



ANNUAL REPORT 2024

Prepared by :
Vietnam Atomic Energy Institute

Published in November, 2025

☎ 84 976 681 529 🌐 www.vinatom.gov.vn

📍 59 Ly Thuong Kiet, Ha Noi, Viet Nam

VIETNAM ATOMIC ENERGY INSTITUTE

The
ANNUAL REPORT
for 2024

Editorial Board

Dr. Tran Chi Thanh, Chief Editor
Dr. Nguyen Hao Quang
Assoc. Prof. Nguyen Thi Kim Dung
Dr. Hoang Sy Than
MSc. Nguyen Thi Dinh
Dr. Pham Kim Long
MA. Pham Thi Thu Trang

Hanoi, November 2025



Vietnam Atomic Energy Institute

To: All Readers

Date: 15 November, 2025

The Annual Report for 2024 aims to summarize the significant activities of the Vietnam Atomic Energy Institute (VinAtom) during the period 1 January to 31 December 2024.

The first main part of this publication seeks to provide the status and illustrative descriptions of VinAtom's activities and results of research, services, and applications.

The second part presents the reports of scientific research projects at ministerial and institutional levels which are accomplished and accepted during the year concerned. The research reports are categorized into the following subjects:

1. Nuclear Physics, Reactor Physics
2. Research Reactor, Nuclear Power Technology, Nuclear Safety, Nuclear Power Technology
3. Instrumentation, Nuclear Electronics
4. Industrial Applications
5. Applications in Ecology, Environment and Geology
6. Applications in Biology, Agriculture and Medicine
7. Radiation Safety and Radioactive Waste Management
8. Radiation Technology
9. Radiochemistry and Materials Science
10. Computation and other related topics.

The reports are expected to offer all readers an insight into the Institute's accomplishments in research and development throughout the year.

A photo collection covering VinAtom's 2024 remarkable events is added into this publication as a vivid description of what we have been through.

The pandemic will pass, but sustainable values remain. We sincerely thank those making great contributions and giving concern to the publication. We highly appreciate your continued trust, cooperation, and support.

Regards.

Editorial Board

Contact Us

+84 976 681 529 

phamtrangvinatom@gmail.com 

www.vinatom.gov.vn 

Contents

ABBREVIATIONS AND ACRONYMS	8
1- VINATOM 2024	10
1.1. VINATOM MEMBERS AND HUMAN RESOURCES	11
1.2. INVESTMENT RESOURCES	14
1.3. RESULTS OF RESEARCH, DEVELOPMENT AND APPLICATIONS	14
1.3.1. HIGHLIGHT OF RESEARCH ACTIVITIES AND SERVICE IMPLEMENTATION	14
1.3.2. RESULTS OF APPLICATIONS AND SERVICES	15
1.4. SCIENTIFIC PUBLICATIONS	20
1.5. TRAINING AND DEVELOPMENT OF HUMAN RESOURCES	21
1.5.1. Doctoral Training	21
1.5.2. Human Resources Development	21
1.6. INTERNATIONAL COOPERATION	22
1.6.1. Multilateral cooperation activities	22
1.6.2. Bilateral Cooperation Activities	25
1.7. INFORMATION AND COMMUNICATION	27
1.8. INVESTMENT PROJECTS	29
1.8.1. RESEARCH CENTER OF NUCLEAR SCIENCE AND TECHNOLOGY	29
1.8.2. UPGRADING THE TECHNOLOGY SYSTEMS AND FUNCTIONAL EQUIPMENT AND SUPPLEMENTING FUEL FOR THE DA LAT NUCLEAR REACTOR TO ENSURE ITS EFFECTIVE AND SAFE OPERATION AT LEAST UNTIL 2030	29
1.8.3. UPGRADING AND PROCUREMENT OF NEW EQUIPMENT AND RADIOACTIVE SOURCES FOR PRODUCTION, PERIOD 2021–2025	30
1.8.4. RENOVATION, UPGRADING, AND CONSTRUCTION OF NEW WORKSHOPS AND OFFICE BUILDINGS OF THE CENTER	30
1.8.5. INVESTMENT IN LABORATORY EQUIPMENT FOR RESEARCH ON ADVANCED MATERIALS AND RADIOACTIVE WASTE TREATMENT IN COASTAL MINERAL PROCESSING	30
2- RESEARCH REPORTS 2024	32
2.1. NUCLEAR PHYSICS, REACTOR PHYSICS	33
STUDY ON MEASUREMENT OF ELASTIC SCATTERING CROSS SECTIONS OF $^{197}\text{Au}(p,p_0)$ REACTION IN LOW PROTON ENERGY REGION USING THE PELLETRON 5SDH-2 ACCELERATOR 34	
Do Thi Khanh Linh, Le Xuan Chung, Tran The Anh, Bui Thi Hoa, Nguyen Hai Ninh	
STUDY ON DETERMINATION OF RADIOISOTOPES IMPURITIES GENERATED DURING THE SYNTHESIS OF ^{18}F RADIOISOTOPES ON THE KOTRON13 CYCLOTRON	36
Mai Van Vinh, Dam Thi Tam, Nguyen Tuan Anh, Nguyen Xuan Viet, Nguyen Bich Thuy	
STUDY OF THE STRUCTURE OF UNSTABLE NUCLEI Be, C AND O THROUGH THE ANALYSIS OF THE DIFFERENTIAL CROSS-SECTION DATA OF PROTON-NUCLEUS AND DEUTERON-NUCLEUS REACTIONS	40
Do Cong Cuong, Dao Tien Khoa, Nguyen Hoang Phuc, Le Xuan Chung, Do Thi Khanh Linh, Nguyen Hai Ninh, Nguyen Tri Toan Phuc, Nguyen Duc Kien	

NUCLEAR REACTION STUDY ON NATURAL BORON ISOTOPES WITH LOW-ENERGY PROTON BEAM FROM THE 5SDH-2 PELLETRON ACCELERATOR	44
L.X. Chung, D.T.K. Linh, L.T. Anh, N.T. Anh, T.T. Anh, M.V. Dien, B.T. Hoa, P.D. Khue, N.T. Nghia, Đ.T. Tran	
2.2. RESEARCH REACTOR, NUCLEAR POWER TECHNOLOGY, NUCLEAR SAFETY, NUCLEAR POWER ECONOMY	49
DEVELOPMENT AND IMPROVEMENT OF EXPERIMENTAL MEASUREMENT TECHNIQUES FOR NATURAL CONVECTION FLOW	50
Thanh Tung Duong, Thanh Tram Tran, Tri Vien Tran, Hoang Tuan Truong, Chi Thanh Tran, Tat Thang Nguyen, Hiroshige Kikura	
STUDY ON PHYSICAL DESIGN, THERMAL-HYDRAULIC ANALYSIS, AND SAFETY ASSESSMENT OF A SMALL MODULAR REACTOR FOR A FLOATING NUCLEAR POWER PLANT	55
Nguyen Thi Thanh Thuy, Vo Thi Huong, Duong Thanh Tung, Hoang Tan Hung, Le Tran Chung, Tran Thanh Tram, Nguyen Thi Dung, Cao Dinh Hung, Pham Nhu Viet Ha	
2.3. INSTRUMENTATION, NUCLEAR ELECTRONICS	60
STUDY AND DEVELOPMENT OF A GAMMA CAMERA USING SILICON PHOTOMULTIPLIERS AND A YSO(CE) SCINTILLATOR ARRAY	61
Lai Viet Hai, Nguyen Thi Minh Hien, Dang Quoc Trieu	
STUDY ON DEVELOPMENT OF AN ENVIRONMENTAL RADIATION MONITORING SYSTEM USING A NaI-SiPM SCINTILLATION DETECTOR COMBINED WITH THE INTERNET OF THINGS (IoT).....	64
Vu Van Tien, Mai Văn Dien, Nguyen Duc Tuan, Vu Trung Tan, Đinh Anh Tuan, Bui Duc Ky, Vuong Thu Bac, Nguyen Hai Ninh, Nguyen Thanh Hung	
2.4. INDUSTRIAL APPLICATIONS.....	69
RESEARCH AND APPLICATION OF LOW VOLTAGE TECHNIQUES TARGET TO DETECT AND LOCATE LEAKS IN WATERPROOF MEMBRANES ON THE CONCRETE SURFACE	70
Dinh Quoc Dat, Nguyen Duc Huyen, Nguyen Xuan Thao, Nguyen Tien Phong, Luong Thi Hong	
DEVELOPMENT OF THE TRAINING PROGRAM ON ULTRASONIC TESTING METHODS FOR CARBON STEEL CASTINGS IN ACCORDANCE WITH THE REQUIREMENTS OF SNT-TC-1A BY THE AMERICAN SOCIETY FOR NON-DESTRUCTIVE TESTING.....	74
Pham Thanh Tung, Dao Dinh Dang, Nguyen Minh Duc, Nguyen Van Du, Ngo Thi Kieu Oanh	
A STUDY ON THE APPLICATION OF NON-DESTRUCTIVE TESTING (NDT) METHODS TO ASSESS THE CURRENT STATUS OF SOME IMPORTANT SAFETY COMPONENTS OF THE DALAT NUCLEAR REACTOR	77
Tran Dang Manh, Doan Phuc-Thuan, Mai Thai Nam, Vu Duc Vinh, Vu Xuan Thanh, Nguyen The Man, Pham Minh Tuan, Pham Quang Huy, Nguyen Kien Cuong	
2.5. APPLICATIONS IN ECOLOGY, ENVIRONMENT AND GEOLOGY.....	82
STUDY ON ESTABLISHING A PROCEDURE FOR DETERMINING STABLE ISOTOPE VALUES ($\delta^{13}\text{C}$, $\delta^{15}\text{N}$) IN MARINE FISH SAMPLES FROM COASTAL AREAS	83
Nguyen Duc Tam, Nguyen Tai Tue, Nguyen Thi Hong Thinh, Luu Viet Dung, Vu Hoai, Mai Dinh Kien, Vu Thi Hien, Phuong Hai Yen	
EXPERIMENTAL STUDY TO IDENTIFY THE ORIGIN OF TUYEN LAM LAKE SEDIMENTS USING ISOTOPIC TECHNIQUES	87

Le Xuan Thang, Nguyen Thi Huong Lan, Phan Son Hai, Nguyen Minh Dao, Vo Tran Quang Thai, Nguyen Huu Nghia, Tran Tuan Anh, Tran Quang Thien, Phan Quang Trung, Vo Thi Mong Tham, Tuong Thi Thu Huong, Chau Thi Nhu Quynh, Nguyen Viet Duc	
2.6. APPLICATIONS IN BIOLOGY, AGRICULTURE AND MEDICINE	91
SUMMARIZATION OF THE PROCESS OF DEVELOPING A SECONDARY STANDARD FOR RADIOACTIVITY OF I-131 IN VIETNAM	92
Dinh Xuan Hoang	
PREPARATION OF ESSENTIAL OILS ENCAPSULATED LIPID NANOEMULSIONS FOR THE PREVENTION AND TREATMENT OF BOTRYTIS CINEREA CAUSING DISEASE IN STRAWBERRIES	96
Tran Thi Ngoc Mai, Le Xuan Cuong, Vu Ngoc Bich Dao, Nguyen Ngoc Thuy Trang, Le Van Toan	
PREPARATION OF NANOSTRUCTURED LIPID CARRIERS CO-ENCAPSULATING HAEMATOCOCCUS PLUVIALIS EXTRACT AND PALM OIL FOR SKIN PROTECTION AGAINST UV RADIATION	99
Vu Ngoc Bich Dao, Nguyen Minh Hiep, Tran Thi Ngoc Mai, Nguyen Vo Duy Tuan, Pham Ho Thuat Khoa, Le Thi Thu Thuy, Pham Bao Ngoc	
STUDY ON THE DEVELOPMENT OF AN ANALYTICAL PROCEDURE TO DETERMINE THE TOTAL AND BIOAVAIABLE RARE EARTH ELEMENTS CONTENT IN ALLUVIAL SOIL SAMPLES USING ICP-OES	102
Tran Hoang Mai, Le Ba Thuan, Ngo Quang Huy, Luu Xuan Dinh, Nguyen Dinh Viet	
THE STUDY ON DETERMINING ORGANIC-GROWN DALAT STRAWBERRIES IS BASED ON $\delta^{15}\text{N}$ ISOTOPE COMPOSITION USING THE EA-IRMS SYSTEM	107
Nguyen Huu Nghia, Tran Quang Thien, Nguyen Minh Dao, Le Xuan Thang, Nguyen Thi Huong Lan, Vo Thi Mong Tham, Le Van Toan, Pham Dinh Hai	
2.7. RADIATION SAFETY AND RADIOACTIVE WASTE MANAGEMENT	109
STUDY ON ESTABLISHMENT OF PHOTON REFERENCE FIELDS IN ACCORDANCE WITH THE NEW ICRU95 OPERATIONAL QUANTITIES	110
Bui Duc Ky, Nguyen Ngoc Quynh, Nguyen Huu Quyet, Tran Thanh Ha, Pham Bao Ngoc, Bui Thi Anh Dzung, Nguyen Dang Nguyen, Dang Thi My Linh, Duong Thi Nhung, Tran Van Trung, Dang Thi Minh Hue, Do Thi Hai	
2.8. RADIATION TECHNOLOGY	115
STUDY ON FABRICATION OF MAGNETIC IRON OXIDE/CHITOSAN ADSORBENTS GRAFTED BY IRRADIATION FOR ENHANCED REMOVAL OF HEAVY METAL IONS FROM AQUEOUS SOLUTIONS	116
Nguyen Thi Kim Lan, Dang Van Phu, Nguyen Chi Thuan, Ngo Phu Trieu, Nguyen Ngoc Duy	
STUDY ON ENHANCEMENT OF STRUCTURAL PROPERTIES AND PHOTOCATALYTIC ACTIVITY OF BiVO_4 THIN FILMS VIA PHOSPHOR (P^+) ION BEAM IRRADIATION	120
Luu Anh Tuyen, Pham Thi Hue, Nguyen Thi Ngoc Hue, Phan Trong Phuc, La Ly Nguyen, Lo Thai Son	
2.9. RADIOCHEMISTRY AND MATERIALS SCIENCE	123
STUDY ON HEAP LEACHING TECHNOLOGY PROCESS TO OBTAIN RARE EARTHS FROM ION-ADSORBED CLAY-KAOLINITE MINERALS	124
Nguyen Van Tung, Nguyen Thi Lien, Luu Xuan Dinh, Ngo Quang Huy, Nguyen Trong Hung, Bui Ba Duy, Le Quang Vu, Nguyen Thi Men	

