healthy mice (n=3) and showed a rapid clearance in kidneys.

Conclusions

Full complexation of Sc(III) with Lp was achieved at room temperature, and NMR studies confirmed the formation of a mononuclear Sc(III) complex. Nonetheless, while the thermodynamic stability of ScL_p is lower than that of DOTA and AAZTA complexes, its key advantage is due to the efficient radiolabelling of ^{44}Sc and ^{47}Sc under mild conditions across a broad concentration range. In addition, preliminary kinetic inertness studies with L_p yielded promising results in human serum was observed in the timeframe of the study. Preliminary measurements showed no decomplexation in the presence of hydroxyapatite. The preliminary animal research indicated that the elimination of ^{47}Sc-L_p occurs via the renal system. Free ^{47}Sc has a widespread uptake within the heart, lungs, spleen, kidney, and femur. The presence of free ^{47}Sc in heart and lungs may indicate some decomplexation *in vivo* but studies with longer circulating conjugates must be assessed. Overall, this study demonstrates the viability of the $[Sc(L_p)]^-$ complex as promising scaffolds for theranostics radiopharmaceutical applications with scandium isotopes.

FULLY AUTOMATED RADIOACTIVE COPPER NANOPARTICLE SYNTHESIS: TARGET DEVELOPMENT, SEPARATION, AND SYNTHESIS

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Introduction

Rising cancer rates worldwide continue to drive innovations in diagnostic and therapeutic agents. In this context, radionuclides are often produced using medical cyclotrons or nuclear reactors. To be effective, they should support both imaging and treatment, with half-lives appropriate for labelling, visualisation, and therapy. Additionally, the target material must be affordable, readily available, and able to provide consistent, high-quality performance [1–3]. Theragnostics have seen significant recent growth. This study forms part of the OPTICS (Optimised Production of Theragnostic Isotopes of Copper and Scandium) project, which seeks to implement an automated and modular system for radiopharmaceutical/nanoparticles production. Specifically, my work explores the use of mixed copper isotopes (^{61}Cu, ^{64}Cu). Through irradiations at the Dalton Cumbrian Facility, we are advancing automated processes for dissolution, separation, nanoparticle synthesis, and antibody conjugation.

Description of the Work or Project

Copper radioisotopes were generated from natural and enriched nickel targets (^{nat}Ni, ^{61}Ni) via irradiation (pelletron accelerator) and automated separation. Targets were prepared by dissolution, pH adjustment, and electrodeposition, followed by alpha (15 MeV) transmutations. Using Dowex 1x8 resin, nickel and copper were efficiently separated. Catechin-mediated synthesis produced copper nanoparticles at 30 °C under nitrogen using 0.1 M NaOH at pH 11. All processes were conducted in a fully automated, three-unit system.

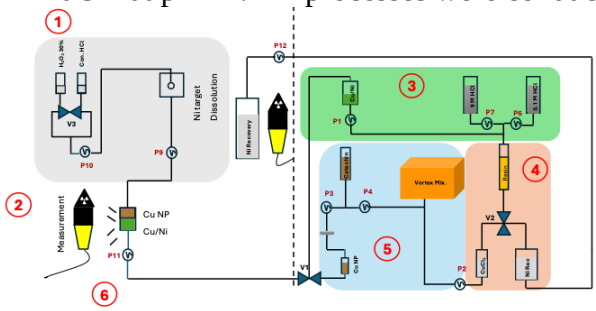

Figure 1 The schematic representation of the entire automation process is shown. The target is located inside the fume hood, where the irradiation takes place (on the left side of the figure). Following the dissolution step, the separation and synthesis processes are carried out in the hot cell (on the right side of the figure).

Conclusions

Gamma counter measurements confirmed the successful transmutation of $^{61/64}$Cu. In addition, size analysis and electron microscopy revealed that the resulting Cu nanoparticles have diameters between 1 and 50 nm.

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IN VITRO OPTIMIZATION OF IEDDA CLICK RADIOLABELING TOWARD THE DEVELOPMENT OF PRETARGETED IMAGING

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Introduction

While TCO–Tz IEDDA click chemistry shows promise for pretargeted imaging, optimization of radiolabeling efficiency, kinetics, and stoichiometry remains limited. Most studies focus on proof-of-concept, leaving key translational barriers unresolved. This study seeks to address these gaps.

Description of the Work or Project

TCO-anti-PD-L1 antibody conjugates will be prepared using a lysine-based method and evaluated for modification efficiency and structural integrity by LC–MS and SEC–HPLC, respectively. Radiolabeling of DOTA-Tz with ^{68}Ga will be conducted to establish labeling curves, followed by assessment of specific activity and in vitro stability. The binding efficiency and optimal stoichiometric ratio of the in vitro IEDDA reaction between the TCO-anti-PD-L1 conjugate and ^{68}Ga-DOTA-Tz will then be systematically investigated.

The TCO-to-antibody ratio (TAR) of the TCO-anti-PD-L1 conjugate ranged from 1.5 to 17.4, depending on the applied molar excess of TCO to antibody (3:1–80:1). The theoretical maximum specific activity of ^{68}Ga-DOTA-Tz was calculated to be 5.81×10^3 MBq/μmol. The in vitro stability of ^{68}Ga-DOTA-Tz at 4 h post-incubation was 92.8 ± 1.6% in PBS and 85.4 ± 4.3% in serum. The in vitro IEDDA click radiolabeling yields were 36.9% and 89.9% at TCO:Tz ratios of 1:1 and 50:1, respectively.

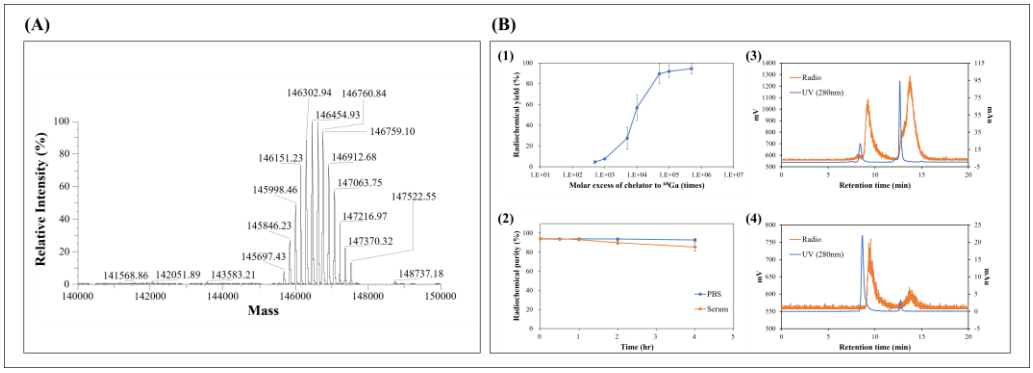

Figure: LC–MS spectra of the TCO-anti-PD-L1 conjugates (A), and radiolabeling characteristics, stability, and IEDDA click radiolabeling assays (B).

Conclusions

The in vitro IEDDA radiolabeling efficiency between the TCO-anti-PD-L1 conjugate and ^{68}Ga-DOTA-Tz reached ~90%. The resulting complex showed excellent stability (>99.7% in PBS and 96.9% in serum), providing a solid foundation for further in vivo evaluation.

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In Vitro Evaluation of $^{68}Ga/^{177}Lu$ Anti-HER2 Pretargeted Radioimmunotherapy Platform Using Bioorthogonal Click Chemistry

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Introduction

Pretargeted radioimmunotherapy via bioorthogonal IEDDA click chemistry enables precise HER2 targeting. We optimized the in vitro reaction between TCO-trastuzumab and $^{68}Ga/^{177}Lu$-DOTA-tetrazine to assess labeling efficiency and demonstrate feasibility for in vivo translation.

Description of the Work or Project

The TCO-trastuzumab conjugate exhibited a TCO-to-antibody ratio of 6.04 as determined by LC-MS. The synthesized ^{68}Ga- and ^{177}Lu-DOTA-tetrazine showed radiochemical purities (RCP) of 93.4 ± 2.0% and 92.1 ± 0.9%, respectively. The estimated maximum specific activity of ^{177}Lu-DOTA-Tz was 4.34 ± 0.70 GBq/μmol. Preliminary IEDDA click reaction assays demonstrated that a TCO-to-Tz ratio of 10:1 yielded 78.76% labeling efficiency for ^{68}Ga-DOTA-Tz and 49.85% for ^{177}Lu-DOTA-Tz. In vitro stability studies indicated that the ^{68}Ga-DOTA-Tz-TCO-trastuzumab complex maintained RCP and 94.7 ± 3.1% in serum at 4 h, while the ^{177}Lu-DOTA-Tz-TCO-trastuzumab complex remained >98% stable in both media for up to 168 h.

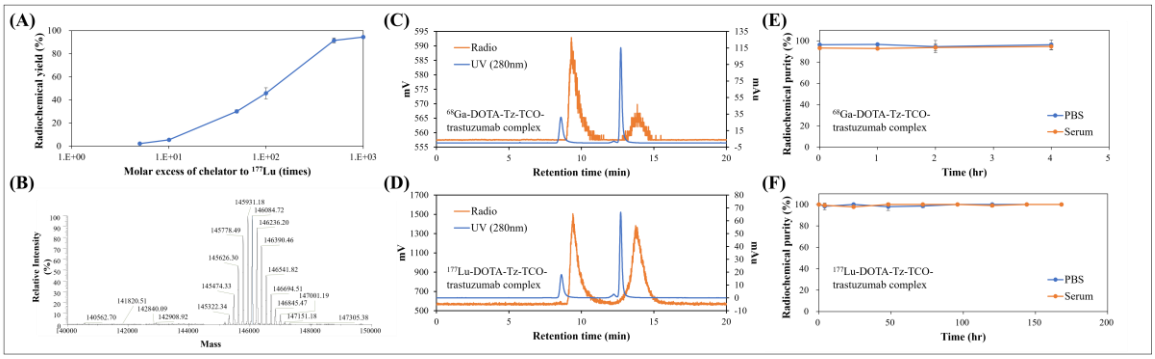

Figure: (A) ^{177}Lu-DOTA-Tz radiolabeling curve; (B) LC–MS spectrum of TCO-trastuzumab; (C–D) In vitro IEDDA reaction; (E–F) Stability of ^{68}Ga- and ^{177}Lu-labeled complexes.

Conclusions

This study demonstrates the feasibility of a HER2-targeted $^{68}Ga/^{177}Lu$ pretargeted radioimmunotherapy platform using IEDDA click chemistry, showing efficient labeling, excellent stability, and strong potential for future in vivo translation.

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MACHINE LEARNING CLASSIFICATION FOR IRRADIATED MATERIAL GAMMA RAY SPECTRA

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Introduction

Radioisotope identification with gamma ray spectroscopy is an important part of environmental monitoring and security and remains one of the most abundant non-destructive analytical tools for identification and quantification. This work investigates the use of gamma ray spectroscopy with thallium doped Sodium Iodide scintillators NaI(Tl), Cadmium Zinc Telluride (CZT), and High Purity Germanium (HPGe) semiconductors across a variety of sample types. The goal of this research is to identify spectral components using Machine Learning (ML) classification algorithms, rather than relying on the traditional peak-search and nuclide identification process.

Description of the Work or Project

Gamma ray signatures were measured across three detector systems (NaI, CZT, and HPGe) to evaluate their differences across the dataset. NaI(Tl) was selected for rapid deployment capabilities and high detection efficiency, CZT semiconductor offered room temperature operation with moderate resolution, and HPGe semiconductor gave the most precise isotopic fingerprinting [1]. This work distinguishes well-known isotope signatures using ML algorithms to characterize single isotope sources and complex irradiate samples from the University of Texas at Austin TRIGA reactor (coal, soil, tomato leaves, and U_3O_8) [2]. The overarching goal is to build a dataset that supports the development of ML algorithms for automated classification of increasingly complex spectra.

To have rapid and reliable classification, ML models use spectra from each sample type in the training, test, and validation dataset to avoid fitting and increase statistical robustness [3]. Early results demonstrate improved classification accuracy when models are trained on simplified and well characterized spectra before application to complex irradiated sample data.

Conclusions

Gamma ray spectroscopy with NaI(Tl), CZT, and HPGe detectors provide complimentary advantages in the characterization of isotopes and irradiated materials. Integrating ML techniques trained on curated spectra enhances the ability to discriminate complex sample types. This experimental and computational approach can advance nuclear forensic and safeguard capabilities by providing a scalable and automated method for isotope and fission product spectra classification.

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A HISTORICAL RECONSTRUCTION OF THE CONCEPT OF ISOTOPE AND ITS EDUCATIONAL VALUE

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Introduction

The existence of isotopes was not predicted by any of the early atomic theories proposed by Perrin, Lenard, Jeans, Thomson, Nagaoka, Rutherford, or Nicholson. Yet, the idea had been remarkably anticipated by Crookes as early as 1886 (Crookes 1886), when he suggested that atomic weights might represent averages of slightly different atomic species. The recognition of isotopy emerged at the turn of the twentieth century through studies of radioactive decay, which revealed the existence of chemically inseparable substances displaying distinct radioactive properties. These findings challenged the established structure of the periodic system and prompted new interpretations of atomic identity.

Description of the Project

This project presents a historical reconstruction of the emergence of the concept of isotopes, from early speculations by Crookes to the experimental and theoretical contributions of Rutherford, Soddy (Soddy 1913; Soddy 1914), and J.J. Thomson (Thomson 1912). The consolidation of the isotopic concept found strong theoretical support in Bohr's atomic model (Bohr 1913), which incorporated the reduced mass of the nucleus. This refinement explained the *isotopic effect*—the slight spectral differences observed between isotopes of the same element—thus providing a powerful theoretical foundation for isotopy.

The presentation connects this historical narrative with science education, proposing that exploring the development of the isotopic concept can serve as an effective tool for teaching the *nature of science* (NOS). Through an example of classroom reconstruction, the work shows how historical inquiry into the evolution of scientific ideas can promote students' understanding of how science progresses and how scientific models are built and revised.

Conclusions

Today, isotopes are introduced in high-school physics curricula mainly as a factual notion, with little reference to their historical and conceptual development. Reintroducing this history into teaching could foster a deeper understanding of the epistemological processes underlying scientific discovery. The case of isotopes vividly illustrates how empirical evidence, conceptual shifts, and even linguistic creativity (Kragh 2025) intertwine in the advancement of science—an essential perspective for developing scientific literacy and an authentic view of the nature of science.

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EXPERIENTIAL LEARNING FOR HIGH SCHOOL STUDENTS TO MEASURE NATURAL RADIOACTIVITY USING PORTABLE GAMMA-RAY DETECTOR

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Abstract

Radioactivity is a fundamental property of matter and the environment, ensuring that all living organisms on Earth have been continuously exposed to ionizing radiation. The theoretical approach to teaching this concept often overlooks the chance to address common misconceptions about natural radioactivity. This omission represents a missed pedagogical moment that may contribute to discouraging future generations from pursuing careers to achieving a sustainable future. This study presents a hands-on learning experience for high school students at the National Laboratory of Frascati (LNF) of the National Institute of Nuclear Physics (INFN). Using the CAEN GammaEDU system, students mapped the natural radioactivity in the LNF area.

A total of 71 in-situ gamma-ray measurements were conducted within the 0.12 km^2 area, each with a duration of 7 minutes. The CAEN GammaEDU system is a portable spectrometer, which incorporates a 3″ NaI (Tl) scintillator, acquired real-time gamma energy spectra to determine the activity concentration and abundance of K, equivalent uranium (eU), and equivalent thorium (eTh), gathering geographic coordinates and photographic documentation via dedicated app. The measurements were performed across seven surface types (asphalt, bricks, cement, grass, gravel, porphyry, and playground) with a field-of-view of 70 cm in diameter. Collocated Co-kriging, a multivariate interpolation method, leverages spatial autocorrelation of sparsely sampled radioelement concentrations and their cross-correlation with surface type to produce a natural radioactivity map.

It resulted that the average concentrations in the area (7.0 ± 0.5 μg/g for eU, 40.5 ± 5.8 μg/g for eTh, and 2.7 ± 0.4% for K) are higher than the global average soil abundances (2.9 ± 0.3 μg/g for eU, 8.0 ± 0.7 μg/g for eTh, and 1.20 ± 0.07% for K. The average total activity concentration in the area is 1087 ± 215 Bq/kg with the highest values (1896 ± 192 Bq/kg) in asphalt and the lowest concentration (417 ± 265 Bq/kg) in the bricks surface type.

This hands-on approach provided students with direct experience in operating scientific instrumentation, acquiring empirical data, and quantifying surface characteristics, thereby demonstrating the complete cycle of a scientific experiment. The practical engagement not only enhanced their conceptual understanding of natural radioactivity but also fostered a connection between theoretical knowledge and applied research, which subsequently increased student interest and motivation.

IMPACT OF B⁻ EMITTING RADIONUCLIDES PROPERTIES ON DOSIMETRIC OUTCOMES OF TUMOR-TARGETING RADIOPHARMACEUTICALS

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Introduction

The efficacy of targeted radionuclide therapy (TRT) in improving outcomes for patients with metastatic cancer, particularly those who are not eligible for standard curative treatments, has been demonstrated. Nevertheless, the selection of the radionuclide constitutes a pivotal step in the development of effective TRT radiopharmaceuticals (RPs).

Description of the Work or Project

The aim of this study was to assess the impact of the nuclear properties of six β⁻-emitting radionuclides (^{47}Sc, ^{67}Cu, ^{111}Ag, ^{161}Tb, ^{177}Lu, and ^{188}Re) on the dosimetric outcomes of two TRT RPs, with distinct pharmacokinetics: the peptide DOTA-folate conjugate cm09, which targets folate receptor, and the monoclonal antibody PFP-HuM195, which binds to the CD33 antigen [1]. Murine biodistribution data were scaled to human models and used to determine biological residence times and the number of disintegrations per unit of injected activity in source organs and tumors. The assessment of absorbed and effective doses for both male and female phantoms and for tumour of different sizes was performed using OLINDA and MIRDCell software.

Results

The dosimetric analysis revealed significant differences among radionuclides and TRT RPs attributable to nuclear properties and pharmacokinetics. In general, radiolabeled DOTA-PFP-HuM195 demonstrated higher tumor concentration, but also slower clearance from healthy organs than radiolabeled cm09. For both RPs, when normalizing to the same absorbed dose to small tumors (2.7-12.4 mm), ^{177}Lu and ^{161}Tb emerged as safer options to label the RPs and ^{188}Re being an opposite.

Conclusions

The present study demonstrates that radionuclide selection should be customized to the specific pharmacokinetics of RPs and the therapeutic goals of the treatment. Furthermore, it contributes to the advancement of personalized TRT approaches for effective treatment.

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Keywords: Radionuclides; Dosimetry; Radiopharmaceuticals; Targeted Radionuclide Therapy (TRT); Pharmacokinetics; Radiation Absorbed Dose

Primary Standardisation and γ-Ray Emission Probability of ^{166}Ho-m at NRC

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Introduction

Holmium-166m (^{166}Ho-m) is a metastable isotope with applications in nuclear medicine and calibration, offering a rich γ-ray spectrum and long half-life that make it a promising alternative to ^{226}Ra in the International Reference System (SIR) [1]. Several intense γ-ray lines, such as the 529.83 keV transition with a probability of >5%, have relatively high uncertainties (>4%), impacting computed calibration coefficients (CC).

Description of the Work

This study evaluates γ-ray emission probabilities of ^{166}Ho-m for energies >100 keV and probabilities >0.1%. Two analysis methods and Monte Carlo simulations were used to deconvolute three doublets, improving emission probability determinations [2]. The CC in a Vinten 671 chamber [3] was obtained through simulation and compared with measurements, considering effects of volume variation and sealed glass container types. Standardisation used the LSC primary TDCR method with three cocktails and two detectors.

Results

Relative activities for ^{166}Ho-m are presented in Fig. 1. All results were consistent within k = 2 of the primary standard. Preliminary γ-spectrometry analysis have shown promising results, such as the reduced the uncertainty of the 529.83 keV line from 4.3% to 0.5%. Using the updated Monte Carlo-derived CC, based on the revised γ-ray probabilities, the agreement between the primary standard and the IC+MC result was improved by 0.6%.

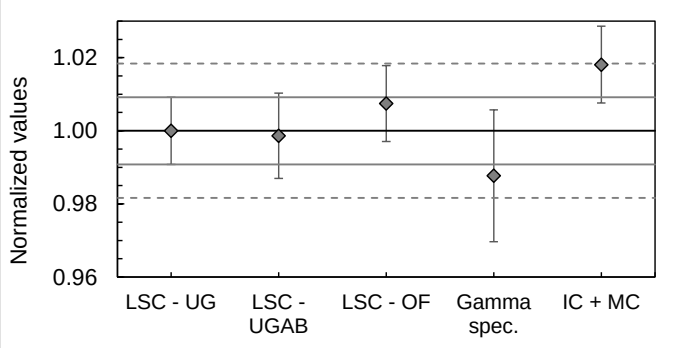

Figure 1: Relative activity of a ^{166}Ho-m sample by TDCR LSC method, γ-spectrometry, and ion chamber (IC) measurement with computed CC. The reference activity was determined from measurements using 10 quenched LSC vials (UG cocktail) and is shown as the grey area. Uncertainties are shown at k = 1.

Conclusions

The improved agreement between TDCR and IC+MC results, supported by the experimental CC determined to be 16.34(18) pA/MBq for a 5 ml serum vial, demonstrates the relevance of this work and its potential to improve activity measurement precision. Longer γ-spectrometry measurements are planned to further enhance precision across the remaining γ-ray lines.

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IMPROVEMENT OF RADIOACTIVE GAS RETENTION SYSTEM DURING 18F-FDG PRODUCTION

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Introduction

At the University of Costa Rica 18F-FDG production is well-established since 2022 by using a cyclotron and synthesis modules from IBA company. In 2020 an issue was reported regarding the ventilation system installed in our facility, due to the dumped gas from the hot-cells in which the synthesis of the radiopharmaceutical takes place. Since then, some ideas have been considered in order to prevent radioactive gas leaks from the production area.

Description of the Work or Project

In the International Conference on Accelerators for Research and Sustainable Development, our team showed the first improvement regarding the changing in position of the HVAC exhaust system, which was considered the direction or trajectory of the wind around the building, moreover, an extension of the exhaust pipe for about 20 meters also was constructed to avoid recirculation of gases due to changes in wind direction. A further improvement took place by installing several components to delay dumped gases within the whole system [1]. Using the installed configuration, we realize that dumped gases cannot travel 500 meters of tubing in order to arrive at the HVAC exhaust system. The new implementation took into consideration changing the position of the pumping system to move the dumped gas through the manifold with the 500 meters of TPE-U tubing, that has been connected out of the 18F hot-cell as an exhaust of the plastic bag that collects gaseous waste from the synthesis. In this form, we manage to warranty that dumped gases are going to be moved when we consider that there are no radioactive sources within the dumped gas.

Conclusions

This work demonstrated that our implementation into the HVAC system prevents any gas leakage to the environment surrounding the facility. The modification shows that any dumped gas can be held the necessary time considering its radioactive decay.

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Geant4 image-based cellular dosimetry for in-vitro Ag-111-irradiated LNCaP cells within the ISOLPHARM Project

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Introduction

The ISOLPHARM project, developed at the INFN-LNL laboratories, aims to produce innovative radiopharmaceuticals using high-purity radioisotopes obtained through the SPES facility. Among the investigated radionuclides, Ag-111 is a β^- emitter showing promising properties for theranostic applications. Within this framework, this work focuses on the simulation-based evaluation of the absorbed dose and cell survival fraction for LNCaP (androgen-sensitive human prostate adenocarcinoma) cells irradiated with Ag-111.

Description of the work or project

The present study, based on a microdosimetric model, plays a key role in facilitating a comparative assessment of the Ag-111 radionuclide against other radionuclides used in radiotherapeutic applications. In particular, this work aims to estimate the absorbed dose and survival fraction of LNCaP prostate cancer cells irradiated with Ag-111, starting from raw microscopy images. The approach uses advanced microdosimetry techniques that take into account irregular cell geometries, which are crucial for accurate dose estimates with β-emitters like Ag. Monte Carlo simulations were performed to estimate the energy deposition and the corresponding absorbed dose.

Conclusions

The algorithm results provide a fundamental step toward understanding the radiobiological effects of Ag-111 at the cellular scale and contribute to the validation of its potential for theranostic radiopharmaceutical development. Future work will integrate the computational predictions with experimental data from the ADMIRAL experiment with internalized Ag-111 to optimize the design of Ag-111-based therapies.

FILLING PHOTONUCLEAR DATA GAPS IN SUPPORT OF ISOTOPE PRODUCTION

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Introduction

Idaho State University (ISU), the New Mexico Institute of Mining and Technology (NMT) and Idaho National Laboratory (INL) have launched a collaboration that is focused on research and education in isotope production and related science and technologies. One of the challenges to the utilization of the photonuclear technique for isotope production has been the large gaps in our knowledge of photonuclear reaction cross sections.

Description of the Work or Project

Our research emphasis is focused on a systematic study of promising photonuclear reactions for the production of many radioisotopes of interest with the aim of enabling a better understanding of the systematics of these processes, thus providing guidance to the development of more reliable physics-based models. We are measuring bremsstrahlung-weighted excitation functions using pulsed electron linear accelerators and activation analysis with targets of natural isotopic abundance. Photonuclear excitation function measurements will include (γ, α), (γ, p), (γ, n), (γ, np), and possibly other reaction channels. For the case of the (γ, n) reactions, we are also developing the nuclear recoil method to perform isotopic separations with the goal of increasing specific activity while exploiting the larger (γ,n) cross sections.

Conclusions

This talk will outline the experimental setup and data analysis techniques we have developed thus far, and highlight some of the opportunities and challenges for the photonuclear approach to isotope production.

This work is funded by the US Dept. of Energy, Grant #DE-SC0023665.

PRODUCTION OF ^{155}Tb VIA HEAVY-ION INDUCED REACTIONS ON NEODYMIUM TARGETS

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Introduction

The radionuclide ^{155}Tb has significant potential in nuclear medicine as a diagnostic isotope and as a theranostic partner to its therapeutic terbium analogues. While several production methods have been investigated but the production of ^{155}Tb for medical applications is still a challenge [1]. The present work aims to explore the different aspects of the production of ^{155}Tb using heavy-ion induced reactions.