STUDY ON ENHANCING THE EFFICIENCY OF MONAZITE CONCENTRATE DECOMPOSITION BY ULTRASOUND-ASSISTED ALKALINE LEACHING TECHNOLOGY	129
Hoang Xuan Thi, Hoang Nhuan, Tran The Dinh, Tran Ngoc Ha, Hoang Van Duc, Ngo Van Tuyen, Luu Xuan Dinh, Le Hong Minh, Nguyen Thi Men, Hoang Thi Tuyen, Vuong Huu Anh, Nguyen Thanh Chung, Nguyen Van Tung, Vu Thi Phuoc	
STUDY ON THE PROCESSING TECHNOLOGY OF BINH THUAN MONAZITE CONCENTRATE BY PRESSURE ALKALI METHOD TO OBTAIN RARE EARTH CHLORIDES	138
Luu Xuan Dinh, Nguyen Dinh Viet, Bui Cong Trinh, Tran Hoang Mai, Nguyen Thanh Thuy, Nguyen Trong Hung, Le Ba Thuan, Le Thi Giang, Le Quang Vu, Ngo Quang Huy	
2.10. COMPUTATION AND OTHER RELATED TOPICS	146
STUDY ON THE CONDITIONS OF DECOMPOSITION OF LIMONITE ORE BY SULFURIC ACID TO OBTAIN Ni AND Sc.....	147
Trinh Nguyen Quynh, Nguyen Trong Hung, Tran Van Son, Bui Ba Duy, Truong Thi Ai, Nguyen Hong Ha, Cao Duy Minh, Do Thi Anh Tuyet	
STUDY AND DEVELOPMENT OF THE MOMENT METHOD FOR DETERMINING RESIDUAL OIL SATURATION IN THE NEAR-WELLBORE REGION INCLUDING DISPERSION AND HYDROLYSIS EFFECTS IN SINGLE WELL TRACER TECHNIQUE.....	152
Tran Trong Hieu, Nguyen Thanh Hai, Huynh Thi Thu Huong, Nguyen Huu Quang, Le Van Son, Nguyen Thi Kim Anh	
A SIMULATION STUDY ON EDDY CURRENT SIGNALS OF TYPICAL ARTIFICIAL DISCONTINUITIES ON NON-FERROMAGNETIC TUBES TO ASSESS THE CURRENT CONDITION OF THE HEAT EXCHANGE SYSTEM	155
Pham Thi Lan Anh, Đâu Tuyet Nhung, Nguyen Nhat Quang, Vu Huy Bach	
A STUDY ON THE APPLICATION OF ARTIFICIAL INTELLIGENCE (AI) FOR THE IDENTIFICATION AND QUANTIFICATION OF RADIONUCLIDE ACTIVITY FROM GAMMA ENERGY SPECTRA USING AN N-TYPE HPGE DETECTOR IN ENVIRONMENTAL RADIOACTIVITY STUDIES (SOIL SAMPLES).	158
Nguyen Thi Thu Ha Duong Đuc Thang, Nguyen Hao Quang, Le Đinh Cuong, Nguyen Huyen Trang, Pham Kim Long, Nguyen An Trung, Nguyen Chi Thanh, Phung Nhu Hai, Phan Tuan Anh	
3- PHOTO ALBUM	162
3.1. HEADQUARTERS	163
3.2. NON-DESTRUCTIVE EVALUATION CENTER.....	172
3.3. CENTER FOR APPLICATION OF NUCLEAR TECHNIQUES IN INDUSTRY	178
3.4. INSTITUTE OF NUCLEAR SCIENCE AND TECHNOLOGY	180
3.5. NUCLEAR TRAINING CENTER.....	190
3.6. NUCLEAR RESEARCH INSTITUTE.....	194
3.7. RESEARCH AND DEVELOPMENT CENTER FOR RADIATION TECHNOLOGY	197
3.8. INSTITUTE FOR TECHNOLOGY OF RADIOACTIVE AND RARE ELEMENTS	202
3.9. CENTER FOR NUCLEAR TECHNOLOGIES	206
3.10. HANOI IRRADIATION CENTER	207
4- APPENDICES.....	210
4.1. LIST OF VINATOM'S INTERNATIONAL SCIENTIFIC PUBLICATIONS IN 2024	211

4.2. LISTS OF INTERNATIONAL PROJECTS 2024	220
4.2.1 - LIST OF VIE PROJECTS 2024	220
4.2.2. LIST OF INT AND NON-RCA PROJECT 2024	220
4.2.3 - LIST OF FNCA PROJECTS 2024	223
4.2.4 - LIST OF RAS PROJECTS 2024	224

ABBREVIATIONS AND ACRONYMS

ANSN	Asian Nuclear Safety Network
CANTI	Center for Application of Nuclear Techniques in Industry
CNT	Center for Nuclear Technique
CNST	Research Center for Nuclear Science and Technology
Dr./PhD	Doctor of philosophy
EPC	Engineering, Procurement and Construction
FDG	Fluodeoxyglucose
FNCA	Forum for Nuclear Cooperation in Asia
FNPS	Floating nuclear power station
GMP	Good Manufacturing Practices
HIC	Hanoi Irradiation Center
IAEA	International Atomic Energy Agency
INST	Institute of Nuclear Science and Technology
ISI	Institute for Scientific Information
ITRRE	Institute for Technology of Radioactive and Rare Elements
JAEA	Japan Atomic Energy Agency
JINED	Japan International Nuclear Energy Development Company
NDE	Non-destructive Evaluation
NRI	Nuclear Research Institute
NTC	Nuclear Training Center
RCA	Regional Co-operative Agreement for Research, Development and Training Related to Nuclear Science and Technology for Asia and the Pacific
R&D	Research and Development
SMR	Small modular reactor
TC	Technical cooperation
VAEA	Vietnam Atomic Energy Agency
VARANS	Vietnam Agency of Radiation and Nuclear Safety
VietGAP	Vietnamese Good Agricultural Practices
VINAGAMMA	Research and Development Center for Radiation Technology
VINATOM	Vietnam Atomic Energy Institute
VND	Viet Nam Dong
WHO	World Health Organization

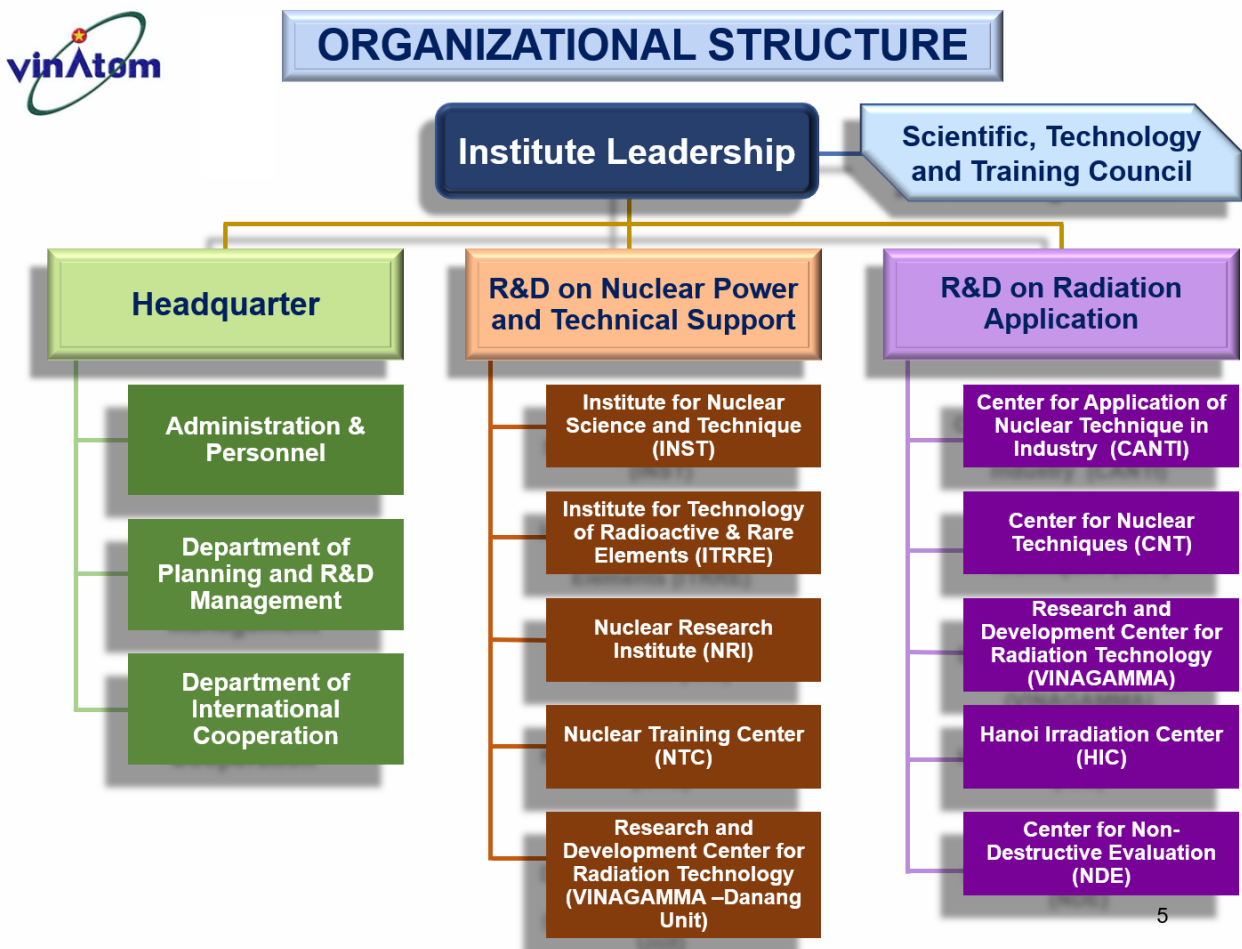
1- VINATOM 2024

1.1. VINATOM MEMBERS AND HUMAN RESOURCES

Vietnam Atomic Energy Institute (abbreviated as VinAtom), a scientific organization under Ministry of Science and Technology, performs the function of assisting the Minister in basic research, application and deployment of research results in the field of atomic energy, technical support for state management on atomic energy, radiation and nuclear safety, education and training in this field under the national laws. VinAtom has its own legal seal and is authorized to open accounts at the State Treasury and commercial banks for its operations in compliance with the law. Its headquarters are located at 59 Ly Thuong Kiet Street, Cua Nam Ward, Hanoi. The current organizational structure of VinAtom is as follows.

COMPOSITION OF VINATOM LEADERS (2024):

- Dr. TRAN Chi Thanh, President
- Dr. PHAM Quang Minh, Vice-President
- MSc. Do Hong Giang, Vice-President



VinAtom comprises 12 subordinate units, including 03 units under the Administrative Division and 09 units under the Research and Development Division. One research facility of VinAtom in Da Nang has been managed, operated, and deployed by Research and Development Center for Radiation Technology since January 14, 2019.



In 2024, under Decision No. 339/QĐ-BKHCHN dated March 6, 2024, VINATOM was assigned a total workforce of **765 employees** across its affiliated units.

In terms of professional qualifications, there are 80 doctorates (including 01 professor and 13 associate professors), 237 masters, 318 people with bachelor's degrees and 130 people with intermediate and elementary education degrees.

Regarding to professional titles, VINATOM has 25 senior researchers and equivalent, 69 principal researchers and equivalent, 502 researchers, engineers and equivalent, 52 technicians and equivalent, and 117 support employees.

With regards to age, there are 135 people under the age of 30 (corresponding to 17.4 %), 520 people in the 30-50 age group (67.9%), 110 people over 55 years old (14.37%).

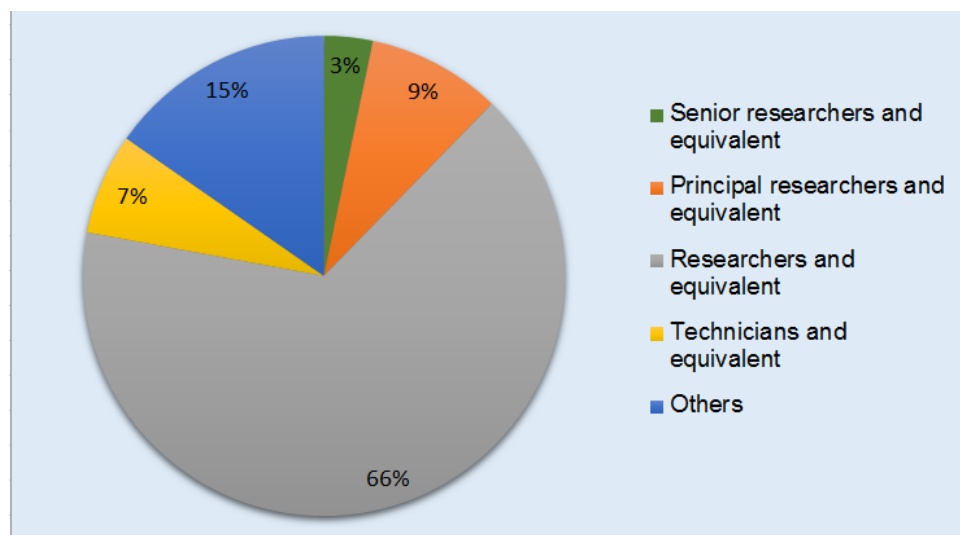
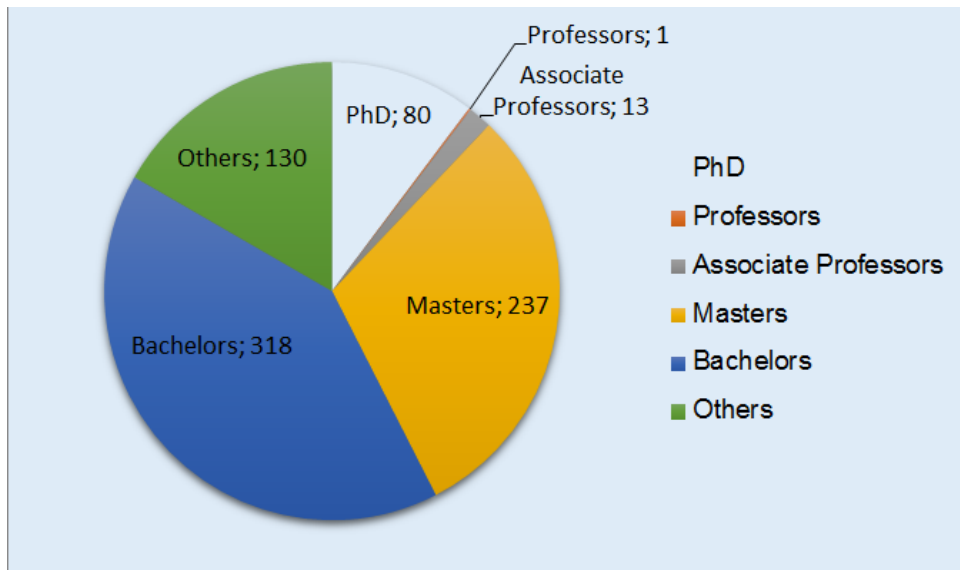


Figure 1 and Figure 2. Academic levels of VinAtom's staff

1.2. INVESTMENT RESOURCES

In 2024, the total investment resources allocated for implementing the activities of the Vietnam Atomic Energy Institute amounted to **VND 156,708.10 million**, of which **VND 149,848.90 million** was funded by the state budget, and **VND 6,859.87 million** was sourced from other funding channels.

1.3. RESULTS OF RESEARCH, DEVELOPMENT AND APPLICATIONS

1.3.1. HIGHLIGHT OF RESEARCH ACTIVITIES AND SERVICE IMPLEMENTATION

Research activities

In 2024, the Vietnam Atomic Energy Institute (VINATOM) published a total of 324 scientific works (papers), including: 93 papers in ISI-indexed international journals, 31 papers in SCOPUS and other international journals, 77 papers in national journals, 44 papers presented at international conferences, 77 papers presented at domestic conferences, one registered utility solution, and contributions to one international publication.

Awards and recognition

The Nuclear Research Institute was honored by the Ministry of Health with the “Vietnam Pharmaceutical Star” award for its products “I-131 Solution” and “I-131 Hard Capsule”, both produced on the **Đà Lạt Nuclear Research Reactor production line.

Events and commemorations

VinAtom successfully organized several events, notably the 40th Anniversary Celebration of the Restoration and Expansion of the Đà Lạt Nuclear Research Reactor.

Reactor operation

The Da Lat Nuclear Research Reactor was operated safely and efficiently, exceeding planned targets with a total operating time of 3,700 hours across 47 extended operation cycles at 500 kWt (compared to the planned 25 cycles, 100 hours each).

Radioisotope production

The production capacity of reactor-based radioisotopes for cancer diagnosis and treatment continued to be maintained and met domestic demand effectively, with a total production of 1,067 Ci in 2024 (against a target of 1,000 Ci), 100% of which was produced at the Da Lat Reactor.

Cyclotron operation

The 13 MeV Cyclotron accelerator at the Hanoi Irradiation Center, invested in 2013, has gradually achieved stable operation with promising results. By the end of 2024, the Center had produced over 300 batches of VinAtom FDG, supplying more than 160,000 mCi of FDG radiopharmaceuticals to major hospitals in Hanoi, supporting PET/CT diagnostic imaging for over 10,000 patients.

Radiation monitoring network

VinAtom ensured the continuous operation of the Environmental Radiation Monitoring and Early Warning Network, consisting of 11 monitoring stations across the country, one central control station at the Institute for Nuclear Science and Technology in Hanoi, and regional stations at the Da Lat Nuclear Research Institute and the Ho Chi Minh City Nuclear Center.

Scientific and technical services

Scientific, technical, and applied research services conducted by VinAtom’s affiliated units were maintained stably with positive growth in 2024. The total revenue of the Institute reached VND 441.39 billion for the year.

1.3.2. RESULTS OF APPLICATIONS AND SERVICES

In 2024, despite limited state investment resources, complex fluctuations in the global economic and political landscape, and numerous domestic challenges, the service and implementation activities of VinAtom’s affiliated units remained relatively stable. The Institute’s total revenue for 2024 (as of December) reached VND 441.39 billion, compared to VND 359.67 billion in 2023, as detailed below:

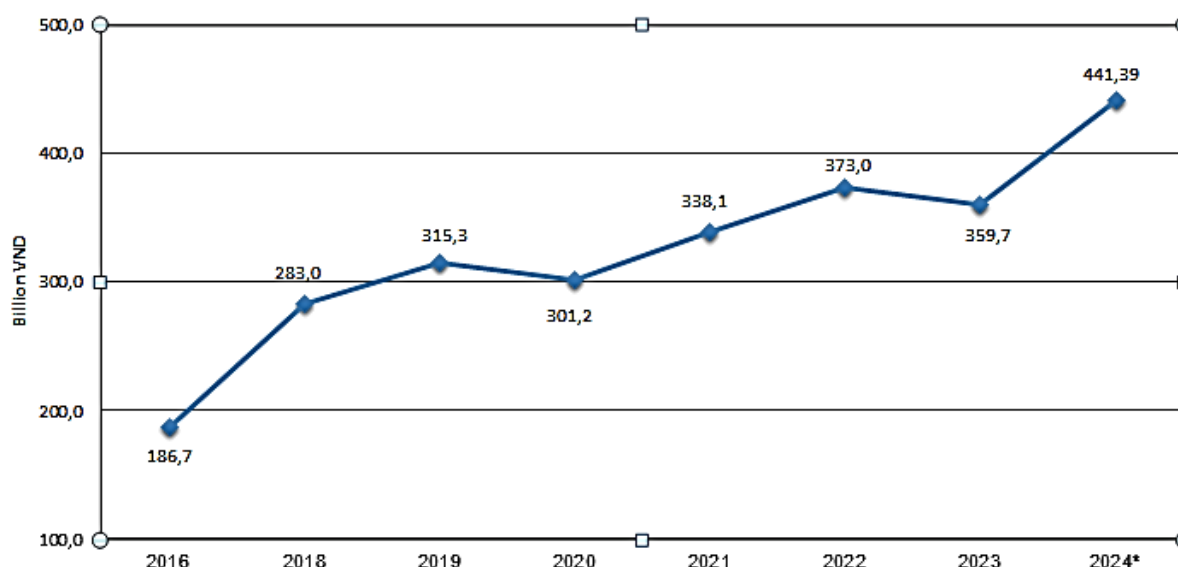


Figure 3. Total revenue from all types of services of VINATOM

Nuclear Research Institute (NRI)

NRI has continued to implement nuclear energy application services in support of the country's socio-economic development. Specifically:

- Production of radiopharmaceuticals in compliance with GMP-WHO standards, supplying 23 domestic institutions and hospitals with a total of 1,067 Ci of various radioisotopes (compared to 1,650 Ci in 2023, a decrease of 35.3%), with 100% of the output produced at the Đà Lạt Nuclear Research Reactor.

- Dosimetry services provided for nearly 5,800 radiation workers, with 23,879 personal dosimeter readings, calibration of 247 radiation measuring instruments, inspection of 106 medical X-ray devices, and radiation safety assessments and reports for 195 medical X-ray rooms and radioactive sources, including radioactive source transportation and storage.

- Analytical services performed for approximately 2,500 samples involving 8,500 parameters, in compliance with ISO/IEC 17025:2017 (VILAS 519), supporting export agricultural product quality assessment, domestic food safety assurance, and VietGAP evaluation and certification for 50 organizations.

- Environmental radioactivity analysis and inspection services, conducted in accordance with ISO/IEC 17025:2017 (VILAS 525), were carried out for various import-export goods samples.

The total revenue from NRI's implementation and service activities reached VND 48.2 billion (compared to VND 69.5 billion in 2023, a decrease of 30.6%), including:

- Production of radiopharmaceuticals and labeling kits: VND 34.9 billion
- Personal dosimetry, calibration, and equipment inspection services: VND 7.4 billion
- Analytical and environmental radioactivity analysis services: VND 4.9 billion
- Training and refresher courses on radiation and nuclear safety: VND 0.8 billion
- Other services: VND 0.3 billion

Institute for Nuclear Science & Technology (INST)

INST's research outcomes have been applied across various fields, including ionizing radiation metrology, radiation safety assurance, consultancy for radiotherapy and nuclear medicine facilities, radiation and environmental assessment and analysis, water resource evaluation, sample analysis, as well as training services, and maintenance and repair of nuclear equipment.

The total revenue from INST's application and technical service activities as of the end of November 2024 reached VND 21.96 billion, representing a 29.8% increase compared to VND 16.91 billion in the same period of 2023. The breakdown is as follows:

- Radiation safety and dosimetry services: VND 16.10 billion
- Analytical and environmental services: VND 3.55 billion
- Training services: VND 2.31 billion

Institute for Technology of Radioactive Waste and Rare Elements (ITRRE)

ITRRE is making continuous efforts to implement scientific and technological activities aimed at building a sustainable revenue structure, achieving financial autonomy, investing in research and development activities, and covering operational expenses.

Its traditional products have already established strong brand recognition in the market and are trusted and widely used by customers across various sectors. The Technology Deployment Center** and production teams at the Phùng facility continuously improve processes and management practices to enhance operational efficiency, maintain clean production environments, and strengthen wastewater treatment, emission and dust control, thereby ensuring environmental safety and promoting sustainable development.

In addition, ITRRE has collaborated with the Vietnam Rare Chemicals Joint Stock Company to provide technical consulting and support for radioactive waste management.

The total revenue of ITRRE in 2024 reached VND 145.56 billion, including:

- Production of zinc-based products: VND 140.00 billion
- Production of thermal stabilizers and inhibitors: VND 0.25 billion
- Analytical, testing, and evaluation services: VND 0.36 billion
- Consulting services for radioactive waste management: VND 0.83 billion
- Scientific and technological services with Laos and Korea: VND 0.65 billion
- Other services: VND 3.47 billion

Research and Development Center for Radiation Technology (VINAGAMMA)

VINAGAMMA is currently operating and utilizing three industrial irradiation facilities, including two Cobalt-60 gamma irradiators (SVST-Co60/B and VINAGA1) and an electron beam accelerator (UELR-10-15S2), to provide the following services: sterilization of medical and pharmaceutical products; pasteurization of seafood, dried and frozen foods; disinfection of insects and molds in agricultural products; and production of radiation-based products for applications in medicine, agriculture, and aquaculture (such as silver nanoparticles, chitosan-based products, superabsorbent materials, and plant and animal growth stimulants). The Center also provides consulting services, equipment supply, and materials** related to the field of industrial irradiation.

In 2024, the Center's total revenue reached VND 140.69 billion, including:

- Irradiation services: VND 58.00 billion
- Other services and miscellaneous income: VND 82.69 billion

Hanoi Irradiation Center (HIC)

Irradiation service is HIC's traditional and core activity, which has maintained stable operation with an annual revenue growth of 10–20%. In 2024, the Center attracted several new clients and expanded irradiation services to new product types, such as filter cores and functional materials for water purifiers.

The total irradiated goods volume in 2024 reached approximately 8,364 m³, equivalent to 1,971 tons of products, with a total irradiation time of about 5,000 hours. Revenue from irradiation services alone increased by VND 1.727 billion, representing a 14% growth compared to 2023.