Description of the Work

The present experiment of ^{18}O + ^{146}Nd was performed in General Purpose Scattering Chamber of Inter University Accelerator Centre (IUAC), New Delhi, India. The beam $^{18}O^{7+}$ was utilized for excitation functions (EFs) measurements of radioisotopes using 15UD Pelletron accelerator facility. The stack foil activation technique followed by offline gamma ray spectroscopy was utilized. A stack consisting of seven thin enriched ^{146}Nd targets was irradiated at 102 MeV beam energy. The excitation function measurements were done in 3-7 MeV/nucleon beam energy range. To complement the measurements, nuclear reaction model calculations were performed using PACE4. From the excitation functions, thick target yields of ^{155}Tb were calculated. The reaction co-products were examined to evaluate radionuclidic purity and identify optimal production energy windows. A systematic comparison of reaction cross-sections and yields was done with ^{16}O + ^{148}Nd and ^{16}O + ^{146}Nd.

Conclusions

There are total eight radioisotopes populated in the ^{18}O+^{146}Nd system. The cross-sections of ^{155}Tb are significant and higher than the predictions made by theoretical code PACE4. The advantage of the present system is that no terbium isotope produced in reaction other than ^{155}Tb. The comparative analysis with the ^{16}O + ^{146}Nd and ^{16}O + ^{148}Nd systems further reveals distinct differences in the production efficiency and purity of ^{155}Tb. More details will be provided in full length article.

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MEDICAL RADIONUCLIDE PRODUCTION R&D AT THE BERKELEY NUCLEAR DATA PROGRAM

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Introduction

The future of nuclear medicine would appear to be the paradigm of personalized medicine — targeted radionuclide therapy to spare healthy tissue, and theranostic medicine, which pairs an imaging isotope with a therapeutic isotope to provide simultaneous, real-time dose delivery and verification, leading to drastic reductions in prescribed patient dose. Candidate isotopes to meet these needs have been identified based on their chemical and radioactive decay properties. The Bay Area Nuclear Data (BAND) Program is currently leading a series of campaigns to perform targeted, high-priority measurements of thin-target cross sections and thick-target integral yields, as part of a larger campaign to address deficiencies in cross-cutting nuclear data needs. These studies will serve to facilitate the production of pre-clinical quantities of radioactivity for emerging and novel medical radionuclides. This talk will focus on the BAND Program's recent campaigns to measure production cross sections for emerging medical radionuclides.

Description of the Work or Project

As part of these campaigns, our recent work has focused on the targeted nuclear data measurements to optimize production of a range of medically-valuable radionuclides. These include the development of new production routes for ^{68}Ga generators, new monitor reactions for >70 MeV accelerator facilities, ^{161}Tb for therapeutic applications, new methods for producing ^{229}Th generators, ^{86}Y for imaging and theranostic applications, and the Auger therapy candidates ^{193m}Pt, ^{119}Sb, ^{71}Ge, ^{77}Br, ^{103}Pd, and ^{180}Ta.

Conclusions

These measurements provide a range of cross section data invaluable to not only the medical isotope production community, but also as new measurements to improve the reliability of the range of modern reaction modeling codes. In addition, these experiments provide valuable insight into the challenges and unexpected nuances involved in precision cross section data measurements.

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ISOTOPE MASS-SEPARATION: RECENT DEVELOPMENTS FOR CLINICAL RESEARCH AT CERN-MEDICIS AND FOR PRISMAP

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Introduction

Electromagnetic mass separation has been developed for the past 70 years for fundamental studies exploiting beams of radionuclides. It is notably done at online ISOL facilities while irradiating a target with an accelerator, as done at ISOLDE at CERN and in different other distributed facilities. It has also been specifically adapted for biomedical research in batch modes, to produce non-conventional radionuclides used in nuclear medicine for the past 7 years at CERN-MEDICIS (medicis.cern). This last mode of operation triggered a consortium, PRISMAP-the European medical radionuclides research programme in Europe (prismap.eu) , where external sources can be produced at leading accelerators and nuclear reactors, and combined with radiochemical and physical separation to reach high molar activity grades, sometimes referred to as “non-carrier added”.

Description of the Work or Project

The development of Isotope mass Separation for biomedical research requires important developments in terms of improved performance, infrastructures, or organization, as compared to previously available state-of-the-art facilities used for nuclear and applied physics studies. As witnessed by Key Performance Indicators (KPIs), CERN-MEDICIS has demonstrated over the past few years the reliable deliveries of non-conventional radionuclides used in theranostics projects involving new radiotherapeutics. It reached a milestone where a first therapeutic mass separated activity of high molar activity Sm-153 could be delivered, and a separation efficiency of more than 70% could be reached for Ra-225, as a generator for Ac-225. Other milestones were reached within PRISMAP, such as the delivery in 4 hours door-to-door from CERN-MEDICIS to DTU (DK) of Tm-165, as a generator for the pure Auger electron emitters Er-165.

Conclusions

While CERN-MEDICIS acts as a pioneer biomedical facility in Europe, and while awaiting for a positive decision to move from PRISMAP to a next PRISMAP+ programme, new isotope mass separation facilities with biomedical programmes have started or are under construction, such as SPES in Legnaro (IT), ISOL@Myrrha in Mol (BE), SMILES in Nantes (FR) or TATOO at PSI in Villingen (CH).

This project has received funding from the European Union’s Horizon 2020 research and innovation programme under grant agreement No 101008571 (PRISMAP)

SECURING THE PRODUCTION OF RADIOISOTOPES IN RESEARCH AND POWER REACTORS

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Introduction

Research reactors are multipurpose facilities playing a key role in the production of radioisotopes for various applications. The BR2 High-Flux reactor operated by the Belgian Nuclear Research Centre (SCK CEN) is for example considered as a major facility for the global production of radioisotopes for nuclear medicine (Mo-99/Tc-99m, I-131, Xe-133, Lu-177, Tb-161, Ir-192, Re-186, Sm-153, Er-169, Y-90, P-32, Sn-117m, W-188/Re-188, Sr-89, …), industry (Ir-192, …) and research (Sc-47, …).

Description of the Work or Project

While the number of accelerators involved in the production of medical radioisotopes (F-18, Cu-64, Cu-67, Zr-89, Ge-68/Ga-68, At-211, Ac-225, …) is increasing, the supply of reactor-produced radioisotopes for nuclear medicine relies on a limited number of research reactors.

This is especially the case to produce Mo-99, a very crucial radioisotope as it decays into Tc-99m which is used in 80% of the 40 million radiodiagnosis nuclear medicine procedures carried out worldwide annually. Since the definitive shutdown of OSIRIS (France) in 2015 and NRU (Canada) in 2018, the global Mo-99 supply chain relies on the irradiation of HALEU ('High-Assay Low-Enriched Uranium') solid targets in only six research reactors: BR2 (Belgium), HFR (The Netherlands), LVR-15 (Czech Republic), MARIA (Poland), SAFARI-1 (South Africa) and OPAL (Australia). The irradiated targets are processed by four facilities: IRE (Belgium), CURIUM (The Netherlands), NTP (South Africa) and ANSTO (Australia). The recovered fission Mo-99 is then sent as bulk to Mo-99/Tc-99m generator manufacturers or central radiopharmacies to supply the hospitals.

The supply chain is based on proven technology involving elaborated logistic networks but is subject to disruption risks as research reactors are ageing and requesting regular maintenance periods to ensure safe and reliable operation. Replacement projects (JHR, PALLAS, KJRR, RA-10, SAFARI-2, …), alternative production technologies (NorthStar, SHINE, …) and initiatives taken at various levels (NMEU, EU Observatory, OECD/NEA, …) will improve the security of supply of radioisotopes in future.

Conclusion

The involvement of CANDU nuclear power reactors in Canada (Bruce Power, Laurentis) demonstrated already their ability for large scale production of therapeutic radioisotopes as Co-60 and Lu-177nca for cancer treatment. They will contribute together with research reactors to meet the increasing demand and to provide reliable supply in future.

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THE SPES ISOL FACILITY: COMMISSIONING WITH RADIOACTIVE ION BEAMS AND FUTURE DEVELOPMENTS AT LEGNARO NATIONAL LABORATORIES

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Introduction

The commissioning of the SPES ISOL facility is in progress at Legnaro National Laboratories. The first on-line tests with SiC-based targets and FEBIAD ion sources are now paving the way toward full RIB operation. Future developments on target-ion source systems, driven by the HISOL_NEXT experiment, will enhance reliability, efficiency, and isotope purity.

Description of the Work or Project

The SPES ISOL facility is designed to deliver high-intensity, high-quality radioactive ion beams through proton-induced reactions on carbide targets. During the ongoing commissioning phase, the on-line front-end and mass separator have been successfully tested with both stable and radioactive ion beams, making use of a SiC target and a FEBIAD ion source. In parallel, the HISOL_NEXT experiment is driving the next generation of ISOL target–ion source systems, introducing additive manufacturing and topology optimization to enhance heat dissipation, isotope release and other key parameters. Novel targets, together with advanced FEBIAD and hot-cavity ion sources featuring optimized geometries, are being developed and tested. These innovations aim to improve reliability, efficiency, and beam purity, consolidating SPES as a state-of-the-art ISOL facility within the European landscape.

Conclusions

The SPES commissioning campaign represents a key step toward routine RIB operation at INFN-LNL. The parallel technological advancements enabled by HISOL_NEXT experiment will ensure long-term performance improvement of SPES targets and ion sources. Together, these activities will position Legnaro among the main European laboratories in ISOL science and technology.

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PRODUCTION OF Co-55 THROUGH AUTOMATED ELECTROPLATING AND PURIFICATION TECHNIQUES

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Introduction

Cobalt-55 (^{55}Co) is a promising PET isotope for extended imaging, thanks to its 17.5-hour half-life and relatively high proportions of β+ emission ($I_{\beta+}$ = 77%, Eγ = 931.1 keV). Additionally, the high affinity of [^{55}Co]Co^{2+} ions for commonly employed macrocyclic chelators, such as DOTA (1,4,7,10-tetraazacyclododecane-1,4,7,10-tetraacetic acid) provides a plethora of functionalised bioactive molecules that can readily be accessed for PET imaging.[1] This preliminary study presents an automated workflow for [^{55}Co]Co production via the ^{58}Ni(p,α) ^{55}Co reaction, aiming to establish a reproducible method with improved operator safety.

Description of the Work or Project

Enriched {^{58}Ni]Ni (>99.5%, Isoflex, USA) was electroplated (50 ± 5mg) onto platinum using a nickel nitrate solution. Proton irradiation of the target (GE PETtrace 880, 35 µA, 14 MeV, 1 h) was performed at the South Australian Health and Medical Research Institute (SAHMRI) and processed with Comecer's ALCEO system.

Results

After 1h of irradiation, the process yield was >250 MBq of [^{55}Co]Co. The automated purification protocol used 6 mL of 6M HCl for target dissolution, followed by 40 mL of 6M HCl to recover the [^{58}Ni]Ni from the purification resin (Ag-1X8), and 20 mL of 4M HCl to extract [^{55}Co]Co. The [^{55}Co]Co/HCl mixture was evaporated to dryness inside the reactor, connected to an anti-acid trap. The isolated [^{55}Co]Co was reconstituted using 3 mL of 0.01M HCl to form [^{55}Co]Cobalt chloride ([^{55}Co]$CoCl_2$), which was transferred to the final product vial with a total workflow time of ~3.5 h. Gamma spectroscopy performed on days 1 and 5 confirmed the presence of [^{55}Co]Co (characteristic Eγ = 931.1 keV) and a minor amount of [^{57}Co]Co (0.45% radionuclidic impurity, Eγ = 122.1 keV), likely due to traces of [^{60}Ni]Ni in the plating material undergoing the ^{60}Ni(p,α) ^{57}Co nuclear reaction. Activity losses were observed in the anti-acid trap (22.4 MBq, 8.96%) and on the purification resin (2 MBq, 0.8%), both considered correctable with further fluidic optimisation. The separation of [^{58}Ni]Ni from the desired [^{55}Co]Co was less than optimal under these current conditions, however, this too can be further improved through adjusting the elution profile.

Conclusion

This preliminary assessment demonstrates the efficient cyclotron production of [^{55}Co]Co, with reduced manual handling and operator intervention. Further optimisation of [^{55}Co]$CoCl_2$ manufacture will support the integration of this relatively unutilised PET isotope for clinical applications.

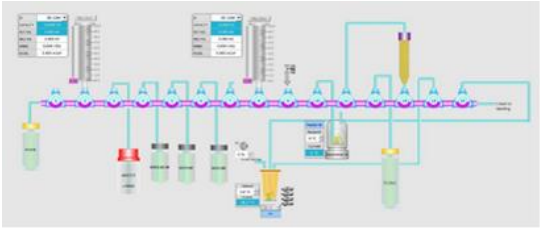

Figure: Schematic of the ALCEO automated purification system.

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A THEORETICAL FRAMEWORK FOR ISOTOPE PRODUCTION AT THE SPES ISOL FACILITY: MAGNESIUM-28 AS A CASE-STUDY

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Introduction

Isotope Separation On-Line (ISOL) is one of the most cutting-edge techniques for the production of exotic nuclides. The Italian ISOL facility SPES, located at INFN-LNL, has recently become operational after its first Radioactive Ion Beam (RIB) was produced in 2024. In this context, the SPES_MED experiment, financed by INFN, has the aim of testing for the first time the production of isotopes of biomedical interest at SPES.

Description of the Work or Project

This study presents a workflow for the theoretical modeling of the ISOL production at SPES. The main steps taken into account are: the generation of isotopes in the target irradiated by protons, the diffusion and effusion processes leading to the release of the species from the target and the ionization of the atoms for subsequent acceleration and formation of the RIB. Such steps can be analyzed combining Monte Carlo simulations (using particle-transport codes like Geant4 or FLUKA) and theoretical models, in order to optimize the parameters of the system which most affect the production yield of the desired isotope. As a case-study, the theoretical analysis of the production of magnesium-28, a radiotracer with applications in biology and medicine, is reported. This considers the production of magnesium-28 via proton-induced nuclear reactions in a silicon carbide (SiC) target, the diffusion in the target discs, the effusion from the target box and the ionization using resonant lasers.

Conclusions

The analysis revealed that, with the current constructive parameters, the diffusion process critically slows down the whole procedure of magnesium-28 production. To overcome this limit, the present work suggests that certain properties of the target, such as the size of the grains and the resistance to high temperature, may have to be improved.

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RADIOPHARMACEUTICALS AND ISOTOPES: THE TRAJECTORY AND POSITIONING FOR GROWTH

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Introduction

The field of radiopharmaceuticals and isotopes is becoming increasingly relevant in medicine. The current phase of resurgence that began less than (around) nine years ago has firmly positioned nuclear medicine as a leading approach in patient care. This positive trajectory continues and is fueled by epidemiological and demographic trends that are driving the growing demand for these technologies.

Description of the Keynote speech

To offer meaningful context for this 12ICI audience, this keynote will highlight the speaker's top six selections of major industry-shaping events since the 11ICI, while acknowledging that many other significant developments have also taken place. The sector has since seen the rise of new industry growth leaders, and several major pharmaceutical companies continue to invest in radiopharmaceuticals – what was not so long back seen as a very small and a niche field. Recent radiopharmaceuticals clinical trials demonstrate expanding breadth of detectable and treatable diseases that could be addressed with this modality. However, this progress and the potential is not without challenges. Efforts to scale up manufacturing capacity for next-generation radiopharmaceuticals and isotopes are aiming to meet the increasing demand, there is an urgent need to address the persistent gap between isotope supply and demand. New innovations and emerging technologies are being introduced to help close this gap. For example, Astral Systems is utilizing its pioneering Multi-State Fusion (MSF) neutron technology for isotope production and novel industrial applications, supporting both fusion and fission industries. It is extremely important to also note that there is a hard race to secure human talent that is needed to effectively deliver the products and services.

This presentation will offer a balanced and objective evaluation of the current landscape, emphasizing the Strengths, Weaknesses, Opportunities, and Threats that are shaping the industry's path to the future. It is clear to the speaker that most participants at the 12ICI are well-engaged in positioning themselves and their organizations suitably, in this period of exciting flux.

Conclusions

The nuclear medicine industry is propelled by several key growth drivers and is well-positioned to enter the next stage of its evolution. Although notable challenges persist, realizing the full potential of the sector is effectively unraveling, thanks to the innovative approaches and careful management of the multitude of critical issues.

References

None

The Japan Astatine Community: Toward a Collective Brain in ^{211}At Science and Clinical Translation

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Introduction

Radiotheranostics, a combination of diagnosis and treatment using radionuclides, is currently developing rapidly in the medical field. The construction of a supply chain for radionuclides and a stable supply are important factors for making radiotheranostics sustainable medical treatment. Astatine-211 (^{211}At) is an alpha-emitting radionuclide that can be produced by using a cyclotron and has been recognized for its potential worldwide. The Japan Astatine Community (JAC), which consists of universities, research institutes, and companies, will promote research and development and clinical application of ^{211}At in Japan through information exchange and events among community members.

Description of the Work or Project

The JAC is working to become a hub for the systematic collaboration of stakeholders in industry, academia, and government for the social implementation of targeted radionuclide therapy using ^{211}At by sharing actions necessary for the early realization of this goal. Our activities are ultimately to obtain the following five outcomes:

1. establish and strengthen the astatine supply network
2. provision of up-to-date technical and professional information on astatine to nuclear medicine professionals
3. study towards international standardization of astatine-labeled drug production
4. access to an international network centered on the WAC
5. promotion of rapid transfer of innovations from scientific societies to industry

The JAC is a member of the Worldwide Astatine Community (WAC) and operates the WAC with 1) the Network for Optimized Astatine labeled Radiopharmaceuticals (NOAR) in Europe, 2) the Astatine User's Community developed by the Department of Energy's Isotope Program in the United States, 3) the Korea Institute of Radiological and Medical Sciences (KIRAMS) in South Korea, 4) Chinese Astatine Community and 5) various industrial partners, which share the same goals to explore the full potential of the ^{211}At in targeted radionuclide therapy. Membership in the WAC is open to all [1].

Conclusions

The JAC, in liaison with the WAC, will facilitate the use and research and development of ^{211}At and support its clinical use in Japan as a hub for skills and knowledge of astatine.

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CNL INTEGRATED ISOTOPES STRATEGY: ADVANCING CANADA'S POSITION IN THE GLOBAL ISOTOPE ECOSYSTEM

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Introduction

Canada has a long-standing legacy in isotope production, historically anchored by the NRU reactor at Chalk River. In recent years, Canadian Nuclear Laboratories (CNL) has launched a renewed isotope R&D program to address emerging needs in medical isotopes. Significant reinvestment in infrastructure and expertise has positioned CNL to play a catalytic role in revitalizing Canada's medical isotope ecosystem. The CNL Integrated Isotopes Strategy will deliver on this endeavor by coordinating research and fostering collaboration and partnerships amongst Canadian medical isotopes producers and users.

Description of the Work or Project

CNL's Integrated Isotopes Strategy responds to growing global and domestic demand for therapeutic isotopes and Canada's need for coordinated production capabilities. The strategy encompasses three core pillars:

1. Access to Emerging Isotopes: In-house small-scale production of Ac-225 and development of Pb-212 generators for theragnostic research and innovation, and large-scale production of selected isotopes under strong commercial partnerships for clinical deployment. This is complemented by expanding Canada's technology readiness for emerging isotopes (Sc-44/47, At-211, Er-165, La-133/135).

2. Ecosystem Development: Deploying a national Medical Isotopes Producer & User Survey (2025/26), energizing a pan-Canadian Cyclotron Network (2026/27), broadening collaborative research and innovation, cooperating on production standardization, building a talent and infrastructure pipeline, and to empower joint grant applications.

3. Informing National Isotopes Strategy: Providing technical support to Canadian government agencies to inform on national interests in medical isotope production and their safe use.

Conclusions

CNL's strategy aims to strengthen Canada's position in the global medical isotope supply chain through innovation, collaboration, and infrastructure development. By bridging gaps in production readiness and fostering partnerships, CNL seeks to accelerate Canadians access to life-saving isotopes and support the next generation of theranostic solutions.

Keywords: Medical isotopes, Ac-225, Pb-212, Cyclotron network, Radiopharmaceuticals, Canada

PUBLIC PERCEPTION AND POLICY IN THE NUCLEAR RENAISSANCE: CIVIC ENGAGEMENT AND LESSONS FROM THE ITALIAN EXPERIENCE

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Introduction

The renewed global attention on nuclear technologies — from energy generation to isotope production for medicine and industry — has brought public perception and policy design back to the center of the international debate. Civil society initiatives, particularly those connected to the Stand Up for Nuclear movement, have played an increasingly important role in promoting a science-based narrative and fostering informed discussion.

Description of the Work or Project

This contribution explores how civic engagement and communication initiatives can support national and international nuclear policies, using the case of Italy as a lens through which to understand broader dynamics. The experience of the Comitato Nucleare e Ragione, part of the global Stand Up for Nuclear network, demonstrates how structured outreach programs, public events, and institutional dialogue can help reshape public understanding of nuclear energy and isotopic applications. The paper analyses the evolution of Italian nuclear policy — including the 2025 governmental draft law on nuclear technologies — and compares it with developments in other European contexts such as France, Finland, and Poland. Through this comparative framework, it highlights the convergence of social, educational, and policy approaches aimed at building public confidence and strategic capacity in isotope production and nuclear innovation.

Conclusions

Strengthening societal trust through transparent communication, education, and policy alignment is essential to enable a sustainable nuclear renaissance. The Italian case, supported by an active civil society and international advocacy networks, offers valuable lessons on how countries can reconcile technological ambition with democratic participation and long-term energy and health goals.

Keywords: nuclear policy, public perception, civic engagement, isotope technologies, energy transition, Stand Up for Nuclear

TRACEABILITY OF BRAZILIAN BELT SOYBEAN SUPPORTED BY ANALYTICAL TECHNIQUES AND MACHINE LEARNING APPROACHES

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Introduction

Soybeans are Brazil's main agricultural export product, playing a strategic role in the country's socioeconomic development. Soybean production is located in the south, southeast, and central-west regions and has been expanding northward, forming the so-called 'soybean belt' as it advances over transition areas between Cerrado and Amazon biomes. Deforestation represents a challenge for the insertion of Brazilian products into the international market. To ensure sustainability and meet traceability requirements, it is essential to have methods capable of discriminate the producing regions and respective biomes.

Description of the Work or Project

This work proposes the application of analytical techniques for the traceability of Brazilian soybeans, with an emphasis on determining geographic origin based on their elemental profile. To this end, 60 soybean samples from four Brazilian biomes: Amazon, Cerrado, Atlantic Forest, and Pampa were analyzed by inductively coupled plasma mass spectrometry (ICP-MS) and neutron activation analysis (NAA). For ICP-MS analysis, the samples were subjected to microwave-assisted acid digestion. Aliquots of 500 mg were weighed into polytetrafluoroethylene tubes, together with nitric acid, hydrogen peroxide and deionized water. Digestion was carried out in a Milestone ETHOS UP system. The solutions obtained were analyzed in an Agilent 8900 triple quadrupole ICP-MS mass spectrometer. For NAA, aliquots of 250 mg were packaged in high-density polyethylene capsules suitable for neutron irradiation. The samples were irradiated at the IEA-R1 nuclear research reactor of the Institute for Nuclear and Energy Research, Brazilian National Commission of Nuclear Energy (IPEN/CNEN), with thermal neutron flux. The induced radioactivity was measured by high-resolution gamma spectrometry using hyperpure germanium detectors. The identification of radionuclides and quantification of mass fractions were carried out using the Quantu software package[1]. Thirty-two elements — As, B, Ba, Br, Ca, Cd, Ce, Co, Cr, Cs, Cu, Eu, Fe, Gd, Hg, K, La, Mn, Mo, Na, Nd, Ni, P, Pb, Rb, S, Sc, Ta, Tb and Zn — were determined in all samples. The data were subjected to univariate (NPANOVA) and multivariate (PERMANOVA) statistical analyses, in addition to the application of supervised machine learning algorithms Random Forest (RF), Support Vector Machine (SVM), K-Nearest Neighbors (KNN) and Multilayer Perceptron (MLP) to classify the samples according to the biome of origin.

Conclusions

The results indicated statistically significant differences between chemical profiles of the biomes, evidencing the potential for discrimination. The classification models achieved accuracy of up to 92% (RF), indicating the feasibility of using the elemental profile combined with machine learning for soybean traceability.

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SOIL TO PLANT TRANSFER FACTOR DEPENDS ON GROWTH CYCLE: THE USE OF SUNFLOWERS FOR PHYTOREMEDIATION OF RADIONUCLIDE-CONTAMINATED SOIL

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Introduction

The last nuclear power plant in Germany was shut down on 15 April 2023. During decommissioning, contaminated construction waste and soil must be disposed of. To avoid costly deep geological repository disposal, methods for volume reduction and decontamination are being explored. This paper focuses on phytoremediation, specifically examining sunflowers' potential for radionuclide uptake from contaminated soil, to optimize efficiency and time.

Material and methods

The soil comes from the former Dresden Rossendorf reactor site, operated from 1957 to 1991[1]. Due to the time since decommissioning, the radionuclides are in a chemical equilib-rium. This state is difficult to reproduce on short time scales by spiking uncontami-nated soils. The soil is sieved to 2 mm to remove concrete before planting. The experiment uses plant pots (18 cm x 17 cm) in a climate chamber with optimal growth conditions. Small sunflowers, Helianthus annuus, are planted, having shown promise in preliminary trials. Hoagland solu-tion supports plant growth[2], with sunflowers analysed monthly. Three pots are harvested monthly, with plants divided into stem, leaf, and flower. Each component's gamma activity is measured using an HPGe detector, and soil-to-plant transfer factors are calculated based on the soil's specific activity.

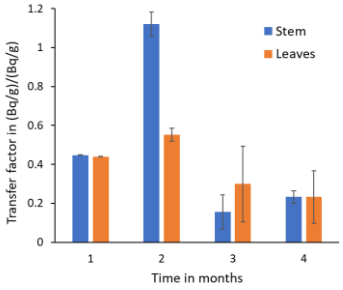

Fig. 1: The diagram shows the temporal development of the transfer factor for Cs-137 in stems and leaves of sunflowers in the first few months.

Results and discussion

The experiments show that the transfer factor for ^{137}Cs and ^{60}Co in stems and leaves peaks after the second month, indicating most radionuclide uptake occurs then. Fig. 1 illustrates the ^{137}Cs transfer factor relative to sunflower growth phases: plants grow in length between the first and second month, ending by the third month[3]. Transfer factors decreased in the third month. This work demonstrates that ^{137}Cs and ^{60}Co uptake depends on sunflower growth phases.

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DIRECT CONDITIONING OF RADIOACTIVE LIQUID ORGANIC WASTE IN NOVEL GEOPOLYMERS: A DURABILITY AND ROBUSTNESS STUDY

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Introduction

Radioactive Liquid Organic Waste (RLOW), including lubricating oils, extraction solvents, and scintillation cocktails, is typically classified as intermediate- or low-level waste. Its management presents significant challenges due to its complex physico-chemical nature, which makes it incompatible with conventional cement-based conditioning matrices. This incompatibility results in waste forms with low loading factors which cannot meet national Waste Acceptance Criteria (WAC). As a result, additional treatment steps such as incineration are often required prior to conditioning and disposal. However, these steps are expensive, and many industrial incineration plants have their own set of WACs that some RLOW inventories cannot meet. Due to these limitations, many countries continue to stockpile RLOW. Therefore, more affordable, effective, and safer management options must be developed.

Description of the Work

Alkali-activated geopolymers (GPs) offer a promising alternative for the direct conditioning of RLOW, i.e. without the need for prior treatment. These materials, formed by activating aluminosilicate precursors (e.g., metakaolin) with alkaline solutions, produce a robust silica-alumina network that is less affected by the presence of organic waste in its mechanical properties and durability. In the H2020-PREDIS project, a metakaolin-based GP matrix was developed to immobilize RLOW. While the matrix demonstrated good mechanical and thermal performance, it showed cracking and complete disintegration upon water immersion. This was attributed to rapid re-absorption of lost water, inducing capillary stresses and cracking [1], which can lead to the release of organic pollutants and radionuclides. In the present work, carried out within WP6 STREAM and WP7 L'OPERA of the EURAD-2 Project, a modified metakaolin-based geopolymer has been developed using Electric Arc Furnace Slag (EAFS) and sand additives to improve immersion stability. The proposed matrix showed promising preliminary compression strength, immersion stability and leaching results, while achieving a waste loading capacity of 30% by volume. In addition, a robustness analysis was also carried out, identifying the main contributors to the compression strength reduction besides the presence of waste.

Conclusions

A modified metakaolin-based geopolymer incorporating additives has been developed for RLOW immobilization, showing improved immersion stability and promising mechanical strength and leaching resistance.

Acknowledgment

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Feasibility Study on an Optimized Gamma Ray Screening Methodology for a Medical Cyclotron Body Using Monte Carlo Simulations

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Introduction

In recent years, research on reduction and clearance for radioactive waste has become a significant focus in South Korea. As part of these efforts, studies are underway for the decommissioning and clearance of metallic components from medical cyclotrons used for producing isotopes like F-18. According to IAEA technical reports [1], performing preliminary radiological screening with detectors such as Cadmium Zinc Telluride (CZT) can be effective for classifying activity levels by zone prior to decommissioning. While precedents exist for screening concrete walls in cyclotron vaults [2], there is no precedent for assessing the complex, metallic components of the cyclotron body such as the dee, magnet coils, yoke, and vacuum chamber using preliminary radiological screening method. This presents a considerable challenge due to their intricate geometry and varying materials.

Description of the Project

Using the FLUKA code, a 11 MeV proton medical cyclotron was simulated the activation and photon-emission response of under a representative operation cooldown history. The cyclotron body was modeled as a multilayer coaxial architecture reflecting actual build materials and realistic thicknesses medium-carbon steel (yoke), copper (coils), and aluminum (vacuum chamber). Radionuclides expected to persist at the present cooldown time were prioritized, treating Co-60 as dominant and Na-22 as conditional; Mn-54 and Zn-65 were included solely to establish conservative upper bounds. Layer and energy resolved self-attenuation and outward transmission were quantified, and the count-rate response at a single external location was simulated for a cadmium-zinc-telluride (CZT) detector.

Conclusions

Within the parameters of this simulation framework, the external CZT spectrum is predominantly characterized by the Co-60 gamma energy at 1173 keV and 1332 keV. These Co-60 signatures, in conjunction with established correlations to the inventories of β-emitter radionuclides, could provide a technical metric for the quantification of activation within the cyclotron structure. When present, Na-22 is unambiguously identifiable via its 1275 keV emission line, which is accompanied by the 511 keV annihilation radiation peak. Conversely, Mn-54 and Zn-65 are predicted to be effectively non-detectable with cooldown period. These simulation outcomes could provide a practical technical rationale for a geometric efficiency corrected single point gamma spectrometry assay, thereby supporting the pre-decommissioning classification process.

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DEVELOPMENT OF SEPARATION METHOD FOR DIFFICULT-TO-MEASURE RADIONUCLIDES FROM NUCLEAR DECOMMISSIONING

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Introduction

The dismantling of nuclear facilities generates a wide variety of radioactive waste, whose accurate characterization is essential for safe and optimized management. Among the various radionuclides present, some are produced by neutron reactions and occur only in ultra-trace amounts. Radionuclides that emit gamma radiation can be quantified directly by γ-spectrometry and are referred to as ETM (easy-to-measure) radionuclides. However, when radionuclides emit β or X radiation, they cannot be detected directly and are classified as DTM (difficult-to-measure) radionuclides. Their determination requires destructive radiochemical characterization methods, including the separation of DTMs from the matrix and from other interfering radionuclides or elements[1].

Description of the Work

This work presents the development of innovative chemical methods for the sequential separation of DTM radionuclides. The objective is to selectively isolate Fe-55, Ni-59/63, Zr-93, Mo-93, Nb-94, and Nb-93m in activated steel, to enable their quantification by more sensitive and reliable measurement techniques, e.g., mass spectrometry, X-ray spectrometry, or liquid scintillation counting after separation.

The developed methodology, based on extraction chromatography resin using TK400, ZR, and Ni resins from TrisKem International, is optimized on stable elements to minimize interferences and maximize recovery yields, as shown in Figure 1.

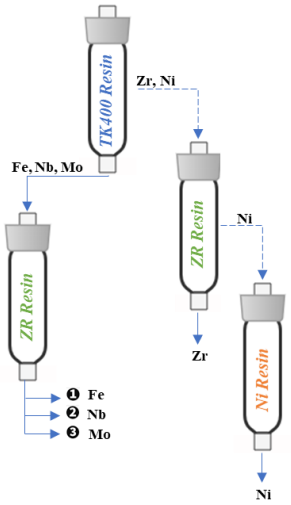

Figure 1: Separation protocol

Conclusions

Preliminary results demonstrate the effectiveness of this new method for the separation of the targeted stable elements, paving the way for a significant improvement in the radiological characterization of decommissioning waste. This advancement will contribute to safer, more economical, and more regulatory-compliant management of radioactive waste.

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PRODUCTION OF NO-CARRIER-ADDED HOLMIUM-166 BY DOUBLE NEUTRON CAPTURE AT MCMASTER NUCLEAR REACTOR

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Introduction

Holmium-166 (^{166}Ho, $t_{½}$: 26.8 h) is a radionuclide with therapeutic ($E_{β^-}$: 1.85 MeV) and imaging ($E_γ$: 80 keV, $I_γ$: 51%) properties[1]. Carrier-added ^{166}Ho, which is used in radioembolization therapies, is typically produced via neutron irradiation of ^{165}Ho. However, for targeted radionuclide therapy (TRT) no-carrier-added (NCA) ^{166}Ho is required to achieve a higher specific activity and improve radiolabelling efficiency. This work evaluates the production of NCA ^{166}Ho by double neutron capture of ^{164}Dy (Figure 1), followed by chemical separation from ^{166}Dy.

Description of the Work

Based on previously published methods irradiating natural Dy[1], enriched $^{164}Dy_2O_3$ (approx. 24 mg) was irradiated in quartz tubes at McMaster Nuclear Reactor at different thermal neutron flux sites: 2.0 × 10^{13} to 6.5 × 10^{13} n/cm²·s at irradiation times of 48-107 hours. After irradiation, targets were left for approx. 70 hours to allow co-produced impurities to decay and for the build-up of ^{166}Ho (Figure 1).

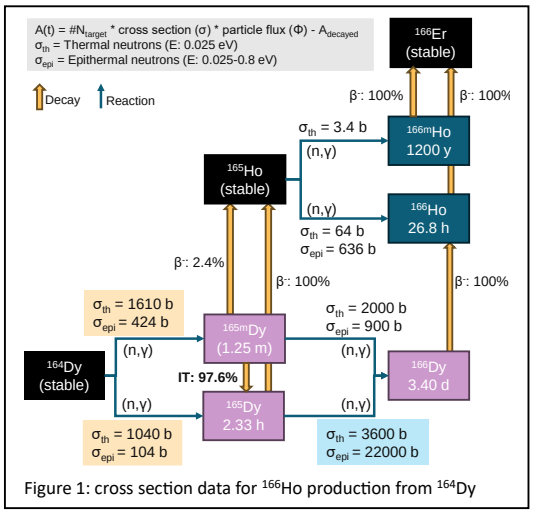

Figure 1: cross section data for ^{166}Ho production from ^{164}Dy

Post-irradiation, the $^{164/166}$Dy/^{166}Ho target material was dissolved in 0.1 M HCl and ^{166}Ho was separated using LN2 resin. Acid concentration was optimized for Ho/Dy separation, with $^{164/166}$Dy eluted in 0.65 M HNO_3 and followed by ^{166}Ho in 1.5 M HNO_3. Fractions were analyzed by HPGe gamma spectroscopy. The LN2-purified ^{166}Ho fractions were reformulated in dilute acid and passed through DGA resin for enhanced Dy removal. The final ^{166}Ho product was eluted in 0.05 M HCl and used in radiolabeling with DOTA. Radiolabeling efficiency was assessed via radio-TLC, while neutron activation analysis or ICP-OES analyses quantified residual Dy and trace metals affecting labeling.

The ^{166}Ho was successfully produced from ^{164}Dy with the highest yields of 2.3 GBq after the first processing cycle and 0.74 GBq after a second processing cycle. Although a high ^{166}Ho recovery is seen after the first processing cycle the product is not fully carrier free, as traces of ^{165}Ho remain from the decay of ^{165}Dy that never converted to ^{166}Dy during the neutron irradiation (Figure 1). An improved labeling efficiency was seen for ^{166}Ho from second processing cycle.

Conclusions

A method for producing and separating NCA ^{166}Ho was developed at McMaster Nuclear Reactor with the purified ^{166}Ho successfully incorporated into DOTA. Further optimization of irradiation schedules, processing techniques, and refining the separation process could significantly enhance production efficiency and labelling ratios.

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SIMULTANEOUS ^{225}AC & ^{212}PB PRODUCTION USING ACCELERATOR-PRODUCED SECONDARY NEUTRONS

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Introduction

As of January 2024 over 3 dozen pre-clinical and clinical targeted alpha therapy studies using ^{225}Ac and ^{212}Pb are underway. However, the production of these radionuclides using both reactor- and accelerator produced radiochemical generators have failed so far to produce the scalable, contaminant-free supply needed for large-scale radiopharmaceutical development. In this talk we will present results that demonstrate the simultaneous production of ^{225}Ac and ^{212}Pb using secondary neutrons produced from the bombardment of high-power Be targets.

Description of the Work or Project

Two experiments at the LBNL 88-Inch cyclotron in 2018 demonstrated a scalable, safe, accelerator-based method for *simultaneously* producing ^{225}Ac [1] and ^{212}Pb via the irradiation of radium salt targets using secondary neutrons [2] from deuteron- and proton-induced irradiation of high power beryllium targets. The ^{225}Ac is produced via the ^{226}Ra(n,2n) reaction which makes the ^{225}Ra 15-day precursor while the ^{212}Pb is made via the ^{226}Ra(n,3n) reaction which produces the 3.6 day ^{224}Ra precursor. While the ^{225}Ac requires chemical separation from the ^{226}Ra target, the ^{212}Pb can be collected via online collection of the ^{220}Rn precursor. This secondary neutron approach was successfully demonstrated, and an optimized neutron production target was designed and tested in 2024. This new target allows for the production of 10-30 mCi of the ^{225}Ra precursor to ^{225}Ac per week and 5-60 mCi of ^{212}Pb/day using 1 gram of radium and commercially available 19-22 MeV proton cyclotrons. The production rate would be approximately 10 times higher using secondary neutrons from a 33-40 MeV deuteron beam.

Conclusions

The method described in this work allows for the large-scale production of both ^{225}Ac and ^{212}Pb using existing medical accelerators, enabling the rapid advancement of these important targeted alpha therapeutic radionuclides.

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PRODUCTION OF THERAGNOSTIC RADIONUCLIDES WITH NEUTRON ACTIVATOR: FESTA EXPERIMENTS

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Introduction

Based on the results of the FESTA program carried out with the MediCyc cyclotron, a collaboration of AIMA Développement with CNRS-iRSD evaluates the production of theragnostic radionuclides using a high-energy proton beam (60 MeV) incident on a beryllium target housed inside a specific activator. Comparisons of irradiations performed at the MediCyc facility on metallic targets (Mo, Lu, Re, Ho) and the resulting activities were benchmarked against Monte-Carlo simulations performed with FLUKA[1, 2], MCNP6[3] and PHITS [4].

Description of the Work or Project

A custom-built activator was coupled to the MediCyc cyclotron (60 MeV, 600 nA). Samples were placed in a modular assembly that allows rapid exchange of target and shielding configurations. Neutron fluences and activation rates were calculated with FLUKA, MCNP6 and PHITS using identical geometries and beam parameters.

Conclusions

MCNP6 reproduces the experimental activities within 10 % for all targets except Mo, where a systematic underestimation of a factor of 20 is observed. FLUKA and PHITS predict neutron fluences up to twice those of MCNP6, leading to an over-estimation of activity by the same factor. For the target, switching from pure Be to BeO improves thermal performance but halves the neutron yield for a given beam energy.
The present activator geometry delivers a good efficiency to produce medically relevant isotopes. Sensitivity studies indicate that a 25 % gain could be achieved by increasing the width of the graphite and PET part and reducing the thickness of the lead, thereby increasing neutron thermalisation.

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EMERGING ACCELERATOR-BASED RADIONUCLIDES TOWARDS THE THERAGNOSTICS PRINCIPLE: DEVELOPMENT AND TRANSLATION

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Introduction

The terbium radioisotope quadruplet or "sisters" have gained international attention, as they have attributes suited for diagnostics and therapy in nuclear medicine [1]. Paul Scherrer Institute (PSI) has been at the centre of Tb-radioisotope research for over a decade. Through the PSI-ISOLDE collaboration, researchers collected and purified ^{149}Tb (α- and β^+-emitter, $T_{1/2}$ = 4.1 h), used for preclinical therapy studies and PET imaging, ^{152}Tb (β^+-emitter, $T_{1/2}$ = 17.5 h), for preclinical and clinical PET imaging and ^{155}Tb for preclinical SPECT imaging, respectively. The research facility has also been at the forefront of development of scandium radioisotopes, with accelerator development towards production of PET nuclides ^{44}Sc ($T_{1/2}$ = 4.04 h) and ^{43}Sc ($T_{1/2}$ = 3.89 h), respectively [2].

Description of the Work

Using high-energy protons to generate spallation reactions from tantalum targets, mass-separated beams of ^{149}Tb and ^{152}Tb, respectively, were implanted at ISOLDE-CERN into Zn-coated Au/Al/Ta foils. Significant activities were transported to PSI for processing.

PSI's IP2 irradiation station, which receives 72 MeV protons from the Injector II cyclotron, was utilized to produce ^{155}Tb using enriched $^{155/156}$Gd target material, as well as $^{43/44}$Sc by irradiating enriched ^{44}Ca target material [2].

At PSI, the chemical separation in question was performed using a separation system, specifically designed and built for the nuclide in question, and manipulators in a hot cell [3]. The target material containing the desired nuclide was dissolved in acid media and the dissolved nuclides loaded on to a resin column. Impurities were rinsed from the column and the desired nuclide eluted using dilute media. As an addition, the product eluent was passed through a second resin column to ensure concentration of the final product.

High production yields were achieved, and extensive preclinical data produced using $^{43/44}$Sc and $^{149/152/155}$Tb, respectively. As a result, first-in-human applications were achieved using ^{152}Tb and ^{44}Sc, respectively [1,2].

Conclusions

Due to interest in the Tb sisters and encouraging preclinical results, facilities such as TATTOOS (as part of the Swiss Large Facilities project IMPACT, to be constructed at PSI) are being built in Europe to address the means of producing $^{149/152/155}$Tb. Following the recent successful clinical application of reactor-produced ^{161}Tb radiopharmaceuticals in Swiss clinics, focus turns to the clinical translation of ^{44}Sc, as part of the EU IHI Thera4Care project.

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DEMONSTRATING THE RADIONUCLIDIC PURITY OF ACTINIUM-225 PRODCUDED FROM A RADIUM-225 GENERATOR

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Introduction

Actinium-225 from a variety of production methods is becoming more widely available. As more and diverse suppliers enter, or intend to enter, the Ac-225 active pharmaceutical ingredient (API) market, the greater the need for demonstrating adequate quantitation of radionuclidic impurities. Regulatory implications for Ac-227 in the USA include; a mandatory spill reporting limit of only 2 nCi, financial assurance requirements for possession over 10 µCi, and an annual limit on intake (ALI) of only 0.4 nCi (Shober, 2022). Some EU member countries have indicated that a separation factor of at least 10^8 (Ac-227 / Ac-225) may be required. Similarly stringent requirements also exist for a variety of other important potential impurities including; Ra-226, Po-210, and Th-229. The importance of individual patient dosimetry cannot be understated, and high-purity Ac-225 aids in these calculations. Standardization of certificates of analysis (CofA) within the industry may not be achievable, however, suppliers and customers can coalesce around the idea of demonstrating the highest possible standards for radionuclidic purity (RNP).

Description of the Work or Project

There are a variety of analytical methods that can be used to quantify radionuclidic impurities in an API, including; inductively coupled plasma mass spectroscopy (ICP-MS), alpha spectroscopy, and gamma-ray spectroscopy. All three techniques are required in order to adequately quantify the overall purity. Reporting radionuclidic purity results as a ratio of impurity activity to Ac-225 activity results in meaningful and easily scalable maximum impurity values. We have demonstrated that by ICP-MS, instrument limits of detection (LOD) of only a few pCi/mCi (mBq/MBq) are possible for both Ac-227 and Ra-226. Data from small scale production indicates that an API limit of ≤ 50 pCi/mCi (≤ 50 mBq/MBq) is easily achievable for both; demonstrating a separation factor of ~10^8 for these important impurities. Further, a relatively fast alpha spectroscopy method for quantifying Po-210 should yield an API limit of <100 pCi/mCi.

Conclusions

The analytical tools necessary to demonstrate the highest possible purity of Ac-225 products already exist. Though there is no USP or EP chapter governing Ac-225, a comprehensive CofA, including RNP results or limits for a variety of important radioactive impurities, will simplify dosimetry calculations and help ensure regulatory compliance.

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APHRODITE-155_Accelerator-based Production of tHeranostic radionuclides: Investigations on TErbium-155

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Introduction

The theranostic radionuclide ^{155}Tb, has attracted the attention of researchers in the field of radiopharmaceuticals for its potential as an Auger and conversion electron emitter, with gamma emission suitable for SPECT imaging. ^{155}Tb can be paired with other terbium isotopes to create emerging theranostic pairs and innovative tools in nuclear medicine for personalized oncology treatments. However, the production of significant quantities of ^{155}Tb is still an open challenge. The PNRR APHRODITE-155 project, funded by Italian Ministry of University and Research and European Union NextGenerationEU, was conceived to address this challenge.

Description of the Work or Project

The APHRODITE-155 project aims to evaluate the best production route for ^{155}Tb using cyclotrons, comparing low and medium energy pathways. The project evaluates the reactions ^{155}Gd(p,n)^{155}Tb (at low energy) and ^{159}Tb(p,5n)^{155}Dy→^{155}Tb (at medium energy) to determine the yields and isotopic and radiochemical purity of the final product. Both experimental and theoretical data are used to optimize ^{155}Tb production and to evaluate the dose contribution of any contaminating radionuclides.

The project, which involves the Italian National Institute for Nuclear Physics (INFN), the University of Ferrara, and the University of Milan, has already made significant progress. In particular, in the development of a protocol for target production by Spark Plasma Sintering, and in the radiochemical processes for Gd/Tb/Dy separation with extraction chromatograpy (mainly with LN and DGA resins). A key aspect of the project involves a comprehensive study using both experimental and theoretical computational approaches. We have performed theoretical calculations to optimize the production of ^{155}Tb and its radionuclidic purity. In parallel, dosimetric studies are being conducted to assess the potential radiotoxicity of the radionuclidic impurities, ensuring that the final product is safe for medical applications. Preliminary results of the project have been disseminated through open-access publications, highlighting the project's commitment to contributing to the broader scientific community.

Conclusions

The APHRODITE-155 project has made substantial progress in understanding and optimizing the production routes of ^{155}Tb. The developed methodologies have proven to be robust, and the integration of theoretical and experimental approaches continues to improve the reliability of the results. The final project outcomes, expected upon its conclusion, will include a comprehensive comparison between the two production routes, providing a clear framework for future clinical applications of ^{155}Tb and paving the way for subsequent in vitro and in vivo tests. The project is on track to complete all activities within the planned timeline, ending on early 2026.

GREEN & SUSTAINABLE APPROACHES TO ISOTOPE LABELLING

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Isotope labelling is expanding into diverse fields, driven by advances in labelling techniques and increasing demand across metabolomics, environmental sciences, forensics, and drug discovery. Emerging applications are also appearing in materials science and industrial process monitoring.

To align with the United Nations Sustainable Development Goals (SDGs) and global policy initiatives such as the European Green Deal, there is a pressing need for greener, more sustainable isotope labelling strategies. We outline recent chemical approaches designed to make labelling processes safer and more environmentally responsible, including methods developed within our research groups that minimize waste and reduce ecological impact.[1,2]

To move beyond "greenwashing" and rhetoric, we discuss quantitative metrics to evaluate sustainability in isotope labelling, including Deuterium Atom Efficiency[3] as well as Radiochemical and Deuterium Yields.[4] We also highlight established green chemistry scoring systems - such as CHEM21 and DOZN, that could be adapted to isotope labelling, along with the role of Life Cycle Assessment, which provides a holistic framework for assessing environmental impact and is relevant for process scale-up. Furthermore, we propose novel metrics tailored to isotope labelling, such as 'Real Labelling Atom Economy'.[5]

Finally, we outline future directions for the field, emphasizing solvent- and catalyst-free labelling methods and opportunities for reagent recycling, to advance truly sustainable isotope labelling practices.

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EFFICIENT SCREENING OF CATION EXCHANGE RESINS FOR RADIOLANTHANIDE SEPARATIONS

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Introduction

Radiolanthanides are increasingly vital in nuclear medicine due to their dual diagnostic and therapeutic capabilities. Their purification relies heavily on advanced separation techniques, with cation exchange chromatography being the most widely adopted method. However, the lack of resins specifically optimized for radiolanthanide separations presents a significant challenge.

Description of the Work or Project

This study introduces a rapid screening method for evaluating strong cation exchange resins based on polystyrene-divinylbenzene (PS-DVB) for radiolanthanide separations. Fourier Transform Infrared Spectroscopy (FTIR) was used to classify resins into four types (A–D) based on sulfonate functional group availability. Type A resins, characterized by strong sulfonate signals, demonstrated superior separation resolution for dysprosium, terbium, and gadolinium. Type B resins exhibited sulfone bridging, reducing sulfonate availability and separation efficiency. Types C and D showed minimal sulfonate content and poor analyte retention. Cross-linking density correlated with process time but not resolution. FTIR combined with bead size data enabled prediction of chromatographic performance, significantly reducing evaluation time, cost, and waste compared to traditional chromatography.

Conclusions

The study successfully developed a predictive method for assessing PS-DVB resin suitability for radiolanthanide separations. Sulfonate availability and bead size were identified as key factors influencing separation efficiency, while cross-linking affected process time. This approach offers a practical and efficient alternative to chromatographic evaluation, facilitating the selection of optimal resins for nuclear medicine applications.

Keywords

Cross-linking, FTIR characterization, TGA-MS, Lanthanide separation, Sulfonate availability, Ion exchange chromatography.

EFFICIENT SYNTHESIS OF [^{68}GA]GA-LABELED BIVALENT HER2 PEPTIDE PROBE ENABLED BY CBT/1,2-AMINOTHIOL BIOORTHOGONAL CLICK CHEMISTRY

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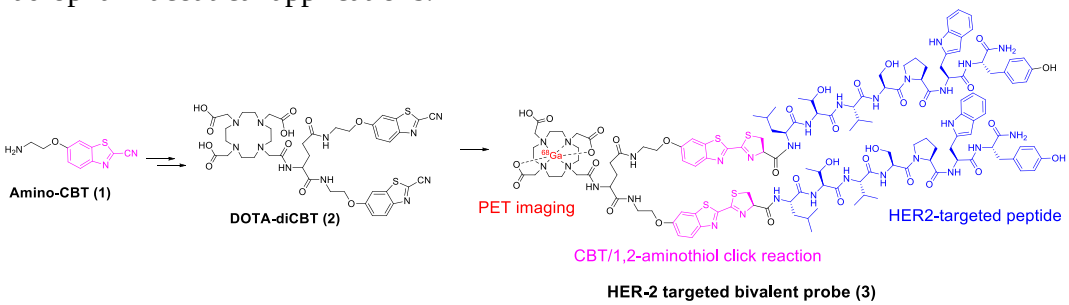
Introduction

Human epidermal growth factor receptor 2 (HER2) is a pivotal biomarker in breast cancer and an established target for positron emission tomography (PET) imaging. Bivalent HER2 probes offer enhanced binding avidity and improved imaging contrast; however, their synthesis remains challenging. Herein, we employed 2-cyanobenzothiazole (CBT)/1,2-aminothiol click chemistry to achieve rapid, metal-free construction of a bivalent HER2-targeted probe efficiently radiolabeled with ^{68}Ga, demonstrating its potential for PET imaging applications.

The Description of the Work and Results

The key reagent DOTA-diCBT (2) was synthesized from amino-CBT (**1**) via ANRORC cyclization followed by amide coupling with DOTA. The HER2-binding peptide **CLTVSPWY** was prepared by automated SPPS on Rink amide MBHA resin. Subsequent CBT/1,2-aminothiol click ligation between the peptide and **2** proceeded efficiently in aqueous acetonitrile/PBS (1:1, pH 7.0) at 37 °C, affording the bivalent precursor **3** in 49.5 % yield. HPLC and MALDI-TOF-MS confirmed its purity and identity ($[M + H]^+$ = 2837.3). Radiolabeling with ^{68}Ga under optimized conditions (1 M NH_4OAc, pH 4.0, 85 °C, 15 min) produced **[^{68}Ga]Ga-3** with 60 % yield and 98 % purity after C18 SPE cartridge purification. **[^{68}Ga]Ga-3** was stable in PBS and human serum for 4 h, demonstrating that the CBT/1,2-aminothiol ligation enables efficient probe construction and is well suited for radiopharmaceutical applications.