The Center also continued to perform well in support services for radiation safety training, radiation measurement and monitoring, emergency preparedness planning, and consulting for licensing and license renewal documentation.

The production of the radiopharmaceutical Vinatom FDG showed significant growth in 2024**, increasing by VND 32.78 billion (up 214%) compared to 2023.

The estimated total revenue for 2024 was VND 58.38 billion, including:

- Irradiation services: VND 13.8 billion
- Radiation safety training and emergency response support: VND 2.35 billion
- Production of Vinatom FDG radiopharmaceuticals: VND 41.8 billion
- Financial revenue: VND 0.429 billion

Center for Application of Nuclear Techniques in Industry (CANTI)

CANTI achieved notable results in service implementation, particularly in the field of tracer applications. CANTI simultaneously executed several high-value tracer service contracts, delivering high efficiency and significant contributions to industrial production. Currently, the Center is implementing three contracts with the Vietnam–Russia Joint Venture (Vietsovetro), all of which are being carried out on schedule and with assured quality. Many of the Center’s service products have been promoted both domestically and internationally, and several new technologies and service products have been included in Vietsovetro’s 2025 implementation and testing plans. CANTI has effectively maintained the operation of its Analytical Laboratory in compliance with ISO/IEC 17025 standards, as well as ensured conformity in its service operations for industrial non-destructive testing (NDT), industrial and environmental tracer applications, and analytical services under the following international management systems: ISO 9001:2015 (Quality Management System); ISO 14001:2015 (Environmental Management System); ISO 45001:2018 (Occupational Health and Safety Management System)

The total revenue from service implementation activities in 2024 reached VND 6.53 billion, including:

- Analytical and environmental services: VND 0.33 billion
- Application of nuclear techniques in industry: VND 6.20 billion

Center for Nuclear Techniques, Ho Chi Minh City (CNT)

As of November 30, 2024, the service implementation revenue reached VND 4.65 billion, which did not meet the planned target of VND 6.5 billion. Notably, the revenue from analytical services declined significantly compared to 2023. CNT has not yet been authorized to include non-destructive testing (NDT)-related functions in its Charter on Organization and Operation. Consequently, this activity has not been incorporated into

CNT's Certificate of Science and Technology Operation, and therefore, CNT has been unable to register conformity assessment business activities in accordance with Decrees No. 107/2016/NĐ-CP and No. 154/2018/NĐ-CP.

NDE Center, Ha Noi

NDE continued to promote the application of research outcomes to industrial production and socio-economic activities, including:

- Training, assessment, and certification of NDT (Non-Destructive Testing) technician qualifications through over 80 training courses with participation from **more than 550 trainees;
- Level III NDT training for domestic and international experts, as well as managers from major corporations such as Nghi Sơn Refinery and Petrochemical LLC, Key Laboratory I, EVNGENCO 3 Power Plant Maintenance Services Company, Vietnam–Russia Joint Venture Vietsovpetro, and Southern Inspection Company, among others;
- Implementation of NDT projects within Vietnam for clients including Sun Group, several thermal power projects, and defense-related organizations such as the Viettel Aerospace Institute, Engineer Command, and EBARA Vietnam Pump Co., Ltd.;
- Consulting services for radiation licensing and radiation monitoring for various industrial and medical facilities.

The total revenue of the Center in 2024 reached VND 13.90 billion, including:

- Radiation safety services (nuclear energy applications): VND 1.40 billion
- NDT services: VND 8.50 billion
- Training services: VND 4.00 billion

Table 1. VINTOM's services and corresponding revenues in 2023 and 2024

No	Services	Revenue (billion VND)	
		Year 2022	Year 2023
1	Irradiation	57.81	71.80
2	Radiation safety, dosimetry	21.76	25.46
3	Analysis services, environment	11.43	9.81
4	Radioisotope production	70.42	76.70
5	Producing zinc products	109.31	140.00
6	NDT	13.55	9.03
7	Application of nuclear techniques in industry	9.69	6.20
8	Training	12.21	8.59
9	Others	53.48	93.80
Total		373.028	359,67

1.4. SCIENTIFIC PUBLICATIONS

In 2024, the scientific research and technological development activities of VinAtom continued to be strongly promoted and achieved notable results in terms of quantity, quality, and effectiveness. The research tasks were increasingly aligned with application areas relevant to the country's socio-economic life, the overall activities of the sector, as well as the Institute's specific research and training needs. Scientific publications have remained at a high level in recent years. In 2024, the total number of scientific papers published in international journals indexed by ISI across the Institute reached 93, compared to 86 ISI papers in 2023.

Table 2. Summary of scientific articles/publications by the members under VINATOM

Units	ISI journals (ISI)	SCOPUS and other international journals	National journals	International conferences	National conferences	International publications	Patents /utility solution	Total
INST	28	12	16	8	13	-	-	77
NRI	32	9	25	21	11	1	-	99
ITRRE	4	4	9	2	11	-	1	31
CNT	12	1	9	8	11	-	-	41
VINAGAMMA	4	-	7	-	7	-	-	18
CANTI	1	1	3	2	8	-	-	15
HIC	4	2	3	2	5	-	-	16
NDE Center	-	-	3	1	5	-	-	9
NTC	3	2	2	-	6	-	-	13
Head Quarters	5	-	-	-	-	-	-	5
Total	93	31	77	44	77	1	1	324

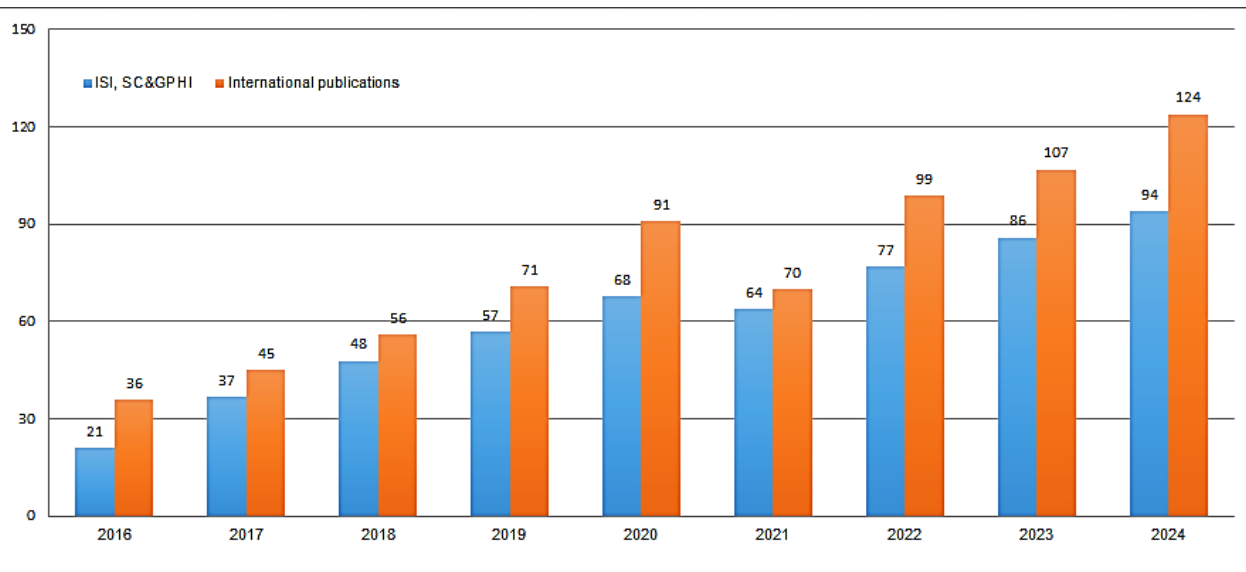


Figure 4. Overview of international publications and ISI articles between 2016 and 2024

1.5. TRAINING AND DEVELOPMENT OF HUMAN RESOURCES

1.5.1. Doctoral Training

In 2024, VinAtom delivered 4 Doctor of Philosophy (PhD) programs including: Atomic and nuclear physics; Theoretical and computational physics; Analytical chemistry; Inorganic chemistry.

In the 2023–2024 academic year, Nuclear Training Center - VinAtom enrolled a total of 12 doctoral and pre-doctoral students, including 4 doctoral and 4 pre-doctoral students in Atomic and Nuclear Physics, 2 pre-doctoral students in Theoretical and Mathematical Physics, 1 doctoral student in Inorganic Chemistry, and 1 pre-doctoral student in Analytical Chemistry, marking a 12% increase compared to the previous academic year. The Center successfully convened a total of 52 doctoral defense panels and conferred degrees to 10 doctoral graduates.

1.5.2. Human Resources Development

Regarding domestic training and professional development for personnel in the field of nuclear energy, the Nuclear Training Center (NTC) has proactively designed and conducted advanced courses to enhance skills and knowledge for staff both within and outside the Institute. The Center has also coordinated and supported internship programs and research skill development to improve the quality of graduates from universities, enabling the selection of highly qualified personnel for the sector's recruitment needs.

In 2024, the NTC proposed and implemented several specialized training courses, including a collaborative program with Japanese partners on Reactor Engineering for staff from units across the North and South of Vietnam. This course aimed to provide participants with foundational knowledge in reactor physics and thermal-hydraulics, as well as hands-on experience with the VVER-1200 simulator used in Russian-designed

nuclear power plants. The Center continued to strengthen career guidance for university students majoring in nuclear energy through practical training and internships at research and implementation units under VinAtom. Training programs were standardized in accordance with the requirements of the Ministry of Science and Technology, attracting and supporting Institute staff and students to enhance collaboration with other research institutes and universities.

One specialized internship was organized for 26 students from the northern region (Hanoi University of Science and Technology; Hanoi University of Natural Sciences) at the NTC, the Hanoi Irradiation Center, and the Institute of Nuclear Science and Technology. Currently, 8 students are conducting research and practical work at the NTC's Nuclear Safety Laboratory, participating in research projects and presenting reports at national scientific conferences, where they have received high accolades.

Radiation safety training in accordance with Circular 34/2014/TT-BKHCHN and professional nuclear energy application training in accordance with Circular 06/2016/TT-BKHCHN continued at the Institute of Nuclear Science and Technology (INST), with 17 courses provided to 431 radiation staff.

The INST also cooperated with the Japan Atomic Energy Agency (JAEA) to organize training courses on "PHITS Code" and "Environmental Radiation Monitoring," and provided lectures and guidance for 1,261 students, trainees, and staff visiting to learn about nuclear energy applications for socio-economic development.

The Nondestructive Evaluation (NDE) Center maintained an average of one radiation safety training class per month for radiation facilities in Hanoi. In addition, the Center collaborated with other units and local Departments of Science and Technology to organize training courses on radiation safety and UPSC, issuing nearly 550 certificates.

Within the framework of the human resource development cooperation program on nuclear and radiological emergency preparedness between VinAtom and JAEA, the Institute of Nuclear Science and Technology organized the 14th "Radiation and Nuclear Emergency Preparedness" training course from October 21–25, 2024. The course provided essential theoretical knowledge and practical skills for personnel responsible for radiation safety and nuclear and radiological emergency response across various agencies and units nationwide.

1.6. INTERNATIONAL COOPERATION

1.6.1. Multilateral cooperation activities

Cooperation with IAEA

The cooperation with the IAEA is considered one of the most effective channels for collaboration in the field of nuclear energy applications and plays a particularly important role in promoting radiation applications for the socio-economic development of Vietnam.

VinAtom is currently implementing two technical cooperation projects with the International Atomic Energy Agency (IAEA) for the 2024–2025 period, namely Projects

VIE1011 and VIE1012, with a total budget of EUR 335,268. The objectives of these projects are to support the implementation of the Center for Nuclear Science and Technology (CNST) project and to enhance non-destructive testing (NDT) capabilities in Viet Nam. VinAtom has also proposed and designed a new technical cooperation project for the 2026–2027 cycle, aiming to further support the implementation of the CNST project. The proposal has been approved by the IAEA, which also recommended expanding the project's scope to include issues related to nuclear power infrastructure development.

Experts from VinAtom, who are members of the Task Force established by the IAEA Director General, have continued to participate in monitoring activities related to the treated water discharge at Fukushima, Japan.

VinAtom remains an active member of the Viet Nam–IAEA–Lao PDR/Cambodia Tripartite Cooperation Agreement. In 2024, VinAtom hosted four delegations from Lao PDR and Cambodia and one delegation from Myanmar for scientific visits and internships at its affiliated institutions. Currently, VinAtom is coordinating with the IAEA to support the organization of a national workshop in Lao PDR on promoting the application of NDT in infrastructure and industrial development. In November 2024, in Hanoi, VinAtom met with the Head of TCAP1/IAEA to review the tripartite cooperation and promote IAEA initiatives such as Atoms4Food and NUTECH Plastic, as well as to discuss the future of bilateral cooperation in the context of Viet Nam's plan to restart its nuclear power program.

VinAtom also hosted and worked with the IAEA delegation led by Deputy Director General Mr. Hua Liu during his official visit to Viet Nam from 21–23 March 2024. During the visit, VinAtom coordinated meetings between the IAEA Deputy Director General and high-level representatives from the Government of Viet Nam, the Ministry of Science and Technology, the Ministry of Health, the Ministry of Agriculture and Rural Development, and K Hospital. The visit also included the ceremony celebrating the 40th anniversary of the operation and expansion of the Da Lat Research Reactor. This visit was highly successful and contributed to enhancing Viet Nam's visibility and position within the IAEA.

VinAtom participated in the 68th IAEA General Conference held in Vienna in September 2024, where it engaged in meetings with international partners such as ROSATOM, JAEA, DAE, and KIRAMS, as well as discussions within the framework of the tripartite cooperation and the IAEA Technical Cooperation among Developing Countries (TCAP) Programme to review VinAtom's two ongoing technical cooperation projects.

VinAtom is also collaborating with the Department of Atomic Energy, PECC1, PECC2, and several domestic universities under the IAEA's INPRO Programme to apply ASENES tools for modeling energy scenarios (including nuclear power) and to use the NESAs methodology for nuclear safety and infrastructure assessment in the case of deploying small modular reactors (SMRs) in Viet Nam. An international workshop on the application of the MESSAGE-NES tool for nuclear energy system modeling under INPRO was organized in Hanoi from 18–22 November 2024.

Cooperation under the Regional Cooperative Agreement (RCA) for Research, Development and Training Related to Nuclear Science and Technology in Asia and the Pacific

VinAtom serves as the National RCA Representative and the national coordinating body for Viet Nam under the RCA framework. Currently, VinAtom coordinates 16 IAEA/RCA (RAS) projects, of which it acts as the lead organization for 9 projects. VinAtom is also directly leading the coordination of Project RAS7040, “Enhancing the Management of Water Resources through Strengthened Regional Cooperation on Isotope-Related Environmental Studies and Applications,” for the 2022–2025 period.

In 2024, key implementation activities included:

- Participation in the 46th RCA National Representatives Meeting held in Beijing (May 2024), which reviewed the 2023 programme and prepared the RCA programme for the 2026–2027 cycle. The Vietnamese delegation also attended the Roundtable Meeting between China, ASEAN countries, and other regional partners on cooperation in the peaceful uses of nuclear technology (15 May 2024).
- Conducting the Socio-Economic Impact Assessment of the RCA Programme in selected thematic areas, including Air Quality (July 2024, with a Case Study in September 2024) and Food Safety (October 2024).
- Participation in the 53rd RCA General Conference held in Vienna (September 2024), where discussions focused on programme policy, governance, and management issues, as well as updates on the socio-economic impacts of the RCA Programme and the roadmap for new member participation.
- Collaboration with the Hanoi Irradiation Center and the Center for Radiation Technology Research and Development to organize a training course under Project RAS1028 (7–11 October 2024) and an Experimental Workshop on Electron Beam Technology (2–6 December 2024) in Ho Chi Minh City.
- Implementation of the Memorandum of Cooperation between VinAtom and the RCARO Office (signed in 2022). A VinAtom delegation attended the Strategic Workshop in the Republic of Korea (11–15 November 2024) to promote collaboration in the peaceful applications of nuclear science and technology between the two countries. In December 2024, a delegation of Korean experts visited VinAtom to discuss potential cooperation areas.
- Participation of VinAtom experts in various RCA regional events and RCARO activities, contributing actively to the enhancement of regional collaboration in nuclear science and technology for peaceful purposes.

Cooperation under the Forum for Nuclear Cooperation in Asia (FNCA)

As the national focal point of the Forum for Nuclear Cooperation in Asia (FNCA), VinAtom currently coordinates nine FNCA projects, of which it serves as the lead organization for six projects related to radiation technology, research reactors, and nuclear safety.

In 2024, VinAtom undertook the following key activities:

- Compile and evaluate five FNCA projects and submitted reports to Japan in preparation for the next project phase.

- Participate in the FNCA Workshop on Radioisotope Production for Medical Applications and the FNCA National Coordinators Meeting held in Japan (March 2024), where the 2024 programme of activities was agreed upon, and preparations for the FNCA 25th Anniversary Celebration were discussed.

- Organize a Vietnamese delegation to attend the FNCA Ministerial Level Meeting and the 25th Anniversary Commemoration Ceremony of FNCA in Japan (December 2024), in collaboration with the Department of International Cooperation (under MOST).

Cooperation with the Joint Institute for Nuclear Research (JINR), Dubna

At present, ten VinAtom staff members are studying and conducting research at laboratories of the Joint Institute for Nuclear Research (JINR) in Dubna, Russian Federation. VinAtom is currently in discussion with JINR on the formulation and implementation of the project Design and Construction of a Large Accelerator Complex for Research and Applications in Viet Nam (VLAC), with the aim of developing a major accelerator complex in the northern region of the country.

1.6.2. Bilateral Cooperation Activities

Cooperation with the Russian Federation

In 2024, cooperation between VinAtom and the Russian Federation primarily focused on collaboration with the State Atomic Energy Corporation of Russia (ROSATOM), including the following key activities:

- Implementation of the Center for Nuclear Science and Technology (CNST) Project
- Signing of the Non-Disclosure Agreement (NDA) on 31 January 2024, and ongoing discussions on Vietnam's participation in the MBIR Fast Neutron Research Reactor Project.

- Signing of an Action Plan with REP and an additional NDA on 22 February 2024, aimed at conducting joint research to support the consideration of a nuclear power plant project in Vietnam.

- Advising the Prime Minister and the Minister of Science and Technology to hold a bilateral meeting with the Director General of ROSATOM during the State visit of President Vladimir Putin to Vietnam (June 2024).

- Advising on the signing of an International Memorandum of Understanding (MoU) between the Ministry of Science and Technology (MOST) and ROSATOM on the implementation roadmap of the CNST Project.

- Developing the Cooperation Roadmap between MOST and ROSATOM for the 2025–2030 period.

- Coordinating activities on public information and communication in the field of nuclear energy and the CNST Project.

- Exchanging proposals on ROSATOM's investment in the Can Tho Irradiation Company, technology transfer of accelerators, coastal mineral processing, and production of new radiopharmaceuticals in Vietnam.

- Continuing discussions with TVEL Company (Russia) regarding the procurement of additional nuclear fuel for the Da Lat Research Reactor.
- VinAtom’s leadership participated in major international events such as the ATOMEXPO 2024 Forum in Sochi (March 2024) and the Youth Nuclear Forum in Obninsk, Russia (June 2024).
- Organizing outgoing and incoming delegations within the framework of bilateral cooperation activities.

Cooperation with Japan

VinAtom continues to serve as the focal point for cooperation with Japanese nuclear energy organizations, particularly with the Japan Atomic Energy Agency (JAEA) in the field of human resource development. Since early 2024, more than 20 staff members have been nominated to participate in ITC, AITC, and MEXT training programs in Japan. In July 2024, VinAtom and JAEA signed an extension of their Cooperation Agreement.

VinAtom also renewed its Cooperation Agreement with Nagaoka University of Technology and continued collaboration with the Japan Nuclear Energy Development Co. (JINED). The cooperation activities included organizing the 6th Training Course on Japanese Nuclear Power Plant Technology (07–18 October 2024) for students and young professionals, and the 14th Vietnam–Japan Forum (03–04 December 2024) under the theme “The Role of Nuclear Power in Climate Change Mitigation and the Economics of Nuclear Energy.”

Cooperation with the United States

VinAtom continues to act as the national coordinator with the U.S. Department of State under the Foundational Infrastructure for Responsible Use of Small Modular Reactor Technology (FIRST) Program. In 2024, VinAtom successfully organized three online workshops with participation from 20 U.S. experts and 47 Vietnamese delegates, covering the topics of small modular reactor models (26–29 March), emergency preparedness (25–26 June), and energy resource optimization (7–14 November).

On 15 February 2024, VinAtom and the U.S. Nuclear Regulatory Commission (US NRC) signed an Agreement on the Exchange of Technical Information and Cooperation in Nuclear Safety, and are now in discussions to sign the CAMP Agreement, enabling VinAtom to utilize the thermal-hydraulic computational tools.

VinAtom also held meetings with the U.S. National Nuclear Security Administration (NNSA) and the U.S. Embassy in Hanoi (26 February 2024) on cooperation in nuclear safety, security, and other atomic energy–related areas, as well as follow-up activities under the FIRST Program (10 July 2024).

VinAtom participated in the Sustainable Development through Peaceful Uses of Nuclear Technology (SDPU) Dialogue Forum, promoting Vietnam’s engagement in the SDPU Initiative and co-sponsoring two working papers to be presented at the NPT Review Conference (PrepCom 2). The Institute also attended the Regional Workshop on

Sustainable Agriculture in the Asia-Pacific Region (July 2024, Thailand) and the Online Workshop on Food Safety & Agricultural Productivity (August 2024).

Cooperation with India

In 2024, VinAtom implemented several cooperative activities with India, including:

Through the Embassy of India in Vietnam, ongoing discussions on collaboration under the IAEA Project VIE1012 on establishing a national certification system for NDT in compliance with ISO 9712 standards.

VINAGAMMA signed a contract with the Board of Radiation and Isotope Technology (BRIT) to procure 625 kCi of Co-60, with delivery completed in June 2024.

The Vietnam Subcommittee under the Vietnam–India Joint Committee on Atomic Energy Cooperation was officially restructured and approved by the Ministry of Science and Technology, with preparations underway for the 4th Subcommittee Meeting to be held in India in 2025.

Coordinating with the Department of International Cooperation (MOST) to prepare materials on bilateral collaboration in rare earth research, processing, and mining for the Prime Minister’s official visit to India (30 July – 1 August 2024) and the MOST delegation visit to India (25–29 November 2024).

Cooperation with the Republic of Korea

In collaboration with Korea Electric Power Corporation (KEPCO), VinAtom organized a delegation to attend the Bitagram International Electricity Technology Expo (BIXPO 2024) from 6–8 November 2024.

Discussions were held with the Korea Institute of Radiological and Medical Sciences (KIRAMS) to develop a draft Memorandum of Understanding (MoU) between the two institutes.

In November 2024, VinAtom exchanged with the Korea Hydro & Nuclear Power Co., Ltd. (KHNP) on revisions to the 2025–2027 Cooperation Plan and proposed a Training Course on Nuclear Power Plant Technology and Project Management under the MoU signed between VINATOM and KHNP on 22 June 2023.

Cooperation with Other Countries

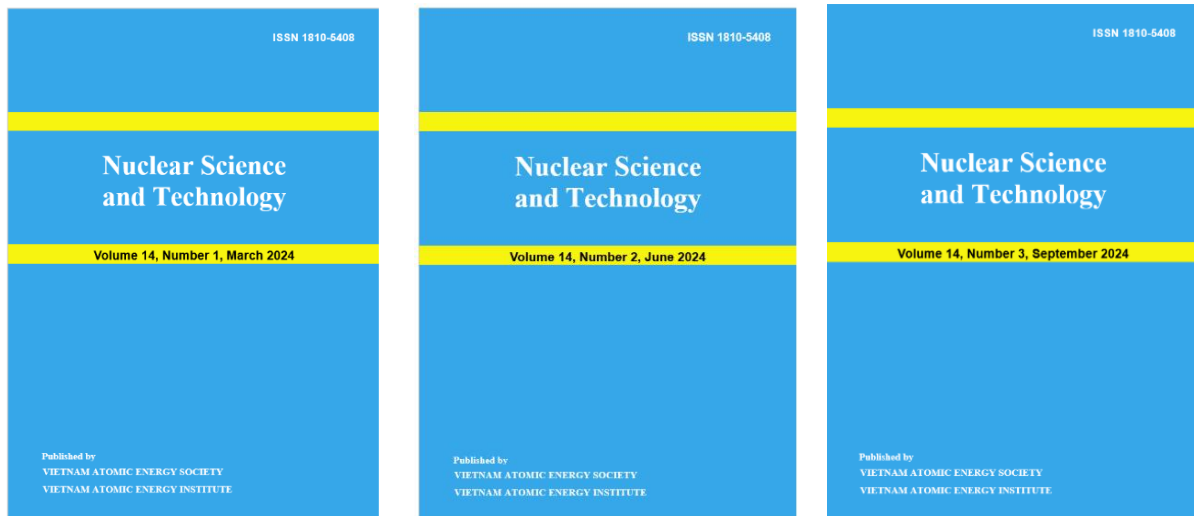
Within its mandate, VinAtom has maintained cooperative relations with several other countries, including China and Australia. Through these cooperative activities, a number of VinAtom staff members have participated in workshops and seminars organized by international partners.

1.7. INFORMATION AND COMMUNICATION

The following publications were completed by VinAtom in 2024:

Journal of Nuclear Science and Technology: The online publishing system (jnst.vn) and the DOI digital identification system for the Journal were put into operation,

which strongly support the online submission and review of articles and tightly connect with domestic and international scientific database systems.



Annual reports for 2023: The electronic version provides an insight in VinAtom’s activities and scientific research projects in 2023. (Available from <https://vinatom.gov.vn/the-annual-report-for-2023/>)

The image shows the cover of the 'ANNUAL REPORT 2023' from the Vietnam Atomic Energy Institute. The cover features a stylized atomic model and the website address 'vinatom.gov.vn'. To the right of the cover, a text box describes the report: 'The VINATOM Annual Report for 2023 has been prepared as an account of works carried out at VINATOM for the period 2023. Many results presented in the report have been obtained in collaboration with scientists from national and overseas universities and research institutions.' Below the text is a blue 'Download' button.

VINATOM Web Portal in Vietnamese and English versions worked properly and was frequently updated for the purpose of disseminating the information.