Conclusions

We herein demonstrate that the CBT/1,2-aminothiol click chemistry provides a rapid, metal-free, and regioselective approach for constructing bivalent HER2-targeted probes. The successful synthesis, radiolabeling, and stability of **[^{68}Ga]Ga-3** confirms its potential as a practical platform for developing PET imaging agents targeting HER2-positive breast cancer.

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INTEGRATING AI-DRIVEN TOOLS AND VIRTUAL LABORATORIES IN RADIOISOTOPE HANDLING TRAINING

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Introduction

The digital revolution in education is profoundly transforming teaching and professional training across all disciplines. Accelerated by the COVID-19 pandemic, this transformation extends learning beyond traditional classrooms through advanced technologies such as artificial intelligence (AI), simulation platforms, virtual reality (VR), and augmented reality (AR). These tools have established flexible, interactive, and globally accessible learning environments that redefine how knowledge is delivered and acquired.

Description of the Work

The accessibility of computer-based educational resources that operate on standard hardware—such as personal computers, tablets, or mobile devices—greatly expands learning opportunities by overcoming economic and geographical barriers. These tools enable personalized instruction, continuous assessment, and timely feedback, fostering self-paced learning in diverse contexts. However, immersive VR and AR technologies offer a substantially higher level of experiential engagement and realism. They allow learners to explore three-dimensional environments, visualize otherwise invisible processes, and perform virtual experiments under safe and controlled conditions. A notable example is the immersive laboratory simulation jointly developed by the Polytechnic of Milan and Leibniz University Hannover, which reproduces realistic scenarios for the safe handling of radioisotopes. In technical domains such as radiological protection and nuclear engineering, these high-fidelity virtual laboratories enable students to replicate complex experimental setups without exposure to hazardous materials, supporting risk-free, hands-on learning. International initiatives—such as the AIRP–EUTERP collaboration—illustrate how AI, VR, and AR can be combined into verified, multilingual training frameworks that advance a global culture of safety, innovation, and continuous professional development.

Conclusions

The ongoing digital transformation of education represents not only a technological advancement but also a cultural and pedagogical paradigm shift. It combines the accessibility of widely available computer-based learning tools with the immersive potential of VR and AR technologies. This hybrid approach ensures inclusivity, sustainability, and adaptability to diverse learning needs while maintaining ethical standards concerning data protection, transparency, and the evolving role of educators. Ultimately, the digital revolution in education fosters co-intelligence between humans and machines, enhancing critical thinking, creativity, and collaboration in line with the goals of the ICRP "Vancouver Call for Action".

Keywords: Digital Education and Training, Virtual and Augmented Reality, Radioisotope Handling and Safety

LINKEDIN AS THE NEW CLASSROOM: STORYTELLING AND AI FOR NUCLEAR COMMUNICATION

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Introduction

The perception of radiation and nuclear technologies remains shaped by emotional bias, cultural fear, and the misconception that "nuclear" equals "dangerous" or "impossible to understand." These barriers hinder both understanding and acceptance of isotope applications that are essential for healthcare and industry. Educational theory and cognitive science show that new knowledge integrates most effectively when it connects to existing neural and emotional frameworks. However, traditional teaching often fails to engage audiences outside academia. This work explores storytelling, AI-generated imagery, and professional social media (LinkedIn) as novel tools to enhance learning, curiosity, and societal acceptance of nuclear and isotope technologies. The approach specifically targets a social and professional audience often overlooked in traditional nuclear communication: well-educated, engaged individuals who, while not experts in radiation or nuclear physics, are active on LinkedIn, a platform traditionally used for professional networking, and who can influence opinions, organizational priorities, and decision-making within industry, policy, and healthcare.

Description of the Work or Project

Drawing on experience from science communication activities conducted on LinkedIn between 2022 and 2025, this study analyzes how narrative-driven content can transform public and professional engagement with radiation and isotope topics. Posts combined scientific accuracy with accessible storytelling, humor, and AI-assisted visuals to explain complex subjects through familiar contexts. Examples include *"Spicy or Radioactive: K-40 in Table Salt,"* aimed at normalizing discourse on radiation and isotopes to overcome fear, rejection, and the assumption that these topics are not digestible; *"The Cat in the Scanner"* and *"The Orlando Airport Case,"* which serve as starting points for discussions where concepts of dose, radioactive decay, use of radiation, and public impact are conveyed through relatable stories; and *"The Iridium-192 Story: From Stardust to Dinosaur Extinction,"* linking stellar nucleosynthesis with manmade isotope production. The presentation draws on both personal experience and an analysis of other science communicators active on the LinkedIn platform to identify common patterns of curiosity, misconception, and engagement across audiences.

Conclusions

Storytelling and visual communication on professional social media platforms offer a powerful means to expand understanding, generate support for nuclear technologies, including the use of radioisotopes, and inform key opinion leaders. Cognitive and emotional accessibility are essential drivers for both learning and trust-building in the nuclear field. These approaches bridge the gap between scientific expertise and societal understanding, helping to normalize radiation as a fact of modern life. They also strengthen the business ecosystem of isotope production and application by fostering acceptance and awareness among policymakers, healthcare professionals, and the public. By integrating principles from cognitive science, educational psychology, and AI-assisted creativity, this work demonstrates that effective education is not confined to classrooms, it occurs wherever curiosity meets credibility.

INFN TRAINING AND EDUCATIONAL ACTIVITIES ON RADIATION PROTECTION AND IONIZING RADIATION

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Introduction

The growing awareness of radiological safety and the implementation of the Italian Legislative Decree D.Lgs. 101/2020 have strengthened the need for structured education on ionizing radiation (IR) and radiation protection. The National Institute for Nuclear Physics (INFN) promotes educational and outreach initiatives across Italy to provide students with reliable scientific knowledge and to foster critical understanding of radiation use in science, technology, and healthcare.

Description of the Project

The **RadioLab project** [1, 2], active since 2004, involves more than ten INFN Sections and university departments in hands-on educational pathways on natural and artificial radioactivity. Students perform experimental measurements, especially of environmental and indoor radon, analyze data, and reflect on the connections between science, health, and regulation. The laboratory thus becomes an active learning tool that integrates scientific knowledge with citizenship education and risk awareness.

The experience has been extended internationally, with activities in **Albania** [3], **Ecuador**, and **Slovakia**, and further developed through **ISOradioLab** [4], an initiative bringing radiation monitoring and educational programs to geographically sensitive areas such as the **Italian minor islands**. Summer and spring thematic schools are organized within the project.

In parallel, INFN coordinates the **International Particle Therapy Masterclass (PTMC)** [5], within the **IPPOG** framework. This project introduces high-school students to the medical applications of IR, particularly medical physics and hadrontherapy, through interactive lectures and treatment-planning simulations.

Conclusions

These coordinated efforts build a sustainable framework for education and outreach in radiation science. Through **RadioLab**, **ISOradioLab**, and the **PTMC**, INFN promotes a scientifically grounded culture of safety and awareness, engaging students in authentic scientific practices and inspiring future careers in physics, medicine, and radiation protection.

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Poster Abstracts

Poster Session 1

INNOVATIVE ELECTROCHEMICAL SEPARATION OF RU-106: ADVANCING PURITY FOR OPHTHALMIC APPLICATIONS

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Introduction

Ruthenium-106 (^{106}Ru) is essential for ophthalmic brachytherapy, but its isolation from fission products is challenging. Both electrochemical (direct/catalytic extraction, redox mediation, electrooxidation) and non-electrochemical (solvent extraction, chemical volatilization) separation methods have been reported. Electrochemical approaches, particularly electrooxidation, offer selective, salt-free recovery [1–3].

Description of the Work or Project

Electrooxidation—anodic conversion of Ruthenium to volatile RuO_4—has yielded up to 95% recovery from pure solutions and 54% from simulated waste (Swain et al.). Building on this, we applied a **novel pulsed potential electrooxidation process**. In this method, short (millisecond) pulses were applied to a cylindrical platinum coated anode that allow for enhanced mass transport, minimized side reactions (by kinetic suppression of oxygen evolution reaction), reduced electrode fouling and optimized RuO_4 volatilization. Using programmed potential pulses on synthetic matrices, we increased Ru-106 volatilization and reduced fission product interference compared to previous constant-potential systems.

Result

Ru-106 recovery from pure and simulated waste: 98 and 67%, respectively".
Total separation time: 2h.
Product purity: >99%", suitable for medical use.

Table. 1 a comparison between the formerly reported electro oxidation method with this study

Sample Type	Swain et al. (%)	This Study (%)
Simulated HLW	54	67
Extraction time (h)	10	2

Conclusions

Pulse potential electrooxidation surpasses previous electrochemical Ru-106 separations in yield, time, selectivity, and purity. This advancement supports reliable, safe production of Ru-106 for ophthalmic brachytherapy and improves nuclear waste management.

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ESTABLISHMENT OF ASTATINE-211 PRODUCTION AND PURIFICATION PLATFORM AT KIRAMS

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Introduction

Alpha-emitting radionuclides offer potent, localized cytotoxicity through irreparable DNA double-strand breaks, making them promise for targeted radiotherapy. Astatine-211 (^{211}At) combines suitable decay properties with a short path length, enabling selective tumor eradication. Its use, however, is constrained by limited production sites, short half-life (7.2 h), and need for ~28 MeV alpha-particle irradiation. Since 2021, Korea Institute of Radiological and Medical Sciences (KIRAMS) has produced ^{211}At, with purification playing a key role in removing target impurities, ensuring high radiolabeling efficiency, and meeting radiopharmaceutical quality standards. This work summarizes our experience in ^{211}At production, purification.

Methods

^{211}At was produced by α-particle irradiation of ^{209}Bi targets (29 MeV, 75–115 μA·h). Irradiated bismuth was powdered to increase surface area and dissolved in concentrated HNO_3. The solution was evaporated to dryness, and the white residue was re-dissolved in 8 N HCl. ^{211}At was extracted into diisopropyl ether (DIPE) and the organic phase was washed with 1 N HCl to remove residual metal impurities. DIPE was then evaporated under reduced pressure, with condensation aiding the transfer of ^{211}At into 4 N NaOH. The alkaline solution was subsequently adjusted to pH 5-6 with acid to yield a chemically pure, labeling-ready ^{211}At solution. Radionuclidic identity and residual metal content were confirmed by high-purity germanium radiation detector and inductively coupled plasma mass spectrometry, respectively.

Results

In recent irradiations (n=7), the wet-extraction process consistently yielded 454.4–816.5 MBq of ^{211}At in solution at pH 5–6, demonstrating the reliability of the established protocol. The purified product exhibited characteristic gamma emissions at 76.9, 79.3, 89.8, and 687.0 keV, confirming radionuclidic identity. Residual metallic impurities were minimal, with bismuth and aluminum levels of 2.8±0.9 ppm and 0.4±0.6 ppm, respectively, meeting radiopharmaceutical quality standards.

Conclusions

This purification not only removes target-derived contaminants but also ensures high radiochemical purity, stability, and labeling efficiency for downstream radiopharmaceutical applications. These results validate the KIRAMS wet-extraction method as an effective approach for producing high-purity ^{211}At suitable for downstream radiolabeling and targeted alpha therapy applications.

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Acknowledgments

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AN AUTOMATED SEPARATION METHOD FOR ISOLATING ZIRCONIUM-89 FROM NIOBIUM-BACKED YTTRIUM TARGETS

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Introduction

The Fedoruk Centre regularly produces zirconium-89 (^{89}Zr) for researchers for applications in positron emission tomography/computed tomography (PET/CT) imaging. Hydroxamate resins are commonly used to separate yttrium target material from ^{89}Zr.[1] However, niobium is not readily removed by these resins when eluting ^{89}Zr in the desired formulation. Previous research[2] suggests that the TRU resin is a candidate for Zr/Nb separation. This work aimed to develop an automated ^{89}Zr purification method that removes niobium.

Description of the Work or Project

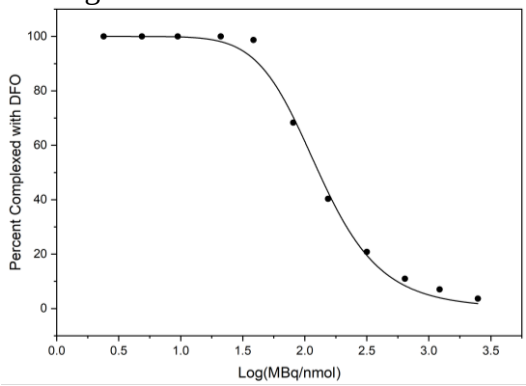
^{89}Zr was produced by irradiation of yttrium-sputtered niobium coins via the ^{89}Y(p,n)^{89}Zr reaction on a TR-24 cyclotron. The coin was bombarded with an incident beam energy of 18 MeV, degraded to ~12.7 MeV, for 5 minutes at 10 µA and for > 2 hours at 40 uA for small and large-activity tests, respectively. A miniAllinOne synthesizer (TRASIS) was used with the TRU (Eichrom Technologies Inc.) and ZR (TrisKem International) resin cartridges for the purification of ^{89}Zr. Target dissolution in 9 M HCl was followed by loading onto the TRU resin. ^{89}Zr was eluted from the TRU resin in 3 M HCl and loaded directly onto the ZR resin. Following H_2O rinses, ^{89}Zr-oxalate was eluted from the ZR resin in 1 M oxalic acid.

Table 1: ICP-MS Analysis.

Resins Used	Y (ppm)	Nb (ppm)	W (ppm)	Ta (ppm)
ZR	< 0.5 - 1	71.8 - 212	14.6 - 38.1	0.72 - 1.4
TRU and ZR	0.4	3	2	0.06

Metal impurities identified in the ZR method were reduced with the addition of the TRU resin (Table 1). A ^{89}Zr effective specific activity of 130 MBq/nmol was determined via deferoxamine mesylate salt (DFO) titration per Figure 1.

Figure 1: ^{89}Zr-DFO Titration



Conclusions

The TRU resin reduces the concentration of impurities in the ^{89}Zr-oxalate product produced from Nb-backed Y coins, while maintaining an effective specific activity of 130 MBq/nmol.

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Keywords: Zirconium-89, automation, radiolabelling, radiometal

DESIGN AND FEASIBILITY STUDY FOR THE LARGE-SCALE PRODUCTION OF ^{67}CU USING A HIGH-POWER LINAC ELECTRON BEAM

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Introduction

^{67}Cu is a β^- emitting radionuclide with strong theranostic potential, combining therapeutic and imaging capabilities for targeted endoradiotherapy. With anticipated FDA and EMA approval for clinical use, scalable production methods will be required to meet the growing demand[1-4]. This work investigates the feasibility of producing ^{67}Cu using the ^{68}Zn(γ,p)^{67}Cu photonuclear reaction, initiated by a high-power linear electron accelerator (LINAC) and an optimized electron-to-gamma converter.

Facility and Beam Parameters:

The proposed accelerator is designed to operate at a beam power of 100 kW. An electron energy of 50 MeV corresponds to a beam current of 2 mA. The beam structure for this work will operate in a pulsed mode with 10 µs pulse width and 800 Hz repetition rate.

Converter and Target Design:

Electrons will be converted to high-energy photons using a tantalum converter. Heat deposition and dissipation during converter irradiation were analyzed in detail.

The converter geometry dimensions are 2 × 2 cm^2 with a total thickness of 3.5 mm. The converter holder materials according to initial planning will be stainless steel at the back and sides of the converter and beryllium plate facing the electron beam. The target is designed to be enriched ^{68}Zn (solid or molten or aqueous solution states are being considered). Monte Carlo simulations (MCNP) were performed to optimize converter thickness (photon yield vs. electron stopping power) and to compute spatial maps of volumetric heat deposition (W/cm^3) within both converter and target assemblies. COMSOL Multiphysics simulations were performed to determine steady-state and transient temperature fields in the converter and target under pulsed beam heating and to evaluate peak temperatures during pulses and the recovery between pulses. Our simulation results indicate that a compact converter can produce several hundred GBq of ^{67}Cu per week. Thermal loads in the converter are within manageable limits with the proposed cooling design. Zinc solution concept offers trade-offs between yield and continuous production capability.

Conclusions

This study demonstrates the technical feasibility of large-scale ^{67}Cu production using a high-power LINAC and optimized converter-target assembly. The proposed system can meet significant material portions expected in clinical demand, with both solid-target and dissolved target designs offering viable production pathways.

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PRODUCTION OF PB-203 AT GIP ARRONAX

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Lead-212 ($T_{1/2}$ = 10.6 h) and lead-203 ($T_{1/2}$ = 51.9 h) can be used as a theranostic pair of isotopes for applications in nuclear medicine. ^{212}Pb is used for α-targeted therapy, while its counterpart ^{203}Pb is suitable for SPECT imaging thanks to its 279.2 keV (80.9%) γ-emission. Currently, ^{203}Pb is produced by irradiating natural Tl, Tl-203 and Tl-205 targets, with protons. In this work, we investigate an alternative production route using ^{205}Tl irradiated with deuterons at GIP Arronax [1] [2].

To prepare enriched Tl-205 targets, we employed an electrodeposition technique using pulse-reverse current onto a gold substrate. Deposition was carried out at 25°C and pH 8, using EDTA as a complexing agent, hydrazine to prevent oxidation, and Brig-35 as a surfactant. A uniform 40 µm deposit with good adhesion was obtained [3]. Separation of Tl and Pb was achieved using Triskem's Pb resin, yielding high-purity Pb-203 in 1 M ammonium acetate solution (pH 5).

Since September 2023, monthly production has been scaled up by increasing the beam intensity (from 50 µA to 70 µA) and irradiation time (from 1 h to 10 h). At Calibration Time (CT, 2 days post-EOB), the radionuclidic purity of Pb-203 exceeded 99.3%, with all impurities below the γ-spectrometry detection limit, except for Pb-201 (< 0.7%). Up to 15 GBq of Pb-203 was obtained at CT. Pb recovery averaged 81 ± 4%, while metallic impurities (Tl, Fe, Ni, Zn, Cu, Hg, and Au) remained below detection limits. Tl recovery consistently exceeded 90%, enabling recycling.

These results demonstrate the feasibility of large-scale production of high-purity Pb-203. Further technical details will be presented in the poster.

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CHARACTERIZATION OF EXTRACTION CHROMATOGRAPHIC RESINS BASED ON MONOAMIDE EXTRACTANTS FOR THE SEPARATION OF TRANSITION AND POST-TRANSITION METAL IONS

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Introduction

Many radionuclides of the transition and post-transition elements show promise in nuclear medicine imaging and therapy. Monoamide extractants have been studied in solvent extraction processes for the processing of spent nuclear fuel but also exhibit interesting selectivity from hydrochloric acid for important target/product pairs of transition and post transition metal ions. Chromatographic techniques using extraction chromatographic (EXC) materials are commonly used to efficiently separate metal ions from complex mixtures.

Description of the Work or Project

Extraction chromatography resins produced with monoamides Di-(2-ethylhexyl)butyramide (DEHBA) and Di-(2-ethylhexyl)isobutyramide (DEHiBA) were studied in batch contact methods for the extraction of selected transition and post-transition metals from hydrochloric and nitric acid. From nitric acid, there was little extraction. However, from hydrochloric acid, the EXC resins exhibited selectivity that allows for the efficient separation of indium from cadmium, gallium from zinc, and mercury from gold. Based on the batch retention data, chromatographic separation methods for the separation of ^{111}In from simulated cadmium targets, ^{67}Ga from simulated zinc targets, and ^{197m}Hg from gold targets were developed. The methods allow for high yields of the target radionuclides while also removing the target material and common metal ion impurities and byproducts.

Conclusions

EXC resins based on the extractants DEHBA and DEHiBA were characterized and chromatographic methods for the purification of ^{111}In from cadmium, ^{67}Ga from zinc, and ^{197m}Hg from gold targets were developed. The methods produce high purity indium, gallium, and mercury in >95% yield, recovering the product radionuclides in a small volume of dilute HCl or acetate buffer.

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CHROMATOGRAPHIC SEPARATION OF COPPER FROM SIMULATED ZINC AND NICKEL TARGETS

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Introduction

Copper-64 and Copper-67 radionuclides form a perfect theranostic pair that can be used to image and treat cancer and other disease. ^{64}Cu and ^{67}Cu are commonly produced, respectively, by irradiation of zinc or nickel targets. Chromatographic techniques using ion exchange and extraction chromatographic (EXC) materials are commonly used to efficiently separate metal ions from complex mixtures. EXC materials containing oxime, amide, and amine extractants have been shown to exhibit selectivity for copper over nickel, zinc, and other metal ions that may be present as impurities in target materials or as byproducts from target irradiation.

Description of the Work or Project

EXC resins produced with *N,N,N',N'*-tetraoctyl-3,6-dioxaoctane diamide (DOODA), tertiary amine, and aldoxime extractants and silica stationary phases with strong cation exchange (SCX) and weak cation exchange (CM) functional groups were evaluated in batch contact experiments for the retention Cu, Zn, Ni and other main group and transitional metal ions from hydrochloric, nitric, and sulfuric acid. Based on batch retention data, column chromatographic methods for the separation of copper from simulated zinc and nickel targets were developed to obtain high purity copper in small volumes of dilute hydrochloric acid or acetate buffer.

Conclusions

Each chromatographic material exhibited strengths and weaknesses in the separation of Cu from target material and impurities. Options for separation methods will be provided to help maximize Cu yield and purity from both zinc and nickel targets.

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CHROMATOGRAPHIC SEPARATION OF MANGANESE FROM SIMULATED CHROMIUM TARGETS

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Introduction

Manganese-52 is a promising positron emitting radionuclide with a half-life of 5.592 days produced via proton irradiation of chromium targets. Chromatographic techniques using ion exchange and extraction chromatographic (EXC) materials are commonly used to efficiently separate metal ions from complex mixtures. An EXC resin produced with the *N,N,N',N'*-tetraoctyl-3,6-dioxaoctane diamide (DOODA) extractant exhibits high selectivity for manganese over chromium and other transition metal ions that may be present as impurities in target material or as byproducts from proton irradiation.

Description of the Work or Project

The DOODA EXC resin was characterized via batch contact experiments from nitric and hydrochloric acids to determine the retention of selected metal ions, including Mn, Cr, and selected main group, transition, rare earth and actinides. Based on the batch retention data, a column chromatographic method was developed to separate Manganese(II) from chromium and other transition metals and main group metals that may be present as impurities in chromium targets or as byproducts from the proton irradiation of chromium. From nitric acid or mixtures of nitric and hydrochloric acid, manganese is efficiently retained and separated from chromium and all other common impurities on the DOODA resin. The manganese can then be recovered in dilute HCl, HNO_3 or acetate buffer and further purified on columns of weak cation exchange (CM) or strong cation exchange (SCX) silica stationary phases.

Conclusions

A chromatographic separation method for the purification of Mn from simulated chromium target material has been developed. The method produces manganese in a high yield (>95%) and purity and may be used to efficiently separate manganese from hundreds of milligrams to grams of chromium target material.

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A SIMPLE TOOL FOR PHOTONUCLEAR ACTIVATION CALCULATION

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Introduction

The beta emitters ^{67}Cu and ^{47}Sc are promising radionuclides for cancer treatment due to decay properties similar to ^{177}Lu and convenient half-lives. ^{67}Cu and ^{47}Sc can be produced by the photonuclear reactions ^{68}Zn(γ,p) and ^{48}Ti(γ,p), respectively. An industrial scale production (i.e. annual production in the tens of TBq / 1 kCi range) of these radionuclides in a bremsstrahlung field of a 40 MeV to 50 MeV electron accelerator is investigated in the scope of a research project. First investigations comprise radiation transport calculations and modelling of the heat transfer of the bremsstrahlung converter but also yield calculations for both the radionuclides of interest and undesired by-products.

Description of the code

A code for the calculation of activities induced by photonuclear reactions is under development. It solves the Bateman equations[1] by numerical integration in small time steps and currently includes a limited number of isotopes. The implementation is derived from a custom-made code for neutron-induced activity calculation developed in the scope of a decommissioning project[2]. The code was originally developed for the analysis of yield measurements for medical radioisotopes. However, it will also be beneficial for the preliminary estimation of the photonuclear activation of bremsstrahlung converter and structural materials. A variety of input data (initial atom densities, reaction rates, power level per time step) are required. Final atom densities and specific activities are output.

Conclusions

As shown in Figure 1, the increase of the ^{65}Zn ($T_{1/2}$ = 244 d) activity after repeated use of an enriched ^{68}Zn sample (for comparison: the limit of unrestricted exemption is 0.1 Bq g^{-1}) is calculated. A negligible change of the isotopic ratio due to ^{68}Zn(γ,*x*n) reactions could be confirmed. Calculated activities, however, strongly rely on the quality of the cross section data of the photonuclear reaction libraries.

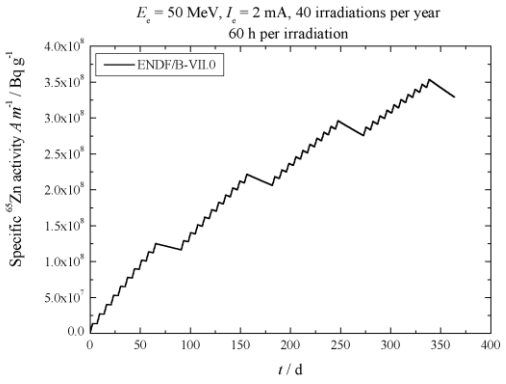

Figure 1: Activity evolution of ^{65}Zn

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Review of a Heat Transfer-Based Evaluation Framework for Isotope Target Integrity in a CANDU Reactor

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Introduction

The increasing global demand for medical isotopes has highlighted the potential of heavy-water moderated reactors, particularly CANDU reactors, as reliable production platforms. Their high neutron flux environment provides favorable conditions for isotope generation; however, the same conditions also impose significant thermal loads on irradiated targets. Excessive heat accumulation within the target assembly may compromise its structural integrity, potentially leading to target failure, radioactive material release, contamination of reactor systems, and unplanned shutdowns. Consequently, a systematic evaluation framework that ensures target integrity under irradiation is essential for both safety assurance and regulatory compliance.