Domestic information on nuclear science and technology was selected, modified in the form of inputs which comply with the IAEA’s standards and regularly contributed to the repository of International Nuclear Information System (INIS), IAEA.

In 2024, the 8th Nuclear Science & Technology Conference for Young Researchers was successfully held in October 2024. The conference featured 68 presentations, including 4 plenary reports, 35 oral presentations, and 29 poster presentations. This was a significant scientific event for the nuclear energy research community, serving as a

platform for young scientists to share and publish their latest research findings. Through the conference, it ignited passion and promoted research activities among scientists in VinAtom's various research fields.

1.8. INVESTMENT PROJECTS

VinAtom continued to implement the major projects in the field of atomic energy. The details are presented as follows.

1.8.1. RESEARCH CENTER OF NUCLEAR SCIENCE AND TECHNOLOGY

Based on the investment policy for the Project approved by the Prime Minister and under the authorization of the Ministry of Science and Technology (the Project Owner), VinAtom has provided support to the Project Management Unit of the Center for Nuclear Science and Technology Research (representing the Project Owner) in signing Contract No. 03/HĐ-2023/CNST-GSPI on November 30, 2023, with the contractor GSPI for the implementation of the package "Preparation of the Feasibility Study Report and Site Documentation."

VinAtom has proactively coordinated with relevant stakeholders to accelerate the implementation progress of the Contract. In 2024, the main tasks carried out include:

- Implementation of the Contract for the preparation of the Feasibility Study Report and Site Documentation. At present, on-site investigations and the development of the project's master layout plan are in progress.
- Completion of the clearance of unexploded ordnance (UXO) and explosive materials at the planned project site.
- Preparation of the revised Pre-feasibility Study Report, which is expected to be submitted to competent authorities for approval of the adjusted investment policy in accordance with applicable regulations.

1.8.2. UPGRADING THE TECHNOLOGY SYSTEMS AND FUNCTIONAL EQUIPMENT AND SUPPLEMENTING FUEL FOR THE DA LAT NUCLEAR REACTOR TO ENSURE ITS EFFECTIVE AND SAFE OPERATION AT LEAST UNTIL 2030

The project, with Nuclear Research Institute as the Project Owner, was approved for investment by the Ministry of Science and Technology under Decision No. 164/QĐ-BKHCN dated February 16, 2023, with a total investment capital of VND 80.488 billion. The project's objective is "to ensure the continued safe and efficient operation of the reactor to meet domestic needs in human resource training, scientific research, and radiopharmaceutical production from now until 2030."

The main investment components include: procurement of additional reactor fuel and the renovation and upgrading of technological systems (specifically: renovation of the secondary cooling system; renovation and repair of the ventilation system of Building I; reinforcement of the horizontal channels and thermal columns of the reactor; and renovation and upgrading of the fire prevention and fighting system).

However, due to the impacts of the current geopolitical situation, sanctions, and economic restrictions imposed by the United States and the European Union on the Russian Federation, the project has faced numerous difficulties. These include significant increases in fuel prices, challenges in making contractual payments to partners, and the need to revise and scale down several investment components to ensure the planned quantity of reactor fuel.

As of now, the contract for the procurement of additional nuclear fuel for the reactor was signed on November 27, 2024. The components related to the “Renovation and Upgrading of Technological Systems” are in the final stage of detailed design preparation and submission for approval by competent authorities, with implementation expected in the first quarter of 2025.

1.8.3. UPGRADING AND PROCUREMENT OF NEW EQUIPMENT AND RADIOACTIVE SOURCES FOR PRODUCTION, PERIOD 2021–2025

The project, with VINAGAMMA as the Project Owner, was approved under Decision No. 36/QĐ-VINAGAMMA dated April 4, 2024, and subsequently revised under Decision No. 90/QĐ-VINAGAMMA dated June 20, 2024. The project is currently in the first phase of contractor selection (2024).

1.8.4. RENOVATION, UPGRADING, AND CONSTRUCTION OF NEW WORKSHOPS AND OFFICE BUILDINGS OF THE CENTER

The project, with VINAGAMMA as the Project Owner, was allocated investment capital from legally generated revenues under the approval of the Ministry of Science and Technology, pursuant to Decision No. 1691/QĐ-BKHCHN dated July 22, 2024.

To date, the project has completed the following contract packages:

- Consultancy for the preparation of the Technical–Economic Report;
- Consultancy for the preparation of the Environmental Permit Application Report;
- Consultancy for geological surveying, including preparation of the terms of reference and cost estimate for the geological survey;
- Consultancy for supervision of the geological survey;
- Consultancy for verification of the detailed design drawings and cost estimates for the renovation and upgrading of the Center’s workshop and office building.

1.8.5. INVESTMENT IN LABORATORY EQUIPMENT FOR RESEARCH ON ADVANCED MATERIALS AND RADIOACTIVE WASTE TREATMENT IN COASTAL MINERAL PROCESSING

The project was initially approved for investment policy under Decision No. 3012/QĐ-BKHCHN dated November 23, 2021, with CANTI as the Project Owner. The Ministry of Science and Technology later approved an adjustment to the investment policy under Decision No. 2718/QĐ-BKHCHN dated October 25, 2024 (replacing Decision No. 3012/QĐ-BKHCHN dated November 23, 2021), designating the Institute for Rare and Radioactive Mineral Technology as the new Project Owner.

The project is currently in the investment preparation stage. The approved budget for the investment preparation phase is VND 390,000,000, as approved by the Ministry of Science and Technology under Decision No. 3104/QĐ-BKHCH dated November 27, 2024.

2- RESEARCH REPORTS 2024



Source: eagetutor.com



Source: <https://1boss.vn/>

2.1. NUCLEAR PHYSICS, REACTOR PHYSICS

STUDY ON MEASUREMENT OF ELASTIC SCATTERING CROSS SECTIONS OF $^{197}\text{Au}(p,p_0)$ REACTION IN LOW PROTON ENERGY REGION USING THE PELLETRON 5SDH-2 ACCELERATOR

Do Thi Khanh Linh, Le Xuan Chung, Tran The Anh, Bui Thi Hoa, Nguyen Hai Ninh

¹Institute for Nuclear Science and Technology, VinAtom, 179 Hoang Quoc Viet, Cau Giay, Hanoi, Vietnam

²Hanoi University of Science, Vietnam National University, 334 Nguyen Trai, Thanh Xuan, Hanoi, Vietnam

Project information:

- **Project name: Study on measurement of elastic scattering cross section of $^{197}\text{Au}(p,p_0)$ reaction in low energy region on the Pelletron 5SDH-2 accelerator**
- **Code: CS/24/04-02**
- **Managerial level: Institute**
- **Implementation time: 12 months (Jan 2024- Dec 2024)**
- **Contact email: dolinh.nt@gmail.com**
- **Published papers related to the project:**

1. D.T.K. Linh, L.X. Chung, et al., Differential cross section measurement for $^{197}\text{Au}(p, p_0)$ reaction with proton beam in energy range from 0.85 – 3.2 MeV, The 8th Conference on Nuclear Science and Technology for Young Researchers in Atomic Energy, 03-04/10/2024, Hanoi.

2. D.T.K. Linh, L.X. Chung, et al., Experimental Excitation Functions of $p+^{197}\text{Au}$ Elastic Scatterings with Protons of Energies from 0.85 to 3.2 MeV, Nuclear Science and Technology, accepted.

The proton elastic scattering reaction on the ^{197}Au nucleus (denoted as $^{197}\text{Au}(p,p_0)$) has garnered significant interest in the field of nuclear physics, as well as in applications. At proton energy below 9 MeV, the $^{197}\text{Au}(p, p_0)$ reaction is primarily governed by the Coulomb interaction. Consequently, the cross sections of this reaction are contributed only from the Coulomb scattering amplitude which can be precisely calculated via the Rutherford scattering theory. The differential cross sections of this reaction at low energy are widely applied in science and technology, such as in the indirect method for cross-section measurement, or material depth profiling in the near-surface region. Despite its importance, a search for the $^{197}\text{Au}(p,p_0)$ cross sections in nuclear databases like EXFOR and IBANDL reveals a lack of data for proton energies in the range of 0.85–3.2 MeV. This study aims to measure the differential cross section of $^{197}\text{Au}(p,p_0)$ at different angles within the above energy range and to apply the results to calibrate the proton beam intensity in nuclear reaction studies using the Pelletron 5SDH-2 accelerator at the Hanoi University of Science, Vietnam National University (VNU-HUS).

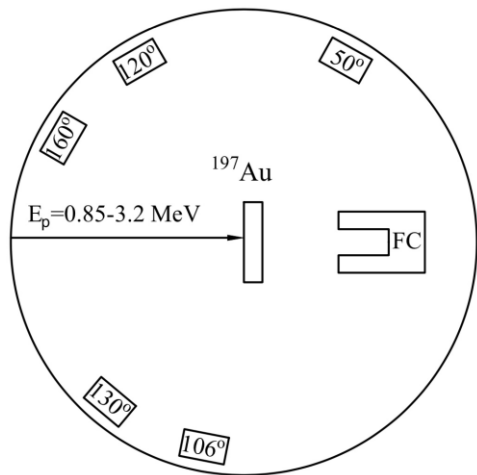


Figure 1: Experimental setups for cross-section measurement. The locations of the five detectors are marked with degrees.

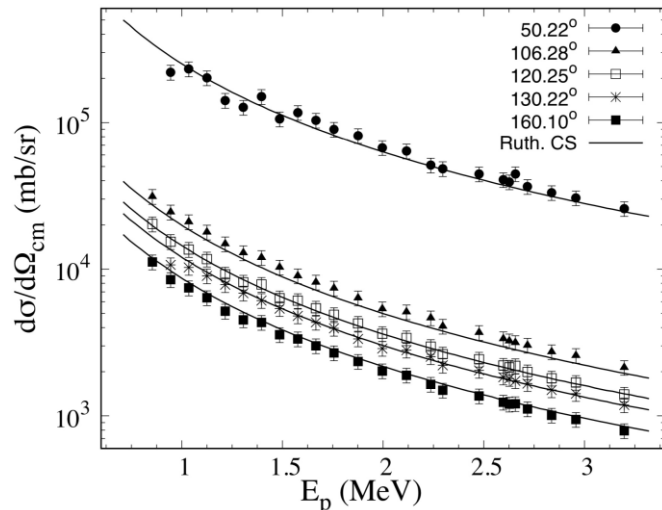


Figure 2: Experimental excitation function of $^{197}\text{Au}(p,p_0)$ reaction (points with error bars) comparing to the Rutherford cross sections (Ruth. CS) at five different scattering angles.

The experimental setup for measuring the differential cross section of $^{197}\text{Au}(p,p_0)$ reaction is presented in Figure 1. The proton beams were accelerated with energies of 0.85-3.2 MeV, and scanned from higher to lower energies with an average step of 120 keV. A ^{197}Au target with a thickness of $156 \mu\text{g}/\text{cm}^2$ fabricated at the LSN laboratory (INFN, Italy) was placed perpendicular to the beam direction. The proton beam intensity was monitored by a Faraday cup (FC) placed at 4.7 cm downstream, with a high voltage of -350 V applied to its suppressor. Charged products were detected by five S3590-09 Hamamatsu Silicon PIN photodiodes placed at angles of 50° , 106° , 120° , 130° , and 160° . The entire experimental setup was placed inside the NEC RC43 scattering chamber. During the measurements, the proton beam intensity was adjusted to a data acquisition (DAQ) rate of 5 kHz. The DAQ dead time was estimated to be about 4% at this rate.

The results of the experimental differential cross-section ($d\sigma/d\Omega_{cm}$) depending on the proton energy (E_p) (also known as the excitation function) of $^{197}\text{Au}(p,p_0)$ reaction at five angles of 50.22° , 106.28° , 120.25° , 130.22° , and 160.10° in the center-of-mass reference frame are plotted in Figure 2 together with the Rutherford cross sections. It is seen that the measured cross sections align well with those calculated from the Rutherford formula over the whole energy range and in all five scattering angles. The aforementioned results show that there is no need to correct the recorded values from the FC when a high voltage of -350 V is applied to the suppressor. The uncertainty for the FC is estimated to be 5%.

STUDY ON DETERMINATION OF RADIOISOTOPES IMPURITIES GENERATED DURING THE SYNTHESIS OF ^{18}F RADIOISOTOPES ON THE KOTRON13 CYCLOTRON

Mai Van Vinh¹, Dam Thi Tam¹, Nguyen Tuan Anh¹, Nguyen Xuan Viet¹, Nguyen Bich Thuy²

¹ Hanoi Irradiation Center, Km 12, Street 32, Minh Khai ward, Bac Tu Liem district, Hanoi

² Nuclear Research Institute, No 01 Nguyen Tu Luc Street, Ward 8, Dalat, Lamdong

Project information:

- **Project name: Study on determination of radioisotopes impurities generated during the synthesis of ^{18}F radioisotopes on the KOTRON13 cyclotron**
- **Code: CS/24/08-01**
- **Managerial Level: Institute**
- **Implementation time: 12 months (Jan 2024- Dec 2024)**
- **Contact email: maivinhhic.com**
- **Published papers related to the project:**

1. Mai Van Vinh, Dam Thi Tam, Nguyen Tuan Anh, Nguyen Xuan Viet, Nguyen Bich Thuy. Determination of radioisotopes impurities generated during the production of ^{18}F radioisotopes on the KOTRON13 accelerator. The 8th Conference on Nuclear Science and Technology for Young Scientist in the field of Atomic Energy, P. 47, October 2024 (in Vietnamese).