Description of the Work or Project

This study reviews a heat transfer–based evaluation framework for assessing the integrity of isotope production targets in CANDU reactors. The framework emphasizes the multilayer thermal pathway of the target, considering conduction through encapsulating structures, convection via carrier gases, and heat removal through reactor coolant interfaces. Analytical methods were applied to evaluate steady-state temperature distributions, thermal gradients, and safety margins against critical material property thresholds, including melting point, thermal fatigue, and creep limits. The framework further addresses uncertainties in thermal conductivity, coolant flow rates, and irradiation-induced property changes, enabling robust sensitivity analysis.

In addition, the evaluation integrates practical reactor conditions such as coolant channel geometries, operating pressure–temperature regimes, and irradiation durations specific to medical isotope production campaigns. By combining analytical modeling with conservative safety factors, the framework establishes quantitative metrics for acceptable thermal performance. This systematic approach also provides design feedback for optimizing target geometry, cladding thickness, and material selection to enhance both thermal efficiency and mechanical resilience.

Conclusions

The proposed heat transfer–based evaluation framework offers a fundamental basis for ensuring the structural integrity of isotope production targets under irradiation in heavy-water reactors. It supports not only safe operation by preventing overheating and structural degradation but also contributes to efficient target design and long-term licensing processes. Ultimately, this framework strengthens the safety case for isotope production in CANDU reactors and serves as a reference methodology for future target development, regulatory assessments, and international collaboration in medical isotope supply chains.

A DEEP ANALYSIS OF GD2O3 TARGETS FOR 155TB PRODUCTION WITH MEDICAL CYLOTRONS

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Introduction

Terbium quadruplets have gained a lot of interest in recent years since they possess all the possible tools for nuclear medicine [1]. Our work focused on ^{155}Tb, suitable for SPECT (Single Photon Emission Computed Tomography) imaging and potential therapy thanks to its Auger and conversion electron emission.
In the framework of the project APHRODITE-155 (Accelerator-based Production of tHeranostic radionuclides: Investigations on TErbium-155) PRIN PNRR 2023-2025 [2] we have developed a technology for Gd_2O_3 target manufacture to be used for Tb-155 production through the ^{155}Gd(p,n)^{155}Tb reaction route using the medical cyclotron at the IRCCS Sacro Cuore Don Calabria Hospital (SCDCH, Negrar di Valpolicella, VR, Italy).

Description of the Work or Project

In this work, the Spark Plasma Sintering (SPS) technique was used to manufacture Gd_2O_3 pellets and targets. Different sintering temperatures and configurations were tested to optimise the process using nat-Gd_2O_3. The final target is composed of Nb backing (disk of Ø 23.5 mm, purity 99.9%), Pt foil (thickness 25 µm, purity 99.99+ %), and Gd_2O_3 sintered pellet starting from powder (particle size < 5 µm). Scanning electron microscopy (SEM), energy-dispersive spectroscopy (EDS) and X-ray diffraction (XRD) techniques were used to analyse powder sizes and shapes, pellets, and target microstructure. The irradiation was performed using the proton beam of the ACSI TR19 cyclotron available at IRCCS SCDCH. The manufactured nat-Gd_2O_3 target (105 mg/cm^2) exhibits high resistance under irradiation, with no signs of damage or detachment observed.

Conclusions

This work demonstrated the feasibility of $^{155}Gd_2O_3$ coin-shaped target manufacturing using the novel SPS technique. The manufacturing protocol for producing ^{155}Tb using a low-energy proton beam has been established and optimized, ensuring the mechanical integrity of the target and minimizing the loss of the expensive material. A tailored recovery process is under development to sustain the eventual production with the enriched material.

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THERANOSTIC POTENTIAL OF [^{64}Cu]$CuCl_2$ TO OVERCOME CANCER HETEROGENEITY

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Introduction

Intrinsic genetic instability and the heterogeneity of malignant cell populations present significant clinical hurdles in oncology, frequently diminishing the effectiveness of conventional receptor-targeted and antigen-based therapies. To address these challenges, Copper-64 chloride ([^{64}Cu]$CuCl_2$) has emerged as a highly promising theranostic agent. Its unique radiophysical properties offer a dual capability for both diagnostic PET imaging, through its positron (β^+) emissions, and therapeutic intervention via cytotoxic negative beta particles (β^-) and Auger electrons, which are particularly potent due to their low energy, high linear energy transfer (LET), and extremely limited tissue penetration (< 1 μm). This makes them highly effective for causing irreversible DNA damage when the radionuclide is precisely targeted to the cell nucleus. ^{64}Cu is unique in its ionic form, which allows it to reach the proximity of DNA to induce damage. The biological rationale for its use is based on the altered copper metabolism in tumor cells, where cancer cells exhibit an increased demand for copper to support rapid proliferation and metastasis. This study aims to provide a comprehensive *in vitro* analysis of the interactions of [^{64}Cu]$CuCl_2$ with human cancer cells to deepen the preclinical understanding of its therapeutic potential.

Description of the Work or Project

The study was conducted using two human tumor cell lines, breast adenocarcinoma (MDA-MB-231) and gastric carcinoma (NCI-N87), and a healthy control line, normal human fetal lung fibroblasts (IMR-90). Cells were exposed to increasing activities of [^{64}Cu]$CuCl_2$ (10, 100, and 250 μCi/mL). Cellular and subcellular uptake, cell viability, and apoptosis induction have been evaluated. Our findings demonstrate a significant differential response between malignant and healthy cells. Tumor cell lines showed significantly higher [^{64}Cu]$CuCl_2$ uptake compared to the healthy IMR-90 controls. The MDA-MB-231 breast cancer line, in particular, exhibited the greatest dose-dependent intracellular uptake, with a marked accumulation of ^{64}Cu in the nuclear compartment. Treatment with [^{64}Cu]$CuCl_2$ selectively and effectively induced apoptosis in both cancer cell lines in a dose-dependent manner. After 120 hours at 100 μCi/mL, apoptosis increased by nearly 100% in MDA-MB-231 cells and 58% in NCI-N87 cells, compared to just 15% in the healthy IMR-90 fibroblasts.

Conclusions

This study confirms that [^{64}Cu]$CuCl_2$ exhibits high selectivity for cancer cells, characterized by preferential intracellular uptake, significant nuclear localization, and the effective induction of apoptosis, while having minimal cytotoxic effects on healthy cells. These findings position [^{64}Cu]$CuCl_2$ as a promising theranostic candidate for developing targeted therapeutic strategies in oncology, offering a powerful tool to overcome the challenges posed by tumor heterogeneity.

DOSIMETRIC EVALUATION OF ^{32}P RADIONUCLIDE THERAPY USING SILICA MICROPARTICLE CARRIERS

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Introduction

Phosphorus-32 (^{32}P) is a pure beta-emitter with favorable physical properties for intratumoral radionuclide therapy (Ross et al., 2022). To improve its therapeutic application, silica microparticles (SMPs) have been explored as carriers. While biological studies provide valuable insights, combining them with computational dosimetry enables a more complete understanding of how such systems influence dose distribution and therapeutic effect (El Hajj et al., 2024).

Description of the Work or Project

SMPs were synthesized, radiolabeled with ^{32}P, and evaluated through preclinical studies. In vitro assays with CT26 colon carcinoma cells—including uptake analysis, CCK-8 viability, and clonogenic survival—were used to assess cellular interaction and radiation effects, while in vivo experiments with Balb/c nude mice provided biodistribution data after intratumoral administration. Such assays are recognized benchmarks in radiobiology for quantifying radiosensitivity. These datasets served as input for Geant4-based Monte Carlo simulations, which generated three-dimensional dose maps and dose-volume histograms. The simulations provided a basis for correlation between absorbed dose and biological impact, and the dose profile from ^{32}P radionuclide therapy.

Conclusions

This integrated experimental–computational approach highlights the potential of silica microparticle carriers to improve localized delivery of ^{32}P. Monte Carlo dosimetry offered detailed insight into spatial dose deposition, complementing preclinical data and guiding the optimization of particle-assisted radionuclide therapy.

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RADIOLABELING OF GOLD NANOPARTICLES WITH ^{44}SC FOR PET DIAGNOSIS OF CANCER

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Introduction

Gold nanoparticles (AuNPs) have been widely used over the last decades in cancer diagnosis and therapy due to their unique physicochemical characteristics, ease of surface functionalization with different chemical groups, low toxicity and biocompatibility both *in vitro* and *in vivo*. On the other hand, Scandium-44 (^{44}Sc) is a positron emitting radioisotope with a suitable half-life (4.04 h), which makes it an excellent candidate for PET imaging. The aim of our study was to radiolabel AuNPs with and without a PSMA-targeting molecule with ^{44}Sc. The radiolabeling process was achieved through functionalization of the AuNPs with a TADOTAGA chelator containing a thiol group that forms very strong Au-S bonds.

Description of the Work

AuNPs with TADOTAGA (AuNPs@TADOTAGA) and AuNPs with TADOTAGA also containing the PSMA-targeting molecule (AuNPs@TADOTAGA@PSMA) were added to trace-free Sodium Acetate buffer 0.2 M (pH 5.6). Then, 10 kBq of $^{44}ScCl_3$ were added and the mixture was incubated at 70°C for 40 min. The reaction mixture was cooled to RT, and the percentage of ^{44}Sc incorporated onto the NPs was determined by instant thin-layer chromatography (ITLC). *In vitro* stability studies were also carried out for both radiolabeled AuNPs in PBS (pH 7.4) at RT and in Human Serum at 37 ºC, for up to 24 h.
The nanoparticles were radiolabeled after 40 min incubation at 70°C. Radiochemical yield was assessed by ITLC and was found to be 100% for both nanoconstructs. Both [^{44}Sc]Sc-AuNPs@TADOTAGA and [^{44}Sc]Sc-AuNPs@TADOTAGA@PSMA demonstrated unique *in vitro* stability in PBS at RT and in Human Serum at 37 ºC for up to 24 h, as evaluated by TLC analysis.

Conclusions

Radiolabeling of both AuNPs with the positron emitter ^{44}Sc was robust, leading to stable radiolabeled nanoconstructs. Based on these preliminary results, we conclude that both nanocomplexes should be further investigated in athymic mice bearing LNCaP tumor xenografts to evaluate their potential for tumor accumulation, both with and without targeting.

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FUNDAMENTAL RESEARCH ON THE PRODUCTION OF MEDICAL RADIOISOTOPES (Tb-161, Lu-177) USING JRR-3

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Introduction

Radioisotopes are widely utilized in Japan as diagnostic and therapeutic agents. However, Japan relies on imports for key nuclides such as Molybdenum-99 (Mo-99), which are produced in nuclear reactors overseas. This reliance raises concern that international circumstances could disrupt domestic supply and impede drug development. Therefore, JAEA has undertaken radioisotope production trials using the JRR-3 reactor, which resumed operation at the end of February 2021. Among these efforts, particular focuses are made on production trials for Lu-177 and Tb-161, as detailed below.

Description of the Work

For the Lu-177 production test at JRR-3, [^{176}Lu] Lu_2O_3 (enriched to 64.3%) for the direct method and [^{176}Yb] Yb_2O_3 (enriched to 99.9%) for the indirect method was used as the irradiation target. [^{160}Gd] Gd_2O_3 (enriched to 98.2%) was used for the Tb-161 production.
Solutions of the target materials (1 M HNO_3) were weighed and dispensed into quartz ampoules to have an irradiation target element of approximately 0.1 mg. The solutions were then evaporated to dryness and sealed to prepare the irradiation samples. These samples were placed in irradiation capsules, pressure welded and irradiated in HR-1, which is neutron irradiation facility in heavy water tank of JRR-3.
The result shows that about 400 GBq of Lu-177 can be produced by irradiating 1 mg of Lu in HR-1 for 14 days. However, since the specific activity is lower than that of Lu-177 distributed in Japan it is difficult to immediately use the current product as a pharmaceutical raw material, but it was confirmed that JRR-3 can produce radioisotopes of sufficient quantity and quality for testing such as labeling tests and non-clinical studies. Similarly, the result shows that approximately 500 MBq of Lu-177 (3 day after EOB) was produced by irradiating 1 mg of Yb for 14 days and approximately 250 MBq of Tb-161 (1 day after EOB) was produced by irradiating 1 mg of Gd for 7 days, suggesting that irradiation of a few grams of Yb or Gd could generally meet the domestic demand. Due to the high cost of the enriched target, re-irradiation of the recovered targets is necessary. We are also planning research and development to improve a column chromatographic separation process for the target radioisotope.

Conclusions

As mentioned above, trial irradiations for Lu-177 and Tb-161 have confirmed the producing capability of JRR-3. Several issues were identified including specific activity and the need for re-irradiation. Moving forward, we plan to investigate these issues. Beyond the specific nuclides mentioned above, we'll advance the development of production and separation processes for broad range of radioisotopes to meet domestic demand.

DOSIMETRIC EVALUATION OF ^{32}P RADIONUCLIDE THERAPY USING SILICA MICROPARTICLE CARRIERS

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Introduction

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Description of the Work or Project

SMPs were synthesized, radiolabeled with ^{32}P, and evaluated through preclinical studies. In vitro assays with CT26 colon carcinoma cells—including uptake analysis, CCK-8 viability, and clonogenic survival—were used to assess cellular interaction and radiation effects, while in vivo experiments with Balb/c nude mice provided biodistribution data after intratumoral administration. Such assays are recognized benchmarks in radiobiology for quantifying radiosensitivity. These datasets served as input for Geant4-based Monte Carlo simulations, which generated three-dimensional dose maps and dose-volume histograms. The simulations provided a basis for correlation between absorbed dose and biological impact, and the dose profile from ^{32}P radionuclide therapy.

Conclusions

This integrated experimental–computational approach highlights the potential of silica microparticle carriers to improve localized delivery of ^{32}P. Monte Carlo dosimetry offered detailed insight into spatial dose deposition, complementing preclinical data and guiding the optimization of particle-assisted radionuclide therapy.

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ZNO MICROFLOWERS SYNTHESIS AS A WAY FOR CYCLOTRON TARGET RECYCLING FOR CU RADIONUCLIDES PRODUCTION

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Introduction

In recent years, zinc oxide has been a material that has attracted the attention of nuclear medicine for its use in the cyclotron production of copper radionuclides, which are extremely interesting in the field of personalized therapies for tumor diseases. Zinc derived isotopes, such as copper 67, 64 and 61, are attracting the attention of the scientific community for their favorable nuclear characteristics. Copper 67 is in fact very interesting in β-emission therapy, having also a γ-emission suitable for SPECT. This isotope can also be used in combination with copper 64 (positron emitter) and copper 61 for PET diagnostics, thus constituting a concrete choice for a theranostic medical approach. In this context, zinc is seen as the ideal material for targets fabrication necessary for the production of these radionuclides species via cyclotron, with particular attention to specific isotopes such as zinc 64, 68 and 70, the isotopic purity of the target is in fact crucial in the final purity of the radioisotope of interest but at the same time heavily contributes to the final cost of these nuclear syntheses. In light of this, an efficient recycling procedure for zinc oxide could be very useful in reducing the cost of the material, effectively allowing the use of the same material for multiple synthesis.

Description

In this work we explore a new and reliable method for the recovery, from used cyclotron targets, of isotopically enriched Zinc Oxide throught the micellar synthesis of ZnO nanoparticles aggregated in the form of particular "*microflowers*". This procedure, based on the use of an organic and aqueous phase in order to obtain specific micelles, is already widely adopted in many sectors where the particles size must be nanometric and uniform. The obtained ZnO microparticles were deeply characterized both morphologically, throught SEM and TEM microscopy (coupled with EDS spectroscopy for the exploration of elemental composition) and crystallographically with XRD spectroscopy in order to identify in details the properties of these materials. The results obtained with this technique allowed an average ZnO recovery of about 95% with favourable mechanical properties and chemical purity that allows to adopt this technique for the efficient recycling of zinc oxide derived from cyclotron targets for the synthesis of copper radioisotopes.

Conclusions

This procedure ensures a high recycling yield together with the compatibility with the most common sintering and pressing techniques, making these ZnO nanoparticles potentially suitable in cyclotron target manufacturing.

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MULTI COPPER AND GALLIUM RADIOISOTOPES PRODUCTION BY IRRADIATION OF ZNO TARGET VIA MEDICAL CYCLOTRON

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Introduction and aim of the work:
Copper radioisotopes are gaining increasing relevance in nuclear medicine due to their versatile decay properties, suitable for both diagnostic and therapeutic applications. Our study investigated their production via proton irradiation of enriched zinc oxide (ZnO) targets. Specifically, ^{61}Cu can be produced via the (p,α) reaction on a ^{64}Zn target in the energy range of 10-20 MeV, ^{64}Cu through the ^{68}Zn(p,nα) reaction in the range of 20-40 MeV, and ^{67}Cu through the ^{70}Zn(p,x) reaction in the range of 10-70 MeV. Interestingly, gallium radioisotopes, also of medical relevance, emerged as significant by-products during the irradiation process. From these observations arises the idea of developing a multi-radioisotope production method through ZnO irradiation. A Zn/Cu separation method was developed to enable the recovery of both gallium and copper radioisotopes and a protocol to recover ZnO from waste, enabling target recycling.

Materials and Methods:
Sintered ^{nat}ZnO pellets (~260 mg) were produced via Spark Plasma Sintering and attached to Au/Nb backing support. Irradiations were carried out using a TR19 cyclotron at 18 MeV, 20 μA, up to 30 minutes. Copper radioisotopes were separated via an automated protocol using CU and TK201 resins. The copper-rich eluate was collected from TK201, while the zinc/gallium-containing waste from the CU resin was further purified using ZR and DGA resins. Purity and recovery efficiencies were assessed by ICP-MS and γ-spectrometry. Both copper and gallium fractions were tested for radiolabelling with DOTA and DOTA-TOC. ZnO was recovered from waste via NaOH precipitation followed by calcination.

Results:
The automated copper purification yielded ~95% recovery with high radionuclidic purity; γ-spectra confirmed the presence of ^{61}Cu as the main isotope, while no impurities of zinc, gallium or cobalt were visible, which demonstrates that any presence of these elements is below the instrumental detection limit. Additionally, gallium was effectively separated from zinc and eluted in water. The labeling of copper with DOTA and gallium with DOTATOC resulted in radiochemical purities above 98% in both cases. ZnO was recovered from the acidic waste solution with ~85% yield and reused for new pellet production.

Conclusion:
This work presents a sustainable approach for the dual production of copper and gallium radioisotopes from a single irradiation of ZnO targets. The developed method combines efficient radionuclide separation with recovery of valuable by-products and target material. This strategy aligns with green chemistry principles, optimizing resource use while minimizing radioactive and chemical waste.

Keywords: Copper radioisotopes**,** Gallium radioisotopes, Zinc oxide targets**,** Sustainable radiochemistry, Theranostics

DEVELOPMENT AND OPTIMIZATION OF EXTRACTION CHROMATOGRAPHY PROTOCOL FOR HIGH-PURITY ^{155}Tb PRODUCTION

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Aim/Introduction

In the field of theranostic radionuclides (RNs), ^{155}Tb has attracted increasing interest within the radiopharmaceutical community due to its emission of Auger and conversion electrons (ACE), with gamma rays suitable for low-dose SPECT imaging. The absence of additional alpha or beta emissions establishes ^{155}Tb an ideal diagnostic match for other terbium isotopes, enabling the development of emerging theranostic pairs for personalized oncology treatments [(1)]. Despite these favorable properties, large-scale production of ^{155}Tb is still an open challenge: one of viable production route is the ^{155}Gd(p,n)^{155}Tb reaction in medical cyclotrons, which could increase its availability in hospital centers. However, radiochemical separation of ^{155}Tb from the target material represents a critical step to obtain high-purity ^{155}Tb suitable for pharmaceutical applications. In the context of the APHRODITE-155 project, funded by the Italian Ministry of University and Research and the European Union NextGenerationEU program, this work focuses on the development of an efficient separation protocol for the production of ^{155}Tb.

Description of the Work or Project

The research activity focused on the development and optimization of an extraction chromatography-based protocol for the separation of Tb starting from a reference solution simulating the conditions of a dissolved irradiated Gd_2O_3 target (containing 85 mg of [^{nat}Gd]Gd_2O_3, Tb standard and Dy standard in 7 M HNO_3). The protocol, semi-automated with a multi-channel peristaltic pump, included a sequence of DGA + LN + DGA resins (TRISKEM). In particular, the first DGA resin was used to perform an initial purification of Tb, successfully removing a significant amount of Gd from the solution. The LN resin was used to eliminate the residual Gd, improving the purity of the sample before the final phase. Finally, the last DGA resin was used to concentrate the purified Tb in water, obtaining a product suitable for further applications and analysis. Fractions collected from the columns were analyzed by ICP-MS, monitoring the elution profiles of Tb, Gd, and Dy form each column.

Conclusions

The present work investigated the separation of Tb from Gd and Dy using DGA and LN extraction chromatography. Preliminary results highlight the efficiency of the developed protocol, supporting its potential as a reliable approach for the large-scale production of high-purity ^{155}Tb.

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A STUDY ON THE PRODUCTION YIELD EVALUATION OF PM-147 USING MCNP–CINDER COUPLING IN A RESEARCH REACTOR ENVIRONMENT

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Introduction

For the development of betavoltaic batteries in extreme environments, this study focuses on promethium-147 (Pm-147) as a promising beta-emitting isotope. Pm-147 undergoes β^- decay with an average energy of 62 keV and a half-life of 2.6 years, making it suitable for long-lived energy sources. Among reported production routes, neutron irradiation of Nd-146 was selected for its ability to yield high-purity Pm-147 without reliance on fuel reprocessing. This work evaluates the production yield and potential byproducts of Pm-147 based on the HANARO research reactor operated by the KAERI. The analysis was conducted by simulating neutron flux distributions using the Monte Carlo code, and isotope generation was further analyzed through MCNP–CINDER coupling.

Description of the Work or Project

To derive the neutron energy fluence incident on the Nd-146 target, MCNP calculations were performed under an equilibrium core configuration at 30 MW thermal power. The neutron flux in the irradiation hall was determined by combining the single-neutron energy fluence with reactor power weighting factors, including the average neutron yield per fission. The calculated flux spectra were then used in CINDER'90 to evaluate isotope production during four irradiation cycles of four weeks each. At the end of bombardment (EOB), the primary radionuclides in the target were Nd-147, Pm-148, and Pm-149. After a cooling period of 147 days, considering the decay of short-lived impurities, the dominant radionuclides were Pm-147, H-3, and Pm-148m. Since Pm-147 is formed via the (n,γ) reaction on Nd-146 followed by β-decay of Nd-147, the maximum activity of Pm-147 is expected around six weeks after EOB. The specific activity of Pm-147 in the Nd_2O_3 target after cooling was estimated to be 1.33 Ci/g.

Conclusions

The production yield of Pm-147 using Nd-146 targets in the HANARO 30 MW research reactor was evaluated through MCNP–CINDER coupling analysis. Although several short-lived impurity isotopes are initially produced, a cooling period enables the recovery of high-purity Pm-147. The predicted yield after cooling corresponds to 1.33 Ci/g of Nd_2O_3 target, demonstrating the feasibility of this production route for high-specific-activity Pm-147 suitable for advanced betavoltaic applications.

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DEVELOPMENT OF A SYSTEM FOR MEASURING BETA-RAY EMISSION RATE IN BETAVOLTAIC BATTERIES

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Introduction

The efficiency of betavoltaic batteries, which convert the decay energy of radioisotope into electricity, strongly depends on the beta-ray emission rate of the source. Accurate measureme nt of this emission rate is essential for quality control, ensuring stable performance and extend ed lifetime of the batteries. However, conventional detection methods, originally designed for gamma-ray measurement, are inadequate for beta-ray detection due to the limited penetration depth of beta particles. To overcome these limitations, we developed a novel system capable o f measuring both absolute and relative beta-ray emission rates of sources with high accuracy.

System for Measuring Beta-ray Emission Rate

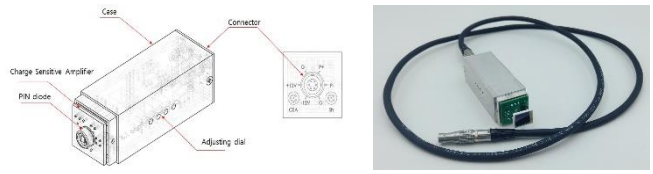

Figure 1. Structure of a beta-ray detector

This measurement system consists of a PIN diode, a charge sensitive amplifier, a shaping amplifier, and a discriminator, and is made of aluminum for electro-magnetic wave blocking, except for the beta ray detection section. A key feature is the use of a light-tight chamber equipped with an XYZ translation stage, allowing precise alignment and distance adjustment between the detector and the beta source. The stage provides ±8.5 mm movement along XY axis and 65~76 mm along Z axis, accommodating various source geometries. By positioning the source within the shielded chamber, the system eliminates absorption losses and enables detection of low-energy beta particles. Furthermore, the XYZ-controlled measurement provides spatially resolved mapping of emission distributions across the source surface, in addition to measuring total emission rates of source.

Conclusions

This system enables accurate and high-resolution beta-ray emission measurement, overcoming the limitations of conventional detectors. This advancement provides valuable tools for quality assurance and optimization in betavoltaic battery manufacturing, contributing to safer, longer-lasting, and more efficient betavoltaic batteries. The methodology also offers broad applicability to radiation detection and nuclear instrumentation research.

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EXCITATION FUNCTION MESUREMENTS OF ^{149}Tb IN THE ^{10}B+^{142}Nd SYSTEM

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Introduction

Terbium-149 ($T_1/_2$ = 4.1 h, Eα = 3.98 MeV (16.7%)) is a promising radionuclide for targeted alpha therapy (TAT). However, the production of ^{149}Tb in sufficient yield and purity remains a significant challenge [1]. The present work explores the production of ^{149}Tb using heavy-ion induced reactions of ^{10}B projectiles on an enriched ^{142}Nd target.

Description of the Work or Project

The experiment was conducted at the Inter University Accelerator Centre (IUAC), New Delhi. A beam of ^{10}B ions was employed for excitation function measurements of radioisotopes produced in the reaction. The stack-foil activation technique, followed by offline γ-ray spectrometry, was used to determine cross-sections. A stack of seven ^{142}Nd foils was irradiated over an incident energy range of approximately 3–6 MeV/nucleon. The obtained experimental cross-sections were compared with the theoretical model calculations of PACE4 code.