Radiopharmaceutical (RP) ^{18}F -FDG is currently one of the most common ^{18}F radioactive compounds in PET, PET/CT imaging techniques. During the production of this radiopharmaceutical, it is necessary to create ^{18}F isotope, but this process can simultaneously generate a number of other contaminated radioactive isotopes in low concentrations (trace amount). The presence and concentration of these contaminated radioactive isotopes depend significantly on the accelerator's capacity the purity of the stable isotopes, the structure of the target and related components.

In the synthesis of ^{18}F isotope and the production of ^{18}F -FDG radiopharmaceutical at the Hanoi Irradiation Center, contaminated radioactive isotopes can be generated from the target body (Ti cavity) and the target window (Ti foil). When transferring the ^{18}F isotope solution to the ALLINONE synthesis module, these isotopes are retained in various types of waste such as the QMA column of the cassette, the recovered water and the wastewater of the ^{18}F -FDG radiopharmaceutical synthesis process.

Therefore, this study aims to determine the c radioactive isotopes contaminants generated during the production of ^{18}F radioactive isotopes. The research results not only ensure the quality of radiopharmaceutical products produced at the Center, also allow to clearly identify the types and concentrations of impure radioactive isotopes generated during the synthesis of ^{18}F and ^{18}F -FDG radiopharmaceutical production. This

enables the establishment of a radioactive waste treatment process for the ^{18}F -FDG radiopharmaceutical production line, thereby improving production efficiency and ensuring radiation safety at the facility

The studies utilize a gamma spectrometer system equipped with an high-purity germanium HPGe ultra-pure germanium (Ge) semiconductor detector. This is an n-type coaxial semiconductor detector from Ortec GMX series, currently in use at the horizontal channel No. 1 - Dalat nuclear research reactor, with a relative efficiency of 25%, a peak/Compton ratio of 48:1 and an energy resolution of 1.90 keV at 1.33 MeV for ^{60}Co . The spectrometer system is connected to Genie 2000 software to record gamma spectra emitted by radioactive isotopes in the samples. Before using the spectrometer system to determine the activities of radioactive isotopes that may be contaminated from the production process of RP ^{18}F -FDG, the gamma spectrometer system was calibrated for energy and efficiency. At the same time, to ensure the accuracy of the measurement, the research team used the PHITS (Particle and Heavy Ion Transport code System) version 3.33 program to calculate and simulate the peak performance curve of the HPGe probe system.

The QMA samples, recovery water, and wastewater were collected after 2 consecutive synthesis runs, as the synthesis module used the chemical KIT cassette for two cycles. Before measuring, the QMA samples were collected from the cassette by removing the plastic casing, retaining only the core column. The recovery water and wastewater samples were collected in glass bottles with lids, at the same time as the QMA samples. The sample information is presented in Table 1.

Table 1. Information about collected samples

Sample number	Production date (dd/mm/yyyy)	QMA mass (g)	Water recovery (ml)	wastewater (ml)
1	03/08/2024	2,70	1,70	2,0
2	18/08/2024	2,70	2,0	2,0
3	03/10/2024	2,72	1,70	1,70
4	12/10/2024	2,72	1,70	1,70
5	31/10/2024	2,71	1,70	1,70

Radioisotopes are identified by the energy of the gamma rays emitted by the isotope and their half-life. The radioactive activity A of the isotopes is determined based on the area of the gamma peaks N_{Sa} with the highest emission probability of I_γ recorded by the spectrometer. The radioactive activity in the isotope samples is calculated by the formula:

$$A = \frac{(N_{Sa} - N_{B.G})\lambda}{\varepsilon_\gamma I_\gamma t_d (e^{-\lambda t_r})(1 - e^{-\lambda t_d})} \quad (1)$$

Where: A is the radioactive activity,

N_{Sa} : gamma peak area of the sample at the gamma energy level of interest (counts) (counts)

N_{Bg} : gamma peak area of the background at the gamma energy level of interest (counts) (counts)

t_r : decay time, t_d : measurement time, λ : radioactive decay constant

I_γ : gamma emission intensity (%)

ϵ_γ : Efficiency at the gamma energy level of interest

Measurements were conducted using a high-resolution low-background gamma spectrometer over a period of 24 to 48 hours until sufficient statistical data was obtained. The results showed the presence of 4 isotopes: ^{48}V , ^{52}Mn , ^{56}Co and ^{96}Tc in the QMA samples. The activity concentrations of the recorded isotopes calculated at the end of production are presented in Table 2. A representative gamma spectrum is shown in Figure 1.

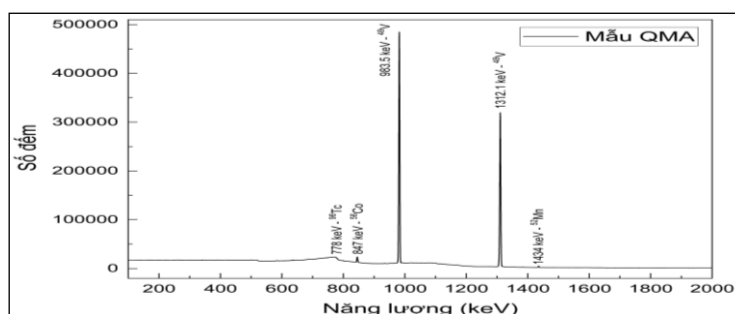


Figure 3. Gamma spectrum of the QMA sample

Table 2. Activity concentrations of radionuclides in QMA, recovered water and wastewater samples

No	Production date (dd/m m/yy)	QMA sample				Water recovery sample				Wastewater sample			
		^{48}V (kBq/kg)	^{52}Mn (kBq/kg)	^{56}Co (kBq/kg)	^{96}Tc (kBq/kg)	^{48}V (kBq/L)	^{52}Mn (kBq/L)	^{56}Co (kBq/L)	^{96}Tc (kBq/L)	^{48}V (kBq/L)	^{52}Mn (kBq/L)	^{56}Co (kBq/L)	^{96}Tc (kBq/L)
1	03/08/2024	888.01	5.78	9.75	0,00	4,88	2,95	16,40	0,00	13,20	0,00	0,00	0,00
2	18/08/2024	495.94	2.71	2,47	0,001	3,21	12,26	48,44	0,00	15,36	0,001	0,03	0,00
3	03/10/2024	1046,88	6,39	0,54	25,81	10,41	1,83	3,54	1,09	20,69	0,56	0,40	1,41
4	12/10/2024	578,79	2,09	1,60	0,92	19,68	11,33	6,66	0,48	18,03	0,28	0,46	0,24
5	31/10/2024	1619,81	5,42	0,33	1,94	7,31	8,99	11,97	0,10	49,35	0,18	0,48	0,10

The isotopes identified in Table 1 are all associated with nuclear reactions that have been detected in previous studies. Among them, ^{48}V was recorded in all 3 types of analyzed samples and exhibited the highest activity, which is consistent with previous studies. This can be explained by the fact that the main components of the target container for ^{18}O target, including the window and target body, are made primarily of titanium. ^{48}V is produced through the nuclear reaction $^{48}\text{Ti}(p,n)^{48}\text{V}$.

However only four radioactive isotopes were detected, which can be attributed to several factors: a) The main material component of the target window and the target body is titanium, whereas the rest are other metal elements with very low content; b) The target has been in use for a relatively short period, and significant chemical corrosion has not yet occurred. c) The low abundance of stable isotopes, small nuclear reaction cross-sections, and long half-lives result in activity levels below the detection limit.

The experimental results determined that four radioactive contaminant isotopes with half-lives from 4.28 days to 77.2 days were generated during the production of ^{18}F radioactive impurities on the KOTRON13 accelerator system. Among these, ^{48}V radioactive impurities (half-life 15.97 days) exhibited relatively high radioactive activity and a long half-life, thus, they need to be carefully handled and treated. In addition, the activity concentrations of this contaminant exceeded the clearance levels specified in Appendix II, Circular No. 22/2014/TT-BKHCHN dated August 25, 2014, issued by the Ministry of Science and Technology on the management of radioactive waste and disused radioactive sources. Therefore, the radioactive waste treatment process for the ^{18}F -FDG radiopharmaceutical production line was developed. This process ensures safety until the radioactivity decays to clearance levels that can be discharged into the environment as regular waste and minimizes the impact of radioactive waste generated from the ^{18}F -FDG radiopharmaceutical production at the Hanoi Irradiation Center.

Based on the research and obtained results, the project "*Study on determination of radioisotopes impurities generated during the synthesis of ^{18}F radioisotopes on the KOTRON13 cyclotron*" identified at least 4 radioactive isotopes (^{48}V , ^{52}Mn , ^{56}Co and ^{96}Tc) as contaminants produced during the synthesis of radioactive isotopes ^{18}F on the KOTRON13 cyclotron. These radioactive isotopes ^{48}V , ^{52}Mn , ^{56}Co and ^{96}Tc were found in the waste products of ^{18}F -FDG radiopharmaceutical synthesis process, including QMA columns, recovery water and wastewater. The activity concentrations of radioactive isotopes ^{48}V , ^{52}Mn , ^{56}Co and ^{96}Tc in the waste of the ^{18}F -FDG radiopharmaceutical synthesis process were all higher than the clearance levels specified in the regulations.

The measurement procedure for QMA samples, recovered water and wastewater samples was developed to align with the sample characteristics and ensure the accuracy of the measurement results. In addition, the radioactive waste treatment process for the RP ^{18}F -FDG production line at the Hanoi Irradiation Center has also been established for practical application in the coming time.

STUDY OF THE STRUCTURE OF UNSTABLE NUCLEI Be, C AND O THROUGH THE ANALYSIS OF THE DIFFERENTIAL CROSS-SECTION DATA OF PROTON-NUCLEUS AND DEUTERON-NUCLEUS REACTIONS

Do Cong Cuong¹, Dao Tien Khoa¹, Nguyen Hoang Phuc¹, Le Xuan Chung¹, Do Thi Khanh Linh¹, Nguyen Hai Ninh¹, Nguyen Tri Toan Phuc², Nguyen Duc Kien¹

¹Institute for Nuclear Science and Technology, 179 Hoang Quoc Viet, Hanoi, Vietnam

²Faculty of Physics and Engineering Physics, University of Science, Vietnam National University, Ho Chi Minh City, Vietnam

Project information:

- **Project name:** Study of the structure of unstable nuclei Be, C and O through the analysis of the differential cross-section data of proton-nucleus and deuteron-nucleus reactions
- **Code:** ĐTCB.06/23/VKHKTHN
- **Managerial Level:** Ministry
- **Implementation time:** 24 months (Jan 2023- Dec 2024)
- **Contact email:** cuong1981us3@gmail.com
- **Published papers related to the project:**
 1. Nguyen Hoang Phuc, Nguyen Tri Toan Phuc, Do Cong Cuong, Impact of Nonlocality Effects in Proton Optical Potential from Folding Model on p+16O Elastic Scattering at Low Energies, Brazilian Journal of Physics 54 (2024) 226.
 2. Do Cong Cuong, Nguyen Tri Toan Phuc, and Nguyen Hoang Phuc, CDCC study of the elastic deuteron scattering on Carbon isotopes, Brazilian Journal of Physics, under review.
 3. Do Cong Cuong, Testing convergence of the solution of the continuum discretized coupled channels method for deuteron-induced reactions, accepted for publication in Nuclear Science and Technology.
 4. Do Cong Cuong, Study of deuteron breakup effects on the elastic deuteron scattering on carbon and oxygen isotopes, Proceedings of the 15th Vietnam Conference on Nuclear Science and Technology (VINANST 15), Nha Trang, Vietnam, 9-11/8/2023 (in Vietnamese).
 5. Nguyen Hoang Phuc, Do Cong Cuong, Dao Tien Khoa, Study of nonlocality effects in p+16O elastic scattering at low energies in folding model approach, Proceedings of the 15th Vietnam Conference on Nuclear Science and Technology (VINANST 15), Nha Trang, Vietnam, 9-11/8/2023 (in Vietnamese).

The study of unstable nuclear structure plays a crucial role in determining the nuclear force in the medium of nuclear asymmetry. In addition, studying the structure of unstable nuclei Be, C and O provides us with information about the formation

mechanism of light isotopes and their natural abundance in the universe. Among many established experiments in the world, the direct nuclear reactions between proton and deuteron reactions with those nuclei are a good tool for structure studies. In Vietnam, these studies can be carried out through the analysis of available experimental data. This research develops a method for direct nuclear reaction data analysis with proton and deuteron targets in inverse kinetic experiments. The analysis results of the experimental data show details of the structure of the Be, C and O isotopes.

An important input parameter in the experimental data analysis of direct nuclear reactions is a nuclear potential. Since the 2000s, the nuclear theory research group of the Institute for Nuclear Science and Technology has successfully developed a method to calculate the microscopic potential of proton-nucleus, alpha-nucleus and nucleus-nucleus in the Hartree-Fock framework. The group's previous calculations were mainly applied in the study of stable nuclei. This project continues to develop and determine the nuclear potential of proton and deuteron with unstable isotopes and then applies it to the experimental nuclear reaction data analysis of the Be, C and O isotopes. The exchange term of microscopic nuclear potential was exactly calculated in the non-local form, thereby enabling the establishment and estimation of the non-local nuclear potential. In the Hartree-Fock framework, the proton-nucleus and deuteron-nucleus potentials were constructed based on the effective nucleon-nucleon (NN) interaction and the wave functions of the colliding nuclei. The elastic and inelastic scattering cross-sections were measured within the framework of the optical model and the distorted wave Born approximation (DWBA) method while the nuclear transfer reaction cross-sections were determined by the DWBA method or the coupled reaction channels (CRC) approach. For the deuteron-nucleus elastic scattering cross-sections, the continuum discretized coupled-channels (CDCC) method was used along with the optical model for the experimental data analysis. In the CDCC method, the deuteron-nucleus scattering process was treated as a collision process of a three-body system, proton+neutron-target, in which the deuteron was separated into protons and neutrons in the continuum state. Deuteron-nucleus studies using the CDCC method indicate the influences of the continuum states on the elastic channel.

The analysis results of the elastic and inelastic $p+^{22}\text{O}$ scattering cross-section data with the use of the optical model and DWBA method, respectively, are illustrated in Figure 1. Both the Woods-Saxon phenomenological potential with CH89 parameters and the microscopic folding potential derived from the effective NN interaction and the wave functions of the colliding nuclei were employed for differential scattering cross-section measurement. The analysis of the elastic scattering data using the folding potential allowed us to determine the proton and neutron radii of ^{22}O as 2.71 and 3.03 fm, respectively. For the inelastic scattering of the 2^+ excitation, folding potential analyses helped to estimate the neutron deformation length of ^{22}O to be $\delta_{2^+}^n = 0.91$ fm while the proton deformation length was $\delta_{2^+}^p = 0.70$ fm corresponding to an electric probability of 21 e²fm⁴. Additionally, elastic scattering cross-section calculations using

non-local folding potential were performed. The analysis of the elastic $p+^{16}\text{O}$ scattering data at low energies showed a strong influence of the non-local effect.

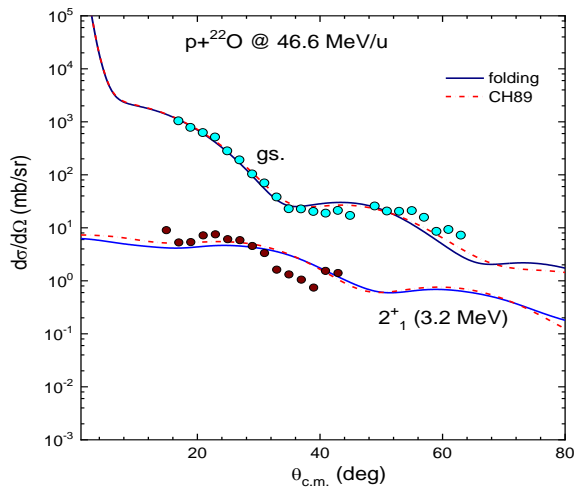


Figure 1. Angular distribution of the elastic and inelastic $p+^{22}\text{O}$ scattering cross-sections described by optical model and DWBA method using both deformed and folding potentials in comparison with the experimental data measured at 46.6 MeV/u energy

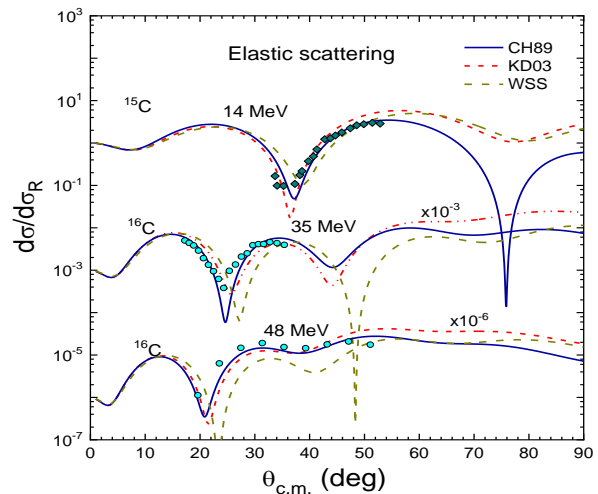


Figure 2. CDCC calculation results of the elastic $d+^{15}\text{C}$ scattering cross-sections at energy of $E_{lab}=14$ MeV and $d+^{16}\text{C}$ at energies of 34.4 and 48 MeV compared with the experimental data

Figure 2 illustrates the CDCC analysis results of the elastic scattering cross-section of deuterons on $^{15,16}\text{C}$. The three-body CDCC calculations well described the experimental data and their results depended strongly on the nucleon-nucleus optical potential. The CH89 and KD potentials gave accurate descriptions of the experimental data, whereas the WSS potential provided significantly erroneous results. It is noted that the neutron separation energy of ^{15}C is $S_n=1.218$ MeV, smaller than the binding energy of the deuteron and therefore the elastic $d+^{15}\text{C}$ scattering should be calculated in the four-body CDCC framework. The good descriptions of the three-body CDCC calculations in this research indicate that the application of these calculations for the elastic scattering of deuterons on unstable isotopes remains reasonable.

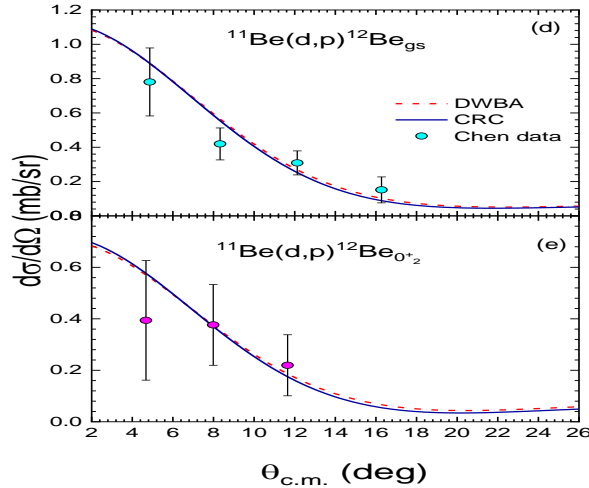


Figure 3. DWBA and CRC calculation results of the $^{11}\text{Be}(d,p)^{12}\text{Be}$ reaction leading to the ground and 0^+ (2.251 MeV) excited states of ^{12}Be compared with the experimental data at deuteron energies of 54 MeV

The cross-section data of the (d,p) transfer reactions was also analyzed by the DWBA and CRC methods for the research on valence neutron shell of unstable isotopes Be, C and O. The DWBA and CRC calculation results of the $^{11}\text{Be}(d,p)^{12}\text{Be}$ reaction at deuteron energy of 54 MeV are demonstrated in Figure 3. The results revealed that the wave functions of valence neutrons were dominated by the $s_{1/2}$ shell, with spectroscopic factors of 0.27 and 0.5 for the ground and 0^+_{2} (2.251MeV) states, respectively. The impact of CRC effects in the $^{11}\text{Be}(d,p)^{12}\text{Be}$ reaction was quite weak.

The microscopic potential calculated from the effective NN interaction and the wave functions of the colliding nuclei has been successfully used for the analysis of elastic and inelastic scattering cross-section data on unstable isotopes Be, C and O. This study also shows that the influence of the non-local effects for the elastic scattering cross-section at low energies is extremely significant. The CDCC calculations successfully described the cross-section data of the elastic deuteron scattering on unstable isotopes Be and C. These results enable the study of the direct nuclear reactions of weakly bound nucleus such as halo nuclei in the future.

NUCLEAR REACTION STUDY ON NATURAL BORON ISOTOPES WITH LOW-ENERGY PROTON BEAM FROM THE 5SDH-2 PELLETRON ACCELERATOR
L.X. Chung¹, D.T.K. Linh¹, L.T. Anh¹, N.T. Anh², T.T. Anh³, M.V. Dien¹, B.T. Hoa³, P.D. Khue¹, N.T. Nghia³, Đ.T. Tran⁴

¹*Institute for Nuclear Science and Technology, VINATOM, P.O.Box 5T-160, Hanoi 100000, Vietnam;*

²*Hanoi Irradiation Center, Minh Khai, Bac Tu Liem, Hanoi, Vietnam;*

³*Faculty of Physics, VNU University of Science (HUS), 334 Nguyen Trai, Ha Noi 100000, Vietnam;*

⁴*Institute of Physics, Vietnam Academy of Science and Technology, Hanoi 100000, Vietnam.*

Project information:

- **Project name: Nuclear reaction study on natural boron isotopes with low-energy proton beam from the 5SDH-2 pelletron accelerator**

- **Code: ĐTCB.08/22/VKHKTHN**

- **Managerial Level: Ministry**

- **Implementation time: 33 months (Jan 2022- Sep 2024)**

- **Contact email: chungxl@vinatom.gov.vn**

- **Published papers and conferences related to the project:**

1. D.T.K. Linh et al., *Angular differential cross section measurement for $^{11}\text{B}(p,\alpha)^8\text{Be}$ reaction with proton energy of 2.5 MeV*, Nuclear Physics A 1046 (2024) 122869.

2. N.T. Anh et al., *Faraday Cup Development for Beam Monitoring and Cross Section Measurement of $p+^{12}\text{C}$ Elastic Scattering with $E_p=0.95\text{-}3.2$ MeV*, IEEE Transactions On Nuclear Science Journal. DOI: 10.1109/TNS.2024.3464493.

3. D.T.K. Linh et al., *"Measurement of $^{10,11}\text{B}$ Target's Thickness by Using the Alpha Transmission Method"*, accepted by Nuclear Science and Technology.

4. L.X. Chung et al., *"Evidence of Effective Thickness Increase of a Rotated Target via Experiments on $^{11}\text{B}(p,\alpha)^8\text{Be}$ Cross Section Measurement"*, accepted by Nuclear Science and Technology.

5. *Faraday Cup Development for Beam Monitoring in nA Scale and Its Application in the Cross section Measurement of $p+^{12}\text{C}$ Scatterings with $E_p=1\text{-}3.2$ MeV*, 24th IEEE Real Time Conference ICISE, 22-26 April 2024, Quy Nhon, Vietnam

6. *Measurement of the $^{10,11}\text{B}(p,\alpha)$ reaction at astrophysical energies, using the Pelletron accelerator in Hanoi University of Science. International Symposium on Physics of Unstable Nuclei 2023, 04-08 May 2023, Phu Quoc, Vietnam.*

7. *Study on $p+^{10,11}\text{B}$ reactions in the proton energy range $E_p=0.35\text{-}3.2$ MeV*, The 16th International Symposium on Origin of Matter and Evolution of Galaxies, 25-28

October 2022, Hanoi, Vietnam.

8. Determination of the ^{11}B target thickness using elastic scattering reaction with proton beam energy from 1.1 - 1.9 MeV, *15th National Conference on Nuclear Science and Technology, 09-11/8/2023, Nha Trang, Vietnam.* (in Vietnamese).

9. Measurement of the angular differential cross-section of $^{11}\text{B}(p, \alpha_0)^8\text{Be}$ reaction with energy $E_p = 2.5$ MeV, *7th Conference on Nuclear Science and Technology for Young Researchers in Atomic Energy, 06-07/10/2022, Hanoi, Vietnam.* (in Vietnamese)

10. Faraday cup development with nA scale applied in nuclear reaction studies on accelerators, *7th Conference on Nuclear Science and Technology for Young Researchers in Atomic Energy, 06-07/10/2022, Hanoi, Vietnam.* (in Vietnamese)

The HUS 5SDH-2 pelletron was installed and operated in 2011. Since that time, the accelerator has provided mainly proton and alpha beams with energy range from 0.35-3.4 MeV and 0.7-5.1 MeV, respectively. The pelletron application has been mostly in element analysis using Proton Induced X-ray Emission and Rutherford Backscattering Spectrometry techniques. For nuclear reaction cross sections, only some feasibility studies have been done. One of the difficulties is that the absolute beam intensity interacting with the target should be precisely measured, while this information is not necessary for many application purposes. This fact leads to another difficulty in preparing the target whose thickness should be thin enough so that the beam can punch through it to reach the current monitor. In order to exploit the HUS pelletron accelerator in nuclear reaction study, this project aims at cross section measurements of reactions induced by proton beam from this pelletron on $^{10,11}\text{B}$ targets.

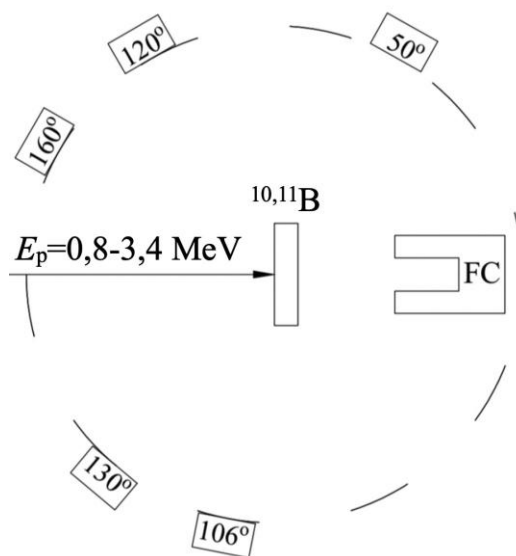


Figure 1. Experimental setup. The rectangles with degree represent the detector locations.

One of the main experimental setups is presented in Fig. 1, illustrating for experiments in the project. The HUS accelerator's energy was calibrated using $^{27}\text{Al