Conclusion

The ^{10}B + ^{142}Nd reaction channel was observed to populate multiple radioisotopes, with the cross-sections of ^{149}Tb being enhanced from theoretical predictions of PACE4. These enhancements are attributed to the non compound processes as PACE4 only predicts cross-sections of compound processes. The population of ^{148}Tb along with ^{149}Tb makes the extraction process complex.

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A NOVEL APPROACH FOR THE DEVELOPMENT OF TITANIUM CARBIDE TARGET FOR THE SPES ISOL FACILITY

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Introduction

Porous carbides are regarded as the most employed target materials for the production of radioactive ion beams for research in the context of ISOL (Isotope Separation On-Line) facilities. According to the ISOL technique, nuclear reactions are induced by the interaction of an energetic primary particle beam with a target, producing a characteristic set of radionuclides that are subsequently released thanks to the high target working temperature (1600÷2000°C), ionized and extracted into a beam.

Description of the Work

Among the possible target materials, titanium carbide is regarded as one of the most suitable materials for the ISOL production of scandium isotopes of medical interest, such as ^{43}Sc, ^{44}Sc and ^{47}Sc [1,2]. However, dedicated studies highlighted issues in the release of Sc isotopes from titanium carbide, effectively limiting the achievable Sc ion beam intensities. In the framework of the INFN HISOL_NEXT experiment, a new generation of higher efficiency ISOL targets is under development for the SPES ISOL facility at INFN-LNL. In particular, regular titanium carbide porous structures are being realized with the Digital Light Processing additive manufacturing technology, paving the way for a new generation of targets capable of providing higher isotope yields. Such aim is achieved by both increasing the target heat dissipation properties, and consequently the acceptable maximum primary beam intensity, and improving the release capabilities thank to the tailored macro- and microstructure. Along with the development of the target production technology, the design of a target with these characteristics required also the definition of a new complex simulation approach, capable of handling complex geometries with many free parameters. Such approach includes the 3D modelling of the target periodic structures, the Monte Carlo simulation of the target interaction with the primary beam, and the Multiphysics simulation of the target working conditions. The complex simulation procedure and the most promising results will be presented in detail.

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CHARACTERISTICS OF SECONDARY NEUTRONS IN ^{18}F PRODUCTION WITH MEDICAL CYCLOTRONS: A MONTE CARLO STUDY

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Introduction

Radioisotopes for radiopharmaceuticals are produced in medical cyclotrons through various nuclear reactions. Secondary neutrons, produced mainly by the (p,n) reactions, cause the activation of medical cyclotrons; therefore, an accurate simulation is necessary to evaluate the radionuclide inventory in activated wastes for decommissioning. However, the $^{18}O(p,n)^{18}F$ reaction typically relies on the physics model in Monte Carlo (MC) codes. Accordingly, the characteristics of secondary neutrons were compared between the MC codes.

Description of the Work or Project

The neutron spectra by different angles (i.e., 15°, 30°, 60°, 90°, 120°, 150°) for an 18 MeV proton beam were compared using two MC codes, MCNP and PHITS. The target was $H_2{}^{18}O$ water for ^{18}F production, and two irradiation conditions were considered. First, to compare with Hagiwara's data[1], which are well-represented by experimental data, a target (volume: 1.2 mL) was assumed. Second, it was assumed that the target chamber was filled with $H_2{}^{18}O$ water and that the proton beam reacted 100% for a conservative approach. However, in reality, the cavity is only 70–80% filled, and the temperature can reach ~230 ˚C; therefore, liquid, a few bubbles, and vapor coexist. Considering that the chamber cavity of the IBA 18/9 cyclotron is 2.4 mL, we compared the neutron spectra for cases with liquid (70%) and vapor (30%).

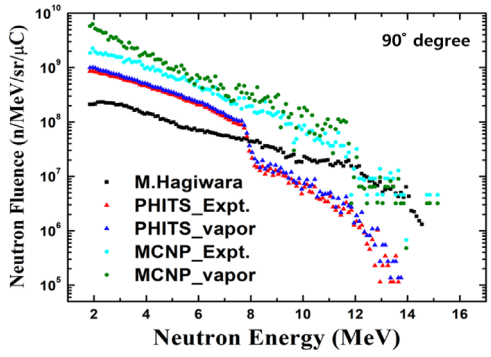

Figure 1: Neutron spectra at 90˚

Figure 1 only shows one of the neutron spectra at a certain angle. The simulations showed that, at backward angles, neutron energies decreased, and the discrepancies compared to the experimental data increased. Above 8 MeV of neutron energy, the two MC codes show substantial discrepancies. Additionally, although the vapor scenario employed approximately twice the quantity of the target than the experiment, interactions with surrounding materials resulted in a similar total neutron fluence and a comparable spectral shape.

Conclusions

Discrepancies between the MC codes increase at backward angles and vary substantially with energy; consequently, the difference of radionuclide inventory will become more pronounced. Therefore, further work is needed to develop and validate more accurate source terms.

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DEVELOPMENT OF AN AUTOMATED ELECTROPLATING SYSTEM FOR SOLID TARGET PREPARATION IN ALPHA EMITTER PRODUCTION

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Introduction:
The growing interest in Targeted Alpha Therapy (TAT) has intensified worldwide research on several alpha-emitting radionuclides, including ^{225}Ac, ^{213}Bi, ^{212}Pb/^{228}Th, ^{211}At. These isotopes offer exceptional therapeutic potential due to their short-range, high-linear-energy-transfer radiation capable of selectively eradicating tumor cells while minimizing damage to surrounding healthy tissue. Among them, ^{225}Ac is currently one of the most promising candidates; however, its large-scale, GMP-compliant production remains challenging. While cyclotron-based routes such as ^{226}Ra(p,2n)^{225}Ac have been demonstrated, automated and contamination-safe systems for target preparation are still lacking. This study have confirmed the feasibility of electroplating alkaline-earth and actinide elements, paving the way for solid target development for alpha emitter generation.

Methods:
An external molecular plating system was developed to electroplate barium (purity 99,999%) —used as a non-radioactive surrogate of radium—onto platinum substrates. The experiments were conducted starting from 150mg ± 5mg of Barium Nitrate [$Ba(NO_3)_2$] powder, then mixed with DMSO [C_2H_6OS] and heated to obtain complete solubilization of barium. After reaching the room temperature, cold ammonium hydroxide [NH_4OH] were added to increase pH. An external plating module (COMECER) has been used for this plating tests. Due to the high applied voltage and currents which is increasing a lot the temperature during the molecular plating, the solution is placed in cavity cooled by an external chiller and kept at constant temperature of 20°C ± 1°C.

Results:
The plating was performed onto a platinum coin with the external plating module applying a constant voltage of 100 V and starting from an initial current 400 mA. Barium electroplating results smooth and repeatable. In an average time of 5 ÷ 6 hours with a final current in a range of 6 ÷ 10 mA, good plating was obtained, in term of colour, hardness and final weight. Starting from Barium powder in Nitrate form Ba (NO3)2, thanks to an Inductively Coupled Plasma Mass Spectrometry, ICPMS, analysis, was observed that Barium in Oxide form BaO was deposited, with a mean yield of 97,5%. This means that due to the hight current and voltage applied a molecular plating has been performed

Conclusion:
This work demonstrates a scalable and contamination-safe electroplating method for preparing solid targets applicable to ^{225}Ac and potentially other alpha emitters. The system represents a key step toward automated, GMP-oriented isotope production workflows supporting the future expansion of TAT.

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RADIOACTIVE ISOTOPE BEAM PRODUCTION WITH KOBRA AT RAON

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Introduction

Korea Broad acceptance Recoil spectrometer and Apparatus (KoBRA) has been constructed at the Institute for Rare Isotope Science (IRIS) as part of the Rare isotope Accelerator complex for ON-line experiments (RAON) in Korea. The facility provides stable or radioactive isotope beams produced using Electron Cyclotron Resonance (ECR) ion source or ISOL system. These beams can be accelerated and transported to KoBRA at energies of 1-40 MeV/u via the SuperConducting Linear accelerator 3 (SCL3).

Description of the Work or Project

KoBRA is dedicated to low-energy nuclear physics research involving nuclear reactions, structure, and astrophysics. The beam commissioning phase began in May 2023. ^{40}Ar ion beam was successfully accelerated up to 16 MeV/u with the SCL3 accelerator and transported to KoBRA. Secondary radioactive isotope beams were produced by in-flight fragmentation reactions using a graphite (^{12}C) target. Stable isotope beams aligned along the N = Z line and neutron-rich isotopes - particularly oxygen isotopes from A = 18 to 22 - were produced and identified. Radioactive isotope beams were identified up to the vicinity of ^{32}Si. Additionally, $^{25}Na^{5+}$ radioactive isotope beam was produced from the ISOL system, accelerated up to 16 MeV/u, and transported to KoBRA.

The abstract shall be prepared in A4-size paper format (210 × 297 millimeters or 8.27 × 11.69 inches) with 25mm (1-inch) margins on all sides. The font size shall be 12-point Times New Roman (or equivalent) with single spacing. Selected key references (please use the example style)[1] may be included. Keywords shall be added to the bottom of the abstract. The body of the abstract should be flush left.

Conclusions

KoBRA has demonstrated successful beam commissioning and isotope beam production, establishing itself as a dedicated science platform for low-energy nuclear research at the RAON facility. These results represent a significant step forward in advancing nuclear structure and reaction studies, and in expanding the applications of isotope beams.

References *(style example)*

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This work was supported by the Institute for Basic Science (IBS-I001-01) and the National Research Foundation of Korea (NRF) funded by the Ministry of Science and ICT (2013M7A1A1075764, RS-2023-00282876).

Keywords: KoBRA, RAON, Radioactive isotope beam, Beam commissioning, Low-energy nuclear physics.

PRODUCTION OF INNOVATIVE RADIOISOTOPES FOR PERSONALIZED NUCLEAR MEDICINE IN ITALY

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Introduction

The development of innovative radioisotopes for both diagnostic imaging and targeted radionuclide therapy is among the most dynamic advances in nuclear medicine. Matched isotope pairs such as terbium ($^{155/161/152/149}$Tb) and copper ($^{61/64/67}$Cu) provide emission properties suitable for both imaging and therapy, making them ideal for a fully integrated theragnostic approach. Additional diagnostic isotopes like ^{52}Mn and ^{89}Zr are promising for hospital-based production. In Italy, growing efforts are being dedicated to establishing local production capabilities for emerging theragnostic isotopes via solid target irradiation.

Description of the Work or Project

At the IRCCS Sacro Cuore Don Calabria Hospital, the Radiopharmacy and Cyclotron Department is actively engaged in optimizing the production and radiochemical purification of copper, zirconium [1], manganese [2], and terbium isotopes. The research focuses on developing efficient medical-cyclotron-based production routes, such as ^{89}Y(p,n)^{89}Zr, ^{52}Cr(p,n)^{52}Mn, ^{x}Zn(p,n)^{x}Cu, and ^{155}Gd(p,n)^{155}Tb, through proton irradiation of enriched solid targets using a TR-19 medical cyclotron with tunable energy, combined with advanced separation and purification methods to ensure high radionuclidic and radiochemical purity. ^{89}Zr is routinely produced up to ≈ 2 GBq, while the other more innovative isotopes are currently under development, with produced activities in the MBq range. Parallel efforts focus on process automation of radiochemical systems, and the standardization of quality control protocols. These activities are carried out in close collaboration with national laboratories such as INFN-LNL, supporting target preparation and irradiation studies, and with academic institutions, including the University of Ferrara, which contribute to the radiochemistry setup development and preclinical validation. Such collaborations are essential to establishing a complete domestic supply chain of high-quality radionuclides and to advancing radiotheragnostic applications.

Conclusions

At IRCCS Sacro Cuore Don Calabria Hospital, the successful routine production of ^{89}Zr and the ongoing development of ^{52}Mn, and terbium and copper isotopes, demonstrates the feasibility of implementing innovative isotope production within a hospital setting. The integration of optimized cyclotron-based methods, advanced radiochemistry, and strong collaborations provides a robust platform for both clinical translation and proof-of-concept studies, supporting future large-scale production in specialized facilities.

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SPS-PRODUCED YTTRIUM TARGET FOR OPTIMIZED ^{89}Zr PRODUCTION

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Introduction

Zirconium-89 (^{89}Zr) is a well-established radionuclide for immunoPET applications. ImmunoPET, a branch of Nuclear Medicine, utilizes radiolabeled antibodies to visualize pathological lesions that may respond to antibody-based therapies. The physical half-life of ^{89}Zr (78.4 h) combined with its β^+ emission fraction (22.7%) makes it an ideal candidate for this purpose, as its decay properties align well with the biological circulation time of antibodies, enabling high-quality imaging even at delayed time points of up to three days post-injection.
Due to these favorable characteristics, the demand for ^{89}Zr has increased significantly. Zirconium-89 production typically involves irradiation of natural yttrium targets with 13 MeV protons in a medical cyclotron, via the nuclear reaction ^{89}Y(p,n)^{89}Zr. This process can be performed using either liquid or solid target, both representing a practical and efficient route for obtaining the isotope. However, solid target is generally preferred for activity scale-up, due to the high saturation yield. Various technologies can be employed for solid target preparation, with Spark Plasma Sintering (SPS) being among the most efficient. Using this technique, yttrium targets can be effectively produced by attaching yttrium foils onto a niobium backing [1].

Description of the Work or Project

The Spark Plasma Sintering (SPS) technique enables the fabrication of solid, coin-shaped targets using natural yttrium foils of varying thicknesses. Each target consists of a niobium (Nb) backing disk and an yttrium foil bonded together. The yttrium foil thickness can be tailored according to the solid target holder design and specific production requirements.
Based on the operational parameters of the TR-19 cyclotron installed at IRCCS Sacro Cuore Hospital, yttrium foils with thicknesses ranging from 150 to 250 µm were used to produce yttrium targets via the SPS process in a dedicated system developed and installed at the INFN laboratories. These targets were subsequently irradiated with 13 MeV protons at a beam current of 50 µA for varying irradiation times to assess their thermomechanical resistance and to determine the corresponding saturation activity, radionuclidic purity, and radiochemical purity after radiochemical separations.

Conclusions

In this work we compared the production capability of zirconium-89 using SPS solid target coins with different yttrium thickness on a medical cyclotron. These results can be used to assess and optimize routine zirconium-89 production capabilities.

Reference

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TOWARDS CHEMICAL ENRICHMENT OF CA-48 VIA ELECTROPHORESIS

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Introduction

^{48}Ca is a stable isotope essential, e.g., for research in superheavy element synthesis[1] and neutrinoless double beta decay studies[2]. Its low natural abundance (0.182%) makes it rare, necessitating enrichment for most applications. Enriched samples are difficult to obtain and extremely costly. Conventional enrichment methods applicable for ^{48}Ca are energy-intensive and technically demanding. Therefore, we explore a more affordable enrichment method from natural calcium.

Electrophoretic Enrichment Efforts in Mainz

For this, we initiated a program towards chemical enrichment based on the electrophoresis method, where an electrical field counteracts the migration of calcium in a liquid. Kishimoto et al.[2] showed that calcium isotopes can be separated based on diffusion velocities D, with $D(^{40}Ca^{2+}) > D(^{48}Ca^{2+})$. Prototype separation cells were built and tested in Mainz. A stepwise evaluation was used to optimize parameters, including current measurements. The working range where separation is accessible was determined. Analytical techniques including triple quadrupole ion-coupled plasma mass spectrometry (ICP-MS QQQ), neutron activation analysis (NAA), and thermal ionization mass spectrometry (TIMS) were tested for their suitability to quantify output and enrichment. For ICP-MS, ^{48}Ca enrichment factor detection limit of $^{48}\mathrm{Ca}_{\mathrm{enriched}}/^{48}\mathrm{Ca}_{\mathrm{nat.}} > 1.09$ was determined.

Conclusions

Countercurrent electrophoresis shows potential for ^{48}Ca enrichment; in a next step, an optimized separation cell, built to allow overcoming technical challenges, will be commissioned on the way to isotope separation.

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Poster Session 2

MONITORING OF GREENHOUSE GASES AND ISOTOPIC SIGNATURES IN URBAN CARBON CYCLES- A CASE STUDY IN GLIWICE, POLAND

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Introduction

Monitoring of greenhouse gases, particularly carbon dioxide (CO_2) and methane (CH_4), including their atmospheric concentrations and isotopic composition, has become more than a scientific curiosity. Atmospheric physics and advanced analytical technologies play a crucial role in this process, enabling precise measurements and detailed analysis of air composition. One of the institutions conducting advanced research in this area is the Institute of Physics – CSE at the Silesian University of Technology, where the MONCO$_2$ project is currently being carried out. The initial tests and measurements of the concentrations of major greenhouse gases are underway, along with analyses of their isotopic composition. This will facilitate the identification of their sources and the modeling of atmospheric processes in future.

Description of the Work or Project

One of the key components of the research infrastructure developed during the implementation of the MONCO$_2$ project includes the following instruments: a GMP343 probe installed on the roof of the Institute of Physics, a CO_2 sensor, and an air sampling collector. Measurements are carried out both in real time and through biweekly air sample collection, which are subsequently analyzed using spectrometric methods. These measurements enable the determination of radiocarbon (^{14}C) levels and comparison with the ^{14}C content of background (clean) air. In the Gliwice area, a significant depletion of atmospheric ^{14}C concentration has been observed—this is known as the Suess effect.The second method employed involves the analysis of air samples using Cavity Ring-Down Spectroscopy (CRDS)—one of the most precise spectroscopic techniques for measuring trace gas concentrations. Currently, the CRDS analyzer is undergoing testing and calibration. CRDS enables simultaneous determination of CO_2, CH_4, and water vapor concentrations, as well as the isotopic composition of carbon in atmospheric air. This technique provides highly accurate results and allows for high-frequency measurements—up to several times per second. Continuous monitoring is conducted, which makes it possible to observe variations in gas concentrations on daily, weekly, and seasonal timescales.

Conclusions

High-resolution measurements of CO_2 and CH_4 also enable the investigation of the carbon cycle in urban environments. In cities, the carbon cycle is particularly disrupted due to significant anthropogenic emissions, primarily from the combustion of fossil fuels. Through precise monitoring and control of these emissions, it becomes possible to optimize processes related to carbon uptake, for example by vegetation or urban green spaces. The study of stable isotopes further allows for the differentiation of these processes across various urban zones—such as areas with abundant vegetation versus industrial districts.

This work has been supported by programme European Funds for Silesia 2021-2027: The modern methods of the monitoring of the level and isotopic composition of atmospheric CO_2 (project no.FESL.10.25-IZ.01-06C9/23-00, PM Barbara Sensuła)

EVALUATION AND MITIGATION OF PERSONNEL RADIATION EXPOSURE DURING RADIOISOTOPE PRODUCTION AT RESEARCH REACTORS

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Introduction

Many research reactors produce radioactive isotopes for a variety of uses, such as medical treatment and industrial processes. The specific isotopes and activities of those isotopes vary depending on the needs of the client. In many cases, production of radioactive isotopes is not the primary mission of the facility. As a result, handling of the produced radioactive isotopes is performed manually in an ad hoc manner, leading to the potential for significant radiation exposure to personnel.

Description of the Work or Project

A study was undertaken to identify the significant sources of personnel exposure and to determine methods of mitigating those exposures. Personnel radiation dosimeter and radiation dose rate survey records were analyzed and correlated to radioactive isotope production activities. It was determined that, as expected, the produced radioactive isotopes were a significant source of personnel radiation exposure. In many cases, the container holding the produced radioactive isotope became quite radioactive during irradiation and added significant additional personnel radiation exposure. Alternate container materials were investigated to determine if the personnel radiation exposure from the container could be significantly reduced or eliminated.

Conclusions

As a result of the study, manual radioactive isotope handling procedures were modified, and irradiation container materials were changed to reduce personnel radiation exposure.

BIOGEOCHEMICAL INVESTIGATION OF MANGROVE ECOSYSTEM TO GAUGE COASTAL ANOXIA AND ECOSYSTEM PROCESSES OF THE LAST 7800 CAL YEAR BP

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Introduction

There has been a growing concern among the scientific community that coastal mangroves are highly receptive to anthropogenic inputs of toxic substances, which in turn could pose a threat to the ecosystem. In this context, we investigate one such anoxic sedimentary organic matter (SOM) deposits of the KaranKadu mangrove, situated in the Tamil Nadu coast. One economical prospect of studying this wet SOM here is somewhat related to their ability to act as a hydrocarbon reserve via their generation from a certain microbial functioning. The persisting microbial niche of the Karankadu mangrove continuously affects the nature and type of SOM stored therein.

Description of the Work or Project

Understanding the changes in SOM under oxic-anoxic pathways can easily be traced through incursions in the $\delta^{34}S$ of bulk sulphur levels, followed by a microscopic inspection of authigenic minerals involving carbonates/iron and sedimentary sulphur (e.g., greigites/pyrites). To envisage whether there exists any such characteristic imprints in the SOM or not, we investigated depth-wise variability in the elemental percentages of organic carbon (OC), total nitrogen (TN) and sulphur (TS), and TOC/TS ratios with their stable isotope compositions ($\delta^{13}C_{TOC}$, $\delta^{34}S_{TS}$) of a ~1m long AMS radiocarbon dated core from Karankadu mangrove reserve.

Though both $\delta^{34}S_{TS}$ (-8‰ to +6‰) and TOC/TS ratio (8.2 to 3.1) in the top few cms showed oxic conditions, there was an apparent regime shift in the sediments beneath this depth ($\delta^{34}S_{TS}$ -26‰ to -10‰, and TOC/TS ratio: 2.4 to 0.9), which clearly highlighted their suboxic-anoxic type. In parallel to this observation, the microscopic investigations of the bottom SOM revealed the presence of biogenic pyrite and greigites inside an egg shell body, pollen grains, and foraminifera lining. Furthermore, the combination of $\delta^{13}C_{TOC}$ values with the grain-size data and different pollen taxa has provided crucial insights into palaeoenvironmental and palaeoclimatic conditions at the temporal scale of the last 7800 cal year BP.

Conclusions

Overall, our data underscores the coastal environmental alteration, anoxia at different time frames, with the associated processes involved in it. Another finding is that the silty clay fraction was enriched in ^{13}C or more positive $\delta^{13}C_{TOC}$ values, and vice versa.

By and large, these findings can be better interpreted for understanding the coastal dynamics and degradation processes of SOM associated with the plausible changes in regional/global climate at the temporal scale.

Keywords: Coastal wetlands, anoxic zone, biogeochemical cycle, Mangroves, Stable isotope, Sedimentary organic matter

OUTPUTS FROM EURAMET PROJECT 21GRD09 - MetroPOEM

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The MetroPOEM project was funded by the European Partnership on Metrology, ID 10.13039/100019599, grant number 21GRD09 MetroPOEM under the European Green Deal that (in part) requires the development of highly sensitive techniques to detect ultra-low levels of radioactive and stable pollutant elements identified as environmental stressors, and their isotope ratios – vital parameters in the identification and attribution of sources of pollutants. Mass spectrometry is a key method for determination of such pollutants and their isotope ratios; MetroPOEM project bridges the traceability gap between activity and mass measurements.

Underlying studies SI-traceable high-precision methods were developed for isotope ratio determination of Li, B, Cr, Cd, Ni, Sb, Pb, and U in environmental matrices, focused on seawater as the model solution, encompassing manual and automated methods for separating analytes from the matrix, evaluating different calibration approaches, instrumental isotope fractionation corrections and estimating uncertainty budgets. Radioactive standard solutions (^{90}Sr, ^{237}Np, ^{234,236}U, ^{239,240}Pu, ^{241}Am) were distributed to partner laboratories for measurement. Various single and multi-collector ICP-MS systems, as well as accelerator mass spectrometry, were used and their performances compared. These findings support the development of methods for stable and radioactive isotope determination.

Reference materials A 250 litre sample of sea water sample was taken from the German EEZ (North Sea) for the development of two reference materials. This material was subjected to processing, including spiking with additional elements based on preliminary analysis and homogenisation. Part of this material was characterised for isotope ratios of Li, B, Cr, Cd, Ni, Sb, Pb, and U to generate 470×250 mL aliquots of a certified reference material with SI traceability for isotope ratios. Additionally, ~50×0,5L liquid RM aliquots of sea water were prepared, spiked with natural U, ^{237}Np, ^{239,240}Pu and ^{241}Am to generate a reference material for radioactive species. A solid reference, based on silica was produced by sol-gel synthesis and spiked with ^{234,235,236,238}U, ^{237}Np, ^{239,240}Pu and ^{241}Am; ~10 kg of inactive silica was produced for testing dissolution procedures. These materials were characterised in accordance with the requirements of ISO 17034 by interlaboratory studies between the project partners, using techniques developed in the project, and will be available to the wider scientific community for method development and validation.

Outputs The three reference materials from the project are now available to the wider scientific community for method development and validation. Additionally, these documents are publicly available:

- Good Practice Guide on mass spectrometry for low-level radioactive pollutants detection
- Report describing the development of measurement methods for isotope ratios that are traceable to the SI for stable polluting elements
- Good Practice Guide on sample processing, treatment, uncertainty budgets, and quantification of mass bias
- Inter-laboratory comparison report, describing detection limits, sample preparation requirements, sample introduction methods, total procedural time, and uncertainty budgets
- Report describing the development of one aqueous certified reference material that is certified for the same stable polluting elements with lowest possible uncertainties.
- Training videos on pollutant monitoring by ICP-MS
- Contributions to new or improved international standards.

Development of a compact spherical radiation detector with isotropic sensitivity for environmental monitoring applications

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Introduction

Radiation accidents and related incidents are increasing worldwide, raising concerns about unintended radioactive contamination and the resulting risks to human health and the environment [1]. In such emergencies, rapid and accurate assessment of the spatial distribution and dose rate of radiation is essential. However, conventional environmental monitoring systems, typically based on a cylindrical NaI(Tl) scintillator, have notable limitations: (1) direction-dependent sensitivity, which causes dose measurement variations and necessitates additional calibration, and (2) bulky system design due to the use of photomultiplier tube (PMT) [2]. To overcome these issues, we propose a novel spherical radiation monitoring system that combines a spherical scintillator for isotropic sensitivity with a silicon photomultiplier (SiPM) readout for compactness and simplicity.

Description of the Work and Results

This configuration enables effective detection of radiation from all directions and facilitates the deployment of a flexible, scalable monitoring network. System performance was evaluated through both simulation and preliminary prototyping. Using the Geant4 Application for Tomographic Emission (GATE) toolkit, we conducted optical and radiation transport simulations. The proposed detector consists of a 50 mm-diameter plastic scintillator coupled to a 3 × 3 array of 6 mm² SiPMs. Optical simulations investigated the effects of surface treatments and reflector materials on SiPM light collection efficiency, while radiation transport simulations analyzed the directional uniformity of sensitivity. Based on these results, a prototype detector has been fabricated and experimentally validated using gamma ray sources.

Conclusions

The proposed system is versatile and can be deployed in diverse environments, including underwater monitoring, vehicle mounted soil contamination assessment, and drone based aerial radiation surveys. By integrating isotropic detection with a compact SiPM based design, this system can enhance environmental radiation monitoring capabilities and contributes to improved preparedness for radiological emergencies and routine radiation safety operations.

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Keywords
Environmental Radiation Monitoring System, Spherical scintillator, Silicon photomultiplier, Isotropic detection

RECONSIDERING THE LINEAR NO-THRESHOLD MODEL: EVIDENCE OF ADAPTIVE RESPONSES FOLLOWING LOW-DOSE IONIZING RADIATION EXPOSURE

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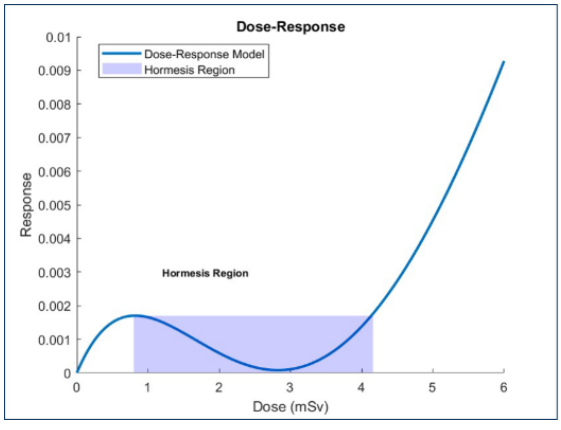
Introduction

Current radiation protection models largely rely on the linear no-threshold (LNT) hypothesis, extrapolating risks from high to low doses of ionizing radiation. However, increasing biological and epidemiological evidence suggests that exposures below 100 mSv may trigger defense mechanisms such as enhanced DNA repair, immune modulation, and adaptive stress responses that are not accounted for by the traditional LNT framework.

Description of the Work or Project

This study introduces a revised dose-response model that integrates biomarkers and mechanistic data to better capture low-dose adaptive responses. The model incorporates pathways of DNA damage response, cell cycle regulation, and apoptosis, which exhibit non-linear activity at low doses. Analyses reveal threshold-like behavior at very low doses (1–5 mSv), where protective pathways such as DNA repair and antioxidant defenses are upregulated. In contrast, exposures above 20 mSv demonstrate a shift toward LNT-type risk patterns. Epidemiological evidence from occupational and environmental studies supports this non-linear profile, showing variability in cancer risk at low doses. Notably, biomarkers including SOD, CAT, and PRKDC emerged as reliable indicators of cellular adaptation, providing practical tools for monitoring and risk assessment.

Conclusions



Findings suggest that low-dose exposures may initially induce protective biological effects before adverse outcomes dominate at higher doses. By incorporating these adaptive mechanisms, the proposed model challenges conventional LNT-based protection standards and supports development of more evidence-based regulatory frameworks. Future work will focus on expanding biomarker integration and validating the model across diverse exposure scenarios.

Keywords: Low-dose radiation, radiological protection, adaptive response, DNA repair, radiation hormesis, linear no-threshold model, Radiation dose-response, environmental exposure, occupational exposure

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SCAR TECHNOLOGY APPLICATION FOR RADIOCARBON MEASUREMENTS IN PHARMACEUTICAL RESEARCH

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Introduction

Radiocarbon (^{14}C) is a powerful tracer isotope with widespread applications in environmental sciences, industrial certification, and biomedical studies. Traditional techniques for ^{14}C detection, such as Accelerator Mass Spectrometry (AMS) and Liquid Scintillation Counting (LSC), are limited by high costs, infrastructure requirements, and/or the need for large sample activities. Saturated-Absorption Cavity Ring-Down (SCAR) spectroscopy, developed at CNR-INO and protected by international patents, represents an innovative laser-based alternative. Compact, highly sensitive, and operationally simple, SCAR is emerging as a transformative platform across ^{14}C applications.

Description of the Work and Results

This work demonstrates, for the first time, the application of SCAR to pharmaceutical research, with a focus on the investigation of drug-induced metabolic alterations at the cellular level. Particularly, by enabling the direct quantification of $^{14}CO_2$ released from ^{14}C-glucose metabolism, SCAR permits detailed investigation of the oxidative pentose phosphate pathway (oxPPP) and its rate-limiting enzyme, glucose-6-phosphate dehydrogenase (G6PD). This capability is particularly relevant in cancer research, where G6PD is frequently upregulated, supporting redox homeostasis, promoting tumor survival, and contributing to drug resistance. The method enables pharmacological assays with reduced radioactivity and improved safety while ensuring precise measurements, allowing the investigation of metabolic vulnerabilities in cancer cell models and the study of potential G6PD inhibitors as candidate anticancer drugs.

Conclusions

SCAR technology bridges a crucial methodological gap between the ultra-sensitive but costly AMS and the cheaper but less sensitive LSC, making radiocarbon tracing more practical for pharmaceutical applications. Its introduction into drug discovery and metabolism studies opens new avenues for investigating biochemical pathways, validating therapeutic targets, and conducting safer, more efficient ADME (Absorption, Distribution, Metabolism, Excretion) studies. By coupling innovation in isotope measurement with biomedical research, SCAR contributes to the broader 12th ICI goals of promoting multidisciplinary collaboration and advancing isotope science in medicine, industry, and regulation.

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RADHAWK: UAV FOR FAST-RESPONSE RADIOLOGICAL MAPPING

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Vertical take-off and landing of the Unmanned Aerial Vehicles (UAVs) employed for Gamma-Ray Surveys (GRS) extend the capability of environmental radioactivity mapping, combining the coverage of airborne methods with the flexibility of ground surveys. They operate without infrastructure for take-off or landing and allow data collection in hazardous areas while keeping operators at a safe distance. The need for rapid and safe radiological assessment makes these systems particularly relevant today.

RadHawk has been developed to address the insufficient integration between avionics and radiation detectors in existing UAV-based GRS systems. It combines a custom quadcopter with a GammaStream digital Multi-Channel Analyzer coupled to a 2-inch $CeBr_3$ scintillator, providing ~60% better energy resolution than NaI for ^{137}Cs detection. A dedicated protocol enables continuous exchange of telemetry and command signals between the onboard computer and the Pixhawk autopilot.

Data are acquired in list mode and processed in real time to yield georeferenced, energy-calibrated spectra. A radio-frequency downlink provides real-time transmission of georeferenced spectra and telemetry, ensuring continuous flight monitoring and timely detection of anthropogenic radionuclides. Post-processing with Full Spectrum Analysis – Maximum Likelihood Estimation enhances radionuclide identification and quantifies K, eTh and eU abundances. The algorithm defines the detector field of view as a function of altitude and links acquisition time to spectral count rate, enabling the analysis to be adapted to the prevailing radiometric conditions.

Efficiency calibration has been performed through Monte Carlo simulations at different altitudes, for both NORM and anthropogenic radionuclides.

The operational deployment of RadHawk demonstrates its effectiveness in delivering rapid and quantitatively reliable radiological surveys, proving its relevance for both emergency scenarios and environmental monitoring.

A METHOD FOR HIGH-PURITY SEPARATION OF PROMETHIUM-147 BASED ON NEODYMIUM

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Introduction

Beta volta cells are manufactured using only radioactive nuclides that emit beta rays. Research on the beta volta system began in the 1950s but subsequently lost prominence as lithium-ion battery development gained traction[1]. However, interest in beta volta cells has recently surged again. Among beta emitters, ^{147}Pm exhibits highly favorable characteristics for beta voltaic applications, but its production remains a challenging task. This is because ^{146}Nd must first undergo neutron irradiation to produce ^{147}Nd, which then decays into ^{147}Pm. Considering the half-life of ^{147}Nd (10.98 days), sufficient cooling time is required for effective ^{147}Pm production[2]. In this study, Nd and ^{147}Pm were experimentally mixed prior to reactor-based production to establish optimal separation conditions.

Description of the Work or Project

To determine separation parameters, cold tests were performed using Nd and Sm. Several ion-exchange resins, including AG50W-4X, LN, LN2, and LN3, were evaluated with HCl and HNO_3 as eluents. Additionally, PAR was employed to visually track separation: the transition from yellow to red upon complexation enabled real-time monitoring of elution by UV-VIS spectroscopy, thereby confirming separation times and yields. These optimized conditions were then validated in hot form using actual Nd/Pm-147/Sm mixtures. In this stage, both UV-Vis spectroscopy and beta detectors were employed to specifically detect Pm-147 in real time. Because the amount of Pm-147 passing through the line was too small for direct counting, a 1 mL detection chamber was developed to enhance detection efficiency.

Conclusions

The optimal separation conditions were achieved with LN2 resin and 0.07 M HNO_3, yielding a resolution (Rs) value of 1.54 and complete separation within 7 hours. While current tests demonstrated separation of 10 mg of Nd, future efforts will focus on scaling up to gram-level targets, as required for practical applications.

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ROCKYRAD: AN EDUCATIONAL TOOL FOR THE OF ROCK RADIOACTIVITY

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Abstract

RockyRad is a compact, and portable educational tool designed to facilitate practical measurement and inquiry-based learning of natural radioactivity in rocks. As an evolution of the traditional Geiger counter, the system includes a detector unit and a kit of rock samples selected with different levels of natural radioactivity. It enables students to compare the radiation levels of igneous and sedimentary rocks, assess the effectiveness of shielding materials, or conduct long-term background radiation measurements.

The dedicated Android application extends the platform's functionality, enabling data exportation for analysis and the sharing of results to support collaborative and citizen science initiatives. This integrated digital environment allows students to rigorously evaluate experimental reliability, precisely calculate uncertainties, and empirically demonstrate their dependence on measurement duration, thus bridging practical observations with underlying theoretical principles. Furthermore, the concurrent display of data as both Counts Per Minute (CPM) and equivalent dose rate (nSv/h) clarifies the understanding of absorbed dose concepts. Teachers can utilize the platform to design curriculum-aligned experiments that foster an interdisciplinary integration of physics, Earth science, and statistics. In the context of contemporary energy discussions, RockyRad promotes scientific inquiry and critical awareness by grounding students' understanding of environmental radiation.

Rapid Analyses of Uranium and Thorium Molten Chloride Salts for Reactor Safeguards

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Introduction

Advanced Molten Salt Reactors (MSRs) are being developed around the world to close the nuclear fuel cycle and ensure long-term, reliable sources of energy. Unlike traditional solid fueled reactors, the liquid nature of the MSR reactor core lends itself to online reprocessing for the extraction of fissile material isotopes including uranium-233 and plutonium-239. To reduce proliferation concerns and support the widespread deployment of these technologies, systems and methods enabling near-real time determination of the fissile material content within the core are currently needed. To this end, we report development of a field-portable sample dissolution, chemical separation, and alpha/gamma spectrometry system for near-real time actinide analyses from highly radioactive molten salt samples. The system enables rapid, in-field forensic evaluation of radioactive molten salt samples, thereby enabling verification of reactor operator declarations.

Description of the Work or Project

Initial development of the system was performed using non-radioactive surrogate molten salts. Following initial development, a prototype, hand-carriable chemical processing system was constructed. Proof-of-principle demonstration of this system was performed using highly radioactive (> 1 Sv/hr) irradiated thorium and uranium molten salt samples. Radioactive samples were received at Idaho National Laboratory within 24 hours of fission. Sample dissolutions were performed in a vented Teflon vial, following which the dissolved sample was separated using a semi-automated series of low-pressure chromatography columns. Following separation, purified actinide solutions were passed directly through thin filters containing a strong cation exchanger (Triskem), following which the filters were dried and transferred to field-portable alpha and gamma spectrometry systems for analysis. Chemical yields for plutonium, thorium and uranium were consistently > 95%, enabling rapid quantification of the total quantities and isotopic purity of fissile isotopes within the molten salt samples. Key metrics including timelines and uncertainties achievable for various fissile isotopes will be reported in this poster.

Conclusions

The field-portable system and method reported in this poster enables rapid quantification of fissile isotopes within highly radioactive molten salt samples. When deployed in a fixed laboratory, this compact system can assist in reducing analytical costs and increasing sample throughput. The system is also intended to be deployable by field inspectors for rapid, in-field measurements at a molten salt reactor or co-located facility, thereby strengthening safeguards and materials accountability efforts for molten salt reactors.

SCALABLE B-RADIATION EXFOLIATION OF ZN–AL LDH: MECHANISTIC INSIGHTS INTO HIGH-FLUX NANOCOMPOSITE MEMBRANES

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Introduction

Two-dimensional layered double hydroxides (LDHs) have attracted significant interest as functional fillers in separation membranes due to their tunable composition and charge-balancing capabilities. However, their high stacking affinity restricts accessible surface area and interfacial interactions within polymer matrices, limiting overall membrane performance. To overcome these limitations, radiation technology offers a promising route for structural modification and nanosheet delamination through controlled energy transfer mechanisms.

Description of the Work or Project

In this work, a β-radiation-induced exfoliation process was developed to delaminate Zn–Al LDH nanosheets, producing defect-free structures with a 61% increase in BET surface area (from 189.2 to 304.0 $m^2 g^{-1}$) and a reduction in basal spacing (from 0.893 to 0.756 nm). Morphological and optical analyses confirmed the formation of thinner nanosheets with improved dispersion and minimized aggregation within the polymer phase. The exfoliated LDH (eLDH) was incorporated into polysulfone (PSf) substrates, followed by polyethylenimine (PEI) spray coating to form thin-film nanocomposite membranes. The resulting membranes demonstrated enhanced hydrophilicity, significantly higher water flux, and improved ion rejection compared to those containing pristine LDH. Mechanistic evaluation revealed that exfoliation exposed more active sites, reduced transport tortuosity, and promoted uniform filler distribution, leading to superior interfacial performance.

Conclusions

The results demonstrate that β-radiation-assisted exfoliation is a scalable, cost-effective, and environmentally friendly technique for preparing high-performance nanomaterials and functional membranes. This approach provides valuable insight into the role of radiation in material engineering and can be extended to other two-dimensional materials for isotope-related separation, purification, and waste management applications.

Keywords:
β-radiation exfoliation, layered double hydroxide, nanocomposite membrane, polyethylenimine, ion separation

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CASE STUDIES ON APPLICATION OF RADIATION DOSE ASSESSMENT PROGRAM

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Introduction

To optimize occupational dose for nuclear power plant workers, an effective worker dose assessment program needs to be developed. Developing such a program requires a prior review and analysis of existing use cases of dose assessment programs. VISIPLAN is a deterministic code designed for worker dose assessment and work plan optimization under the ALARA (As Low As Reasonably Achievable) principle. This paper presents an analysis of two case studies in which VISIPLAN was implemented for occupational dose assessment.

Description of the Work or Project

First, we analyzed a worker dose assessment case for the decommissioning work at Hot Cell 41. Hot Cell 41 is a facility used for reprocessing ceramic fuel and highly enriched uranium spent fuel. In this case, the dose-rate map was generated by 1) geometry modeling, 2) input of source-term data, 3) recalculation of radioactivity using on-site TLD measurements, and 4) dose-rate map derivation. Based on the resulting map, work plan was optimized in accordance with ALARA principle. The collective dose was 0.021 man Sv, and VISIPLAN underestimated the measured collective dose by approximately 20%.

Second, we analyzed a worker dose assessment case for construction work around the BR2 heat-exchanger area. In this case, the dose-rate map was generated by 1) scanning the source distribution using BNFL Instruments' gamma scanner (RadScan 700), 2) modeling the geometry and source term from the scan results, and 3) dose-rate map derivation. Based on the resulting map, work plan was optimized in accordance with ALARA principle. The prediction error of VISIPLAN was about 20~30 % when compared with the measured worker doses. This error is presumed to result from incomplete representation of as-built field conditions and the inherent variability of the work environment.

Conclusions

We analyzed two VISIPLAN-based worker dose assessment cases—Hot Cell 41 decommissioning and construction work around the BR2 heat-exchanger. It is judged that this study can be used as foundational data for the development of worker dose assessment programs. * This work was supported through the National Research Foundation of Korea (NRF) using the financial resource granted by the Ministry of Science and ICT (MSIT). (No. RS-2022-00143994).

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Keywords: dose assessment program, ALARA, occupational dose

DERIVATION OF CROP TRANSFER FACTOR IN KOREA

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Introduction

RADTRAN, a for analyzing the risks and consequences of transporting radioactive materials, can evaluate the internal dose from ingestion pathway. Because the model is based on data from the country where it was developed, there are limitations in reflecting the characteristics of the user country. RADTRAN was found to consider crop transfer factor in the assessment of the ingestion pathway. The purpose of this study is to derive crop transfer factor representing the characteristics of Korea.

Description of the Work or Project

At first, we analyzed the methodology for deriving crop transfer factors. Through the analysis of the method, the components of the transfer factor were listed. Then, the components related to the domestic environment and vegetation were identified, and corresponding values reflecting domestic characteristics were investigated. According to the Korean regulatory guide, crops are classified into four types, and the components were determined for each type. Percent of land in farms and agriculture productions were derived using Korean statistical data. Finally, crop transfer factors were derived for each nuclide and crop type. The values for 10 representative nuclides are presented in Table 1.

Table 1: Crop transfer factor by categories

Nuclide	Grains	Fruits	Kimchi Vegetable	Leafy Vegetable
Co-60	1.41×10^{-4}	2.20×10^{-5}	1.23×10^{-5}	2.56×10^{-6}
Sr-90	1.61×10^{-4}	2.95×10^{-5}	2.41×10^{-5}	4.31×10^{-6}
Ru-106	1.22×10^{-4}	1.92×10^{-5}	1.10×10^{-5}	2.35×10^{-6}
I-131	2.16×10^{-6}	3.28×10^{-7}	1.46×10^{-7}	7.18×10^{-8}
Cs-134	1.32×10^{-4}	2.02×10^{-5}	1.06×10^{-5}	2.30×10^{-6}
Cs-137	1.55×10^{-4}	2.65×10^{-5}	1.89×10^{-5}	3.53×10^{-6}
Ce-144	1.13×10^{-4}	1.70×10^{-5}	8.53×10^{-6}	1.96×10^{-6}
Eu-154	1.42×10^{-4}	2.17×10^{-5}	1.13×10^{-5}	2.42×10^{-6}
Pu-239	1.50×10^{-4}	2.28×10^{-5}	1.16×10^{-5}	2.46×10^{-6}
Am-241	1.49×10^{-4}	2.26×10^{-5}	1.15×10^{-5}	2.44×10^{-6}

Conclusions

In this study, we derived the crop transfer factor reflection Korean environment and vegetation. The results of this study are expected to be utilized in future risk assessment fro the transportation of radioactive waste in Korea. *This work was supported by the Nuclear Safety Research Program through the Korea Foundation Of Nuclear safety (KoFONS) using the financial resources granted by the Nuclear Safety and Security Commission (NSSC) of the Republic of Korea (No. RS-2021-KN059910).

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Keywords: RADTRAN, crop transfer factor, ingestion pathway, Korean environment

DOSE ASSESSMENT OF IONIZING RADIATION THROUGH RADIOSENSITIVE PROTEIN IGFPB3 IN MICE

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Introduction

With the rapid development of precise cancer therapy, radiopharmaceuticals play an important role in the treatments of diffuse and metastatic tumors. Intravenous injection of the radiopharmaceuticals is a common administration method. Before the radiopharmaceuticals reach the tumors. some radioisotopes may undergo off-target effect and redistribution, usually accumulating in the liver, kidneys and bone marrow, causing radiation toxicity. Therefore, rapid dose assessments in vital organs such as liver during the treatments are very valuable for the safety evaluation of radiopharmaceuticals.

Description of the Work or Project

It is well known that proteins originated from various organs, tissues or cells can be rapidly and precisely detected. Our previous proteomic research identified that some proteins in blood such as Insulin-like Growth Factor Binding Protein 3 (IGFBP-3), Serum Amyloid protein A (SAA) and Matrix Metalloproteinase-2 (MMP-2) showed significant increased levels after the mice were exposed to ionizing radiation. However, the underlying mechanisms of the changes of these radiosensitive proteins have not been elucidated clearly.

Here, mice were subjected to total body, head, chest and abdomen irradiation, respectively. The IGFBP-3 levels were measured via Enzyme Linked Immunosorbent Assay (ELISA), Western blot (WB) and Immunohistochemistry (IHC) post-irradiation. It was found that the IGFBP-3 levels showed significant increases in blood and liver tissue of the mice exposed to total body and abdomen irradiation with carbon ions, protons or X-rays. The change of the IGFBP-3 levels in blood is dose-dependent and could be detectable as early as 6 h after irradiation. Meanwhile, similar dose response of the IGFBP-3 levels was also observed in the blood samples from patients receiving radiotherapy.
The IHC results of the liver tissues showed that the levels of IGFBP-3 in the liver cell nuclei and the nonparenchymal cells within the hepatic sinusoids significantly increased. Furthermore, investigations with different kinds of liver cell lines revealed that the IGFBP-3 level in Kuppfer cells (liver macrophages) increased significantly both in intracellular and extracellular after irradiation, indicating that the liver may be the main source of radiosensitive IGFBP-3 in vivo.

Conclusions

The IGFBP-3 level in the blood of mice is in a dose-dependent manner responding to ionizing radiation. This radiosensitive IGFBP-3 is mainly derived from the Kupffer cells in liver. Detecting the upregulation of IGFBP-3 may provide an effective and rapid assessment of radiation dose received by the liver during radiopharmaceuticals.

Keywords

Dose assessment; Liver; IGFBP-3; Radiopharmaceuticals.

INTEGRATION METHOD FOR DETERMINING THE POTENTIAL ALPHA ENERGY CONCENTRATION OF RADON AND THORON DECAY PRODUCTS IN AIR

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Introduction

Radon and thoron, as well as their decay products, pose a serious threat to human health. The problem of exposure to these radionuclides in underground workplaces (especially in mines) has been studied for years. Radon and thoron decay products can accumulate in the respiratory system and are sources of alpha, beta, and gamma radiation. In the case of internal contamination, alpha radiation is particularly dangerous due to its high linear energy transfer (LET) coefficient. Alpha radiation can cause cell damage and, as a consequence, induce cancer.

Description of the Work or Project

In order to assess radon and thoron hazards, a method has been developed that enables simultaneous measurement of the potential alpha energy concentration of radon and thoron decay products. The idea behind the developed method is to simultaneously collect radon and thoron decay products on a filter and then sequentially measure the potential alpha energy using thermoluminescent detectors. The diagram of the developed meter is shown in Figure 1.

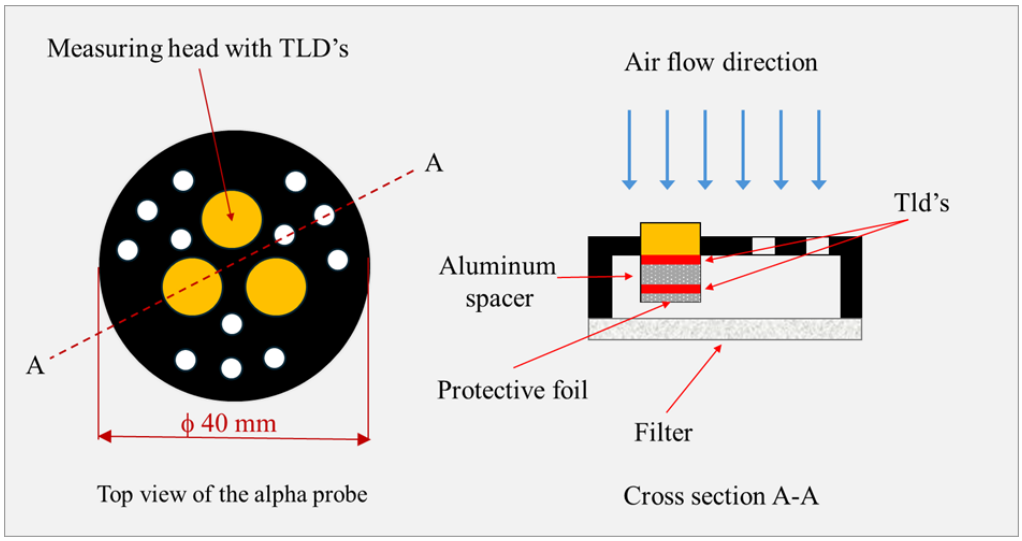

Figure 1. Schematic diagram of the alpha probe designed to measure the potential alpha energy concentration of radon and thoron decay products

Conclusions

The developed method has been verified in laboratory conditions as well as in situ, and the results of comparative tests confirm the effectiveness of the developed method.

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LISE MEITNER AND THE DISCOVERY OF NUCLEAR FISSION: A CASE OF MEMORY IN SCIENCE

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Introduction

The discovery of nuclear fission in 1938-1939 resulted from the close collaboration between Meitner, Hahn, and Strassmann. After her forced emigration from Germany due to her Jewish origins, Meitner continued to correspond with Hahn, following the progress of the Berlin experiments from exile. When Hahn and Strassmann identified barium among the products of uranium bombardment (Hahn and Strassmann 1939), Meitner—together with her nephew Frisch (Frisch 1939; Meitner and Frisch 1939)—provided the theoretical explanation that framed the phenomenon as the splitting of the uranium nucleus.

Description of the Work

This work offers a historical reconstruction of the events leading to the discovery of nuclear fission, drawing on primary sources and historical analyses (Sime 1989; Sime 2010). It situates Meitner's intellectual contribution within the collaborative environment of the Kaiser Wilhelm Institute for Chemistry, emphasizing the interplay between experiment and theory and the continuing scientific dialogue maintained through letters after her exile. Beyond its historical dimension, the project explores how Meitner's experience illuminates broader aspects of scientific practice: a) the role of long-distance collaboration in sustaining research networks under political constraints; b) issues of ethical responsibility in scientific discovery and its applications; c) and the intersection between gender, exile, and recognition in shaping scientific memory. By retracing this episode, the work invites reflection on the processes through which scientific knowledge is constructed, communicated, and remembered, and on how social and cultural factors influence the visibility and acknowledgment of scientific contributions—particularly those of women in physics.

Conclusions

Reassessing Meitner's role in the discovery of nuclear fission highlights the complex interaction of experimental data, theoretical insight, and sociopolitical context in major scientific breakthroughs. Her case exemplifies how science advances through collaboration, interpretation, and dialogue—even across borders and under adversity. Integrating this historical narrative into the study of nuclear physics fosters a richer understanding of scientific practice and contributes to a more inclusive vision of scientific heritage.

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SYNTHETIC ZEOLITES (3A, 4A, 5A, 13X, NaP1) AND THEIR APPLICATION IN REMOVING RADIUM AND BARIUM FROM WATER

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Introduction

Water with elevated radium concentrations occurs as a result of uranium mining and processing, oil and gas extraction, phosphate and metal ore mining, coal mining, and naturally in some drinking and thermal waters. Radium in water poses a radiological hazard and contributes to environmental contamination, highlighting the need for effective removal methods.

Description of the Work or Project

A promising approach for removing radium isotopes from water is the use of zeolites (Samolej and Franus, 2025). Zeolites are microporous aluminosilicates characterized by an open framework of channels and a large specific surface area. In this study, synthetic zeolites NaP1, 3A, 4A, 5A, and 13X were examined. Zeolite NaP1 was obtained by hydrothermal synthesis from fly ash (Wdowin et al., 2014), while the others were commercial materials.

Experiments on radium removal from mine water were carried out using two zeolite forms: granules and fine powder, to assess how physical form affects sorption efficiency. Preliminary results of brine purification efficiency are presented in Figure 1.

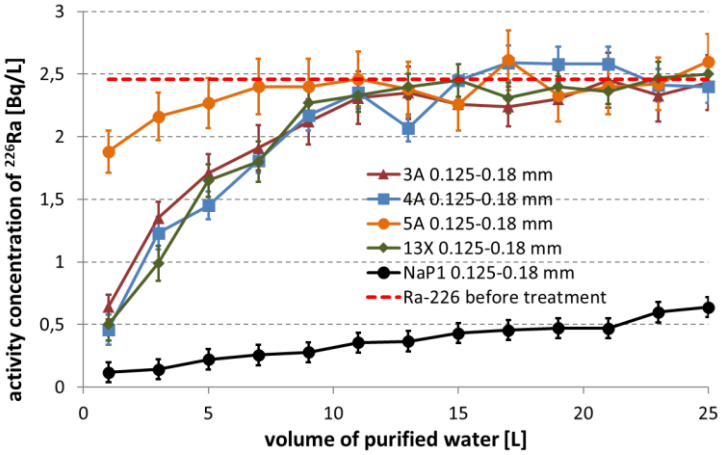

Figure 1: ^{226}Ra activity concentration in purified water as a function of water volume.

The presence of competing cations (Ca^{2+}, Sr^{2+}, Ba^{2+}) in water reduces radium removal efficiency due to their similar physicochemical properties. To better understand this effect, additional experiments on barium removal were performed using radioactive ^{133}Ba as a tracer.

Conclusions

The obtained results proved that the zeolites NaP1 prepared by hydrothermal synthesis showed the best purification performance amongst tested zeolites.

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NEUTRONIC FEASIBILITY STUDY OF DUAL-COOLED ANNULAR DUPLEX PUO2-THO2 FUEL FOR NEXT-GENERATION PW-SMRS: ASSEMBLY LEVEL ANALYSIS

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As we face a shortage of uranium and a growing demand for energy, the nuclear industry is stepping up with thorium-based fuels and innovative reactor designs. Nuclear power is a low-carbon and dependable energy source, but traditional fuel cycles have their challenges, especially regarding waste management and proliferation resistance. Small Modular Reactors (SMRs), like NuScale and AP300,are designed to improve safety and scalability, paving the way for next-generation fuels, including dual-cooled annular duplex designs that enhancether- mal efficiency and extend burnup [1, 2].

This research investigates the viability of employing dual-cooled annular duplex fuel (ThO_2–PuO_2) [3, 4] in PW-SMR assemblies, utilizing neutronic analysis through DRAGON and OpenMC codes [5, 6].

The research aimed to optimize the inner moderator radius while maintaining the fuel volume, identifying specific geometric configurations that enhance initial reactivity. The burnup analysis showed that PuO_2–ThO_2 fuels have a smoother decline in reactivity, which allows for extended cycles. While they may start with lower reactivity, the gradual decrease actually improves fuel usage. Safety evaluations confirmed negative temperature coefficients, emphasizing the poten- tial of PuO_2–ThO_2 fuel to improve the sustainability and economic aspects of advanced nuclear systems,Fig(1).

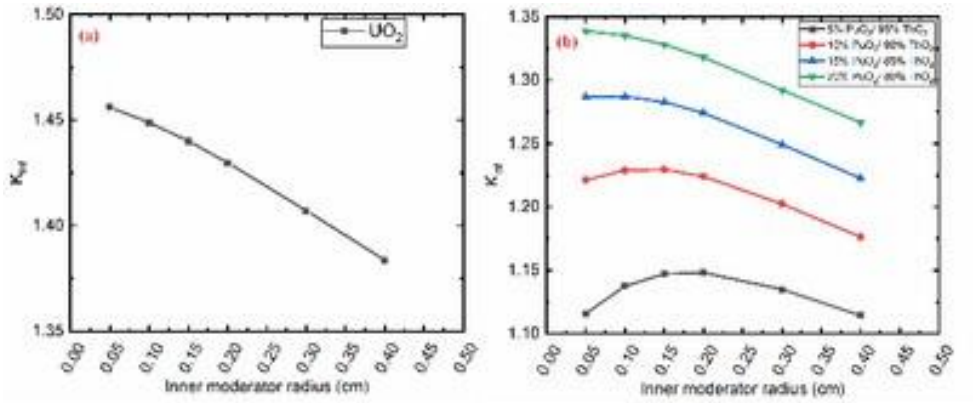

Figure 1: Infinite multiplication factor as a function of inner moderator radius: (a) UO_2 case, (b) PuO_2–ThO_2 cases.

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DESIGN OF A NAI(TI)-BASED RAPID SEAFOOD RADIOACTIVITY INSPECTION SYSTEM

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Introduction

Following the Fukushima nuclear accident, concerns about seawater contamination due to the release of treated wastewater into the ocean have been a persistent source of anxiety among domestic consumers in neighbouring countries regarding the potential radioactive contamination of seafood. Consequently, there has been an increasing demand for testing equipment that can quickly and accurately determine the presence of radioactive materials in seafood. Our previous study developed a system capable of detecting radioactive nuclides at a level of 100 Bq/kg in one minute[1]. However, since large volumes of seafood are handled at distribution sites and a safety standard of 50 Bq/kg is applied, we have developed an upgraded system for seafood sales sites that can measure radioactive substances at 50 Bq/kg levels and reduce measurement time to 30 seconds.

Description of the Work or Project

According to the Korean regulatory standards for radioactive materials in food, three radionuclides were selected for evaluation as target isotopes: I-131, Cs-134, and Cs-137. The sample was configured to represent fish with a density of 0.43 g/cm³ and a weight of 4.1 kg, based on data from Jagalchi seafood market in Busan, South Korea. The sample was modelled as being contained within a standard wooden box with the dimensions of 60 cm × 40 cm × 9.7 cm³, which is commonly used in domestic seafood wholesale markets. The radionuclides were assumed to be uniformly distributed throughout the entire sample volume. To minimize background radiation, 0.5 cm of lead shielding was applied to all surfaces of the detector except the detection face. An additional 0.5 cm of lead shielding was also placed along the sides and rear of the sample. The front door (for loading samples) and the bottom plate (for weighing samples) were left unshielded for operational reasons. Various detector configurations were evaluated in relation to measurement efficiency and detector thickness. The minimum detectable activity (MDA) was then identified for each configuration to achieve a detection limit below 50 Bq/kg.

Conclusions

In this study, the optimal detection system was determined by considering various detector configurations (i.e. the number of detectors, detector positions, and detector size) in order to achieve a system's MDA below 50 Bq/kg. The next step is to verify that the detector design meets the ANSI N42.38 standard for false alarm rates ($\leq 1/60$).

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SUBSTANTIAL AMYLOID CLEARANCE IN PET IMAGING BUT MINIMAL COGNITIVE CHANGE AFTER SIX MONTHS OF LECANEMAB

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Background and Objective
Lecanemab reduces brain amyloid in randomized trials, but short-term real-world data from Asian clinical practice are limited. We evaluated 6-month changes and safety in 2 consecutive amyloid PET imaging evaluating amyloid burden and cognition among patients treated at Ewha Medical Center.

Methods
We retrospectively identified consecutive patients who initiated lecanemab and completed baseline and ~6-month follow-up assessments. Outcomes included MMSE, CDR global, CDR-Sum of Boxes (CDR-SB), and amyloid-PET Centiloid (CL). Paired t-tests assessed within-person change; exploratory two-sample t-tests compared CL change by APOE ε4 status, baseline severity (CDR-SB <4.5 vs ≥4.5), and diagnostic category. Analyses used available pairs (missingness noted).

Results
Forty-one patients were included (mean age 72.3±7.5 years; 70.7% female), with diagnoses of subjective memory impairment (2.4%), mild cognitive impairment (24.4%), and dementia (73.2%). APOE ε4 genotype distribution was 56.1% non-carriers, 36.6% heterozygotes, and 7.3% homozygotes. Paired clinical outcomes were available for 29 patients and paired PET for 29–30 patients. Amyloid-PET Centiloid decreased significantly from 75.3±22.6 to 46.4±25.7, with a mean change of −29.0±17.8 CL (95% CI −35.7 to −22.2; p<0.0001). MMSE scores declined modestly from 22.76±4.82 to 22.14±5.74 (mean change −0.62 ±1.66; p=0.053), while CDR-SB worsened from 4.76±3.13 to 5.12±3.55 (mean change +0.36 ± 0.61; p=0.0035). CDR global scores increased slightly from 0.83±0.47 to 0.88±0.46 (mean change +0.052 ± 0.155; p=0.083).
Exploratory subgroup analyses showed numerically greater Centiloid reduction among APOE ε4 carriers compared with non-carriers (−34.6±11.9 vs −22.3±24.9 CL; p=0.126, one-sided p=0.063). Reductions were similar across baseline severity groups defined by CDR-SB <4.5 versus ≥ 4.5 (−29.7±23.9 vs −24.2±15.8 CL; p=0.504). Patients with MCI showed a trend toward larger reductions than those with dementia (−37.0±18.8 vs −23.8±21.6 CL; p=0.144, one-sided p=0.072).

Conclusions
In this real-world cohort, lecanemab was associated with a large 6-month reduction in amyloid-PET Centiloid (≈−29 CL), consistent with robust target engagement. Cognitive measures were overall stable to slightly worsened over 6 months, a time frame that may be too short to detect clinical benefit despite substantial amyloid clearance. Exploratory analyses suggested numerically greater Centiloid reductions among APOE ε4 carriers and those with MCI, but differences were not statistically significant. Larger, longer follow-up is warranted to relate biomarker changes to clinical trajectories.

OPTIMIZATION OF BEEF DIGESTION PROCEDURES FOR MULTIELEMENTAL DETERMINATION

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Introduction

Elemental profiling has been increasingly applied in beef traceability studies. Reliable multielement data are essential to support authenticity and quality assessments. However, beef is a complex organic matrix, rich in proteins and lipids, which directly affects the efficiency of microwave-assisted acid digestion. Proteins enhance heat generation, whereas lipids may adhere to vessel walls, reducing digestion efficiency and homogeneity[1]. Therefore, choosing appropriate procedure is essential to ensure complete decomposition for accurate and reproducible multielement determination.

Description of the Work

In this study, five acid digestion procedures were evaluated to optimize parameters such as sample mass, acid concentration, digestion time, and temperature, aiming to maximize the extraction efficiency of chemical elements in beef samples. Nine analytical portions of a beef rump cap sample were subjected to acid digestion using each of the procedures. The resulting solutions were analyzed by triple quadrupole inductively coupled plasma mass spectrometry (ICP-MS/MS) and microwave plasma optical emission spectrometry (MP-AES). Reproducibility was assessed based on the coefficient of variation of the values determined in the analytical portions of the rump cap sample. To verify the accuracy of the results and perform analytical quality control, the certified reference materials SRM 1566b Oyster Tissue, RM 8414 Bovine Muscle Powder, and BCR 668 Mussel Tissue were used. The procedure employing 500 mg of sample and 5 mL of HNO_3 (65% v/v) provided the highest overall accuracy, with satisfactory recoveries for 31 elements. However, the procedure using 250 mg of sample, 4 mL HNO_3 (65% v/v) and 1 mL H_2O_2 (30% v/v) showed similar accuracy (29 elements) while achieving a higher number of elements above the detection limits and improved reproducibility of measured mass fractions in the beef samples. This procedure also produced clear digests, ensuring efficient element extraction and was therefore considered the most suitable for multielement determination in beef samples.

Conclusions

The acid digestion procedure was optimized using the lowest mass and reagent consumption, which generated accurate and reliable results allowing the determination of the elements As, B, Ba, Ca, Ce, Cd, Co, Fe, Gd, K, La, Mg, Mo, Na, Nd, Pb, Pr, Rb, Sb, Sr, Th, U, V, Y, and Zn.

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DEVELOPMENT OF A GREEN COFFEE BEAN REFERENCE MATERIAL FOR MULTI-ELEMENTAL ANALYSIS

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Introduction

Coffee is the most widely consumed beverage worldwide and has major economic relevance. Ensuring its quality, safety and authenticity requires reliable analytical methods, which depend on well-characterized reference materials. Certified reference materials (CRMs) provide metrological traceability and support method validation. Given their importance, Brazil has been developing CRMs to strengthen analytical reliability in the coffee sector.

Description of the Work or Project

In 2018, at the Radioisotopes Laboratory of CENA/USP, a certified reference material of organic coffee beans (CRM-Agro C1007a – Café Verde) was produced within a postdoctoral research project. The material was developed for multi-elemental analysis to support studies on nutritional composition, quality, safety and authenticity, addressing a specific demand from the Brazilian coffee sector. Coffee samples of the *Catuai Vermelho* (IAC 99) variety were collected in Ibiraci, Minas Gerais state, and chemically characterized by neutron activation analysis (NAA), inductively coupled plasma optical emission spectrometry (ICP OES) and inductively coupled plasma mass spectrometry (ICP-MS). The material was prepared in accordance with ISO Guide 35, encompassing grinding, sieving, sterilization, storage and characterization steps. Physical profiling included particle size distribution and residual moisture, while chemical evaluation comprised homogeneity and stability tests. The reference material showed a residual moisture of 4.14 ± 0.14 % and a particle size below 175 µm, ensuring uniformity. Reference values were assigned based on the determination of Br, Ca, Co, Cs, Fe, K, Na, Sc, Sb, Rb and Zn by NAA; P, S, Ca, K and Mg by ICP OES; and B, Ba, Co, Cu, Mn, Rb and Sr by ICP-MS. Homogeneity within-bottle and between-bottles was confirmed for all elements, with relative standard deviations below 5 % for appropriate sample masses (10-100 mg for NAA; 50- 200 mg for ICP OES and ICP-MS). Stability testing confirmed that the reference values remained consistent for all determined elements, indicating the material's robustness over time and its suitability for long-term analytical use. The CRM demonstrated uniform elemental composition, suitable particle distribution and low moisture, ensuring analytical reliability.

Conclusions

The green coffee bean reference material exhibited consistent physical and chemical properties, providing a reliable tool for multi-elemental analysis, quality control and research applications in the coffee industry.

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MOCK YTTRIUM-90 GLASS SPHERE STANDARDIZATION FOR NUCLEAR MEDICINE APPLICATIONS

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Introduction

Standards for short-lived radionuclides are vital for accurate nuclear medicine calibration and patient care. The National Research Council of Canada (NRC) typically disseminates standards in common geometries such as 5 mL vials or flame-sealed ampoules, but some clinical products require unique calibration setups. One example is the Yttrium-90 (Y-90) glass sphere radiopharmaceutical used in selective internal radiation therapy. Recent multicenter PET/CT studies have shown significant discrepancies between vendor-stated and independently measured Y-90 microsphere activities [1], highlighting the need for precise calibration geometries in practice.

Description of the Work or Project

Producing a true Y-90 sphere standard requires dissolution of irradiated Yttrium glass, a complex process still under investigation. To meet an immediate client need, NRC prepared a mock standard using unirradiated ("cold") glass spheres surrounded by a standardized Y-90 solution.

An EGSnrc [2] Monte Carlo model was developed to account for some variations in the physical characteristics of the product, such as sphere mass (100–600 mg), Y-90 volume (0.25–0.5 mL), and presence or absence of beta shielding. This model enabled the evaluation of dose distribution and activity measurement configurations. Primary standardization was performed using TDCR and CIEMAT/NIST methods, with comparisons to ionization chamber measurements (Vinten IC) and provider-supplied activity values, resulting in uncertainties greater than 4% at k=2. This uncertainty is much larger than NRC typically disseminates, and given the large variation in the production of the radiopharmaceutical — including differences in sphere mass, activity distribution, and container geometry — the reported uncertainty is likely an underestimate.

Conclusions

The mock Y-90 glass sphere standard provided a rapid, practical solution for radionuclide calibration in a non-standard geometry. By mimicking the physical and radiological properties of the clinical product, the mock standard allowed accurate detector calibration without handling active glass spheres. This approach demonstrates NRC's capability to develop customized artifacts for nuclear medicine applications, ensuring traceability to the SI and meeting diverse client requirements. These findings, together with the reported differences in activity calibration for commercial microsphere products, highlight the metrological importance of developing a fully dissolved primary standard for Y-90 spheres to ensure accurate, traceable activity measurements across devices and modalities.

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INTEGRATED ENVIRONMENTAL RADIOACTIVITY MONITORING BY THE HEALTH PHYSICS GROUP AT LASA: THE EYE RAD NETWORK AND ^{137}Cs TRANSFER IN DAIRY SYSTEMS

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Introduction

The **Health Physics group at LASA laboratory** has a consolidated expertise in environmental radioactivity monitoring and nuclear analytical methods applied to air quality, radiological protection, and public health. Since the late 1990s, the group has contributed to national surveillance of atmospheric radionuclides and trace elements, notably during the **Fukushima Daiichi fallout event**, when isotopes such as ^{131}I, ^{134}Cs, and ^{137}Cs were detected in Northern Italy. Building upon this experience, current activities focus on two complementary fronts:

1. the establishment of **Eye RAD**, a real-time network for environmental radioactivity monitoring; and
2. the long-term assessment of **radionuclide transfer through the food chain**, with emphasis on cesium in alpine dairy systems.

Description of the Work or Project

Within the **EyeRAD (Environmental RADioactivity monitoring network)** INFN project, the group has deployed pilot stations equipped with **high-volume aerosol samplers** and **HPGe spectrometers** operating in continuous acquisition. Data are transmitted to a centralized platform for automatic processing and anomaly detection, enabling prompt response to potential radiological events. The system represents a scalable prototype for national integration of environmental monitoring infrastructures.

In parallel, the group investigates the **environmental persistence and biological transfer of ^{137}Cs** in the **Monte Rosa alpine region**, where fallout-derived cesium remains detectable more than a decade after Fukushima. Field sampling campaigns (2011, 2013, 2023–2024) have quantified ^{137}Cs concentrations in forage, cow feed, and milk, highlighting continued though low-level transfer from soil to dairy products. The measurements confirm the slow ecological turnover of radiocesium and its preferential uptake through the potassium metabolic pathway, providing valuable input for ingestion-dose assessment models.

The combination of continuous atmospheric monitoring (EyeRAD) and food-chain studies establishes a **comprehensive radiological surveillance framework**, linking airborne deposition, environmental transport, and internal exposure through local agricultural products.

Conclusions

The Health Physics group at LASA integrates high-resolution nuclear measurement techniques with long-term field studies to address environmental and dietary exposure to radionuclides. The Eye RAD network enhances early detection and situational awareness, while the dairy-transfer research provides critical data for realistic dose modelling. Together, these activities advance Italy's radiological preparedness and exemplify the synergy between scientific research, environmental protection, and public engagement.

TOWARDS MORE SUSTAINABLE ADVANCED RECYCLING OF SPENT NUCLEAR FUEL

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Introduction

The role of nuclear energy in the future energy mix is currently under discussion. Achieving a greener and more sustainable nuclear energy production requires maximizing the recycling of spent nuclear fuel while minimizing the environmental impact associated with partitioning and reprocessing operations. In this context, the pursuit of more sustainable strategies in nuclear fuel recycling is becoming increasingly important to reduce the overall footprint of current technologies.

Description of the Project

The present study discussed/focused on two significant case studies of how it is possible to enhance sustainability of advanced nuclear fuel recycling. On one side, the introduction of a hydrophilic CHON-compliant stripping agent in the extracting system of a hydrometallurgical process aiming at the Minor Actinides (MA) recovery from Spent Nuclear Fuel enables to obtain a stripping solution containing the ligand and MA cations that could be promptly incinerated to MA oxides. During the incineration, the presence of only carbon, hydrogen, oxygen and nitrogen in the composition leads to the formation of only gaseous aqueous vapours, nitrogen oxides and carbon dioxides, without other solid secondary waste. This is the case of the extracting system proposed for the innovative Selective ActiNide EXtraction process (*i*-SANEX) based on TODGA and PyTri-Diol. [1] On the other side, attempts are under investigation to replace traditional organic solvents with greener and cheaper hydrophobic phases based on Deep Eutectic Solvents (DES), reducing the use of petrochemical diluents and enabling to overcome ligand's solubility issues. [2, 3] In particular, the case of DES containing Tri-Octyl Phosphine Oxide ligand for SNF recycling is presented.

Conclusions

At the current stage, these approaches represent potential improvements over current reprocessing strategies, offering reduced environmental impact and enhanced sustainability for future nuclear fuel recycling processes.

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Keywords: Sustainability, Spent Nuclear Fuel Recycling, Deep Eutectic Solvents, CHON.

MEASURING TROPHIC TRANSFER OF CU INTO N. TRIANGULIFER FROM STROMWATER AND EFFLUENT SOURCES USING STABLE ISOTOPES

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Introduction

Existing regulations do not adequately take into account the dietary exposure of metals, in part because it is difficult to track. In this study, we use stable Cu isotopes within distinct organic matter exposure environments, either stormwater or effluent sources, to track differences in uptake and transfer of Cu from both aqueous and dietary (diatom) sources to an important stream indicator organism, the insect *N. triangulifer* (a mayfly).

Description of the Work or Project

Stormwater or effluent mixed with stream water, were prepared at specific dissolved organic matter concentrations and spiked with Cu^{65} to reach total Cu levels of 10 or 16 µg L^{-1}, established based on the expected acute and chronic toxicity levels in the United States. The dietary source, a diatom Nitzschia grown on glass microscope slides, was exposed to these source waters for 30 hours to equilibrate with the Cu^{65} spike. Cu uptake into *N. triangulifer*, was compared from aqueous exposure only, to uptake from the aqueous and dietary exposure over the course of 3 days.

The partitioning of Cu^{65} to the diatoms varied depending on the source of organic matter, whether stormwater or effluent, with effluent exposure leading to Cu^{65} levels of 62 µg L^{-1} and stormwater exposure leading to 85 µg L^{-1}, suggesting different lability with regards to Cu binding of the organic matter in those sources. When comparing uptake of Cu into mayflies, the aqueous exposure only indicated no difference in Cu uptake rates in the presence of stormwater compared to effluent. When comparing uptake of Cu including both aqueous and dietary exposure, the presence of the Cu^{65} isotope allowed the observation of a distinct and significant increase in Cu uptake at the intermediate and high levels of total Cu concentrations compared to the control in the presence of stormwater, and only at the intermediate level of Cu in the presence of effluent.

When tracking metal uptake under these scenarios, for the purpose of biodynamic modeling, the use of the isotope spike allowed for estimation of aqueous uptake rates and dietary uptake rates that were separated from already internalized Cu concentrations. Distinct rates of aqueous and dietary Cu uptake were determined using the Cu^{65} signal. Dietary Cu uptake rates were 0.28 and 0.54 g diatom g $mayfly^{-1}$ d^{-1}, while aqueous Cu uptake rates were 0.13 and 0.67 L g $mayfly^{-1}$ d^{-1}, respectively for effluent and stormwater source waters, leading to an estimate of 82% and 73% Cu uptake from effluent and stormwater sources, respectively.

Conclusions

While the use of total Cu measurements is reliable for mass concentrations in different components of the system, the use of stable isotopes in trophic transfer experiments, allows more precise estimates of aqueous and dietary uptake rates for use in biodynamic modeling, aiding in the estimation of Cu sources in natural systems.

Keywords: copper, insects, biodynamics, biouptake

RADON EXHALATION CAMPAIGN TO ESTIMATE GREENHOUSE GAS EMISSIONS USING THE 'RADON TRACER METHOD'

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Introduction

Within the framework of the institutional project "GHG emission monitoring in support of EU Climate targets" (GEM), the JRC-Ispra Dosimetry Service carried out a campaign to measure the exhalation rate of radon gas from soil. The results, in terms of exhalation, together with radon concentration data in air, allow the estimation of greenhouse gas emissions through the Radon Tracer Method (RTM).

Description of the Work or Project

The GEM project aims to provide estimates of greenhouse gas emissions, based on experimental observations, atmospheric models and inventories, which are used as independent data for verifying the accuracy and reliability of official emissions reported under the United Nation Framework Convention on Climate Change.

For the measurement of the exhalation rate of radon gas, the Dosimetry Service relied on the accumulation method according to the standard reference ISO, using an active radon gas concentration monitoring instrument coupled to an air pumping system and an accumulation chamber via high-density polyethylene tubes.
Knowing the volume of the chamber and the surface area of the sampling point, the analysis of the radon concentration trend inside the accumulation chamber allowed the estimation of its exhalation from the soil.

The Dosimetry Service carried out two year-long measurement campaigns at two distinct sampling points. Since each campaign covered a full year, the data effectively highlighted the seasonal variability of radon gas exhalation from the soil and the influence of the main physical parameters of the soil.

Conclusions

The focus of the study is the identification of a model for estimating radon exhalation from soil based on Soil Water Content (SWC).
The research is aimed at reducing the uncertainty of the estimates of greenhouse emissions estimates obtained using the Radon Tracer Method.

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We gratefully acknowledge the support of our **patrons, sponsors and partners** for their commitment to the advancement of **isotope science and its applications** in **medicine, energy, environment and fundamental research**. Their contributions have been **essential** in enabling scientific exchange, fostering **international collaboration** and supporting the **participation of researchers from all over the world**.
The **Organizing Committee** also thanks all **speakers, session chairs, reviewers and participants** for their active involvement and valuable contributions, as well as the **local organizing team** and the **conference secretariat** for their dedication and **professional support** throughout the preparation of the event.

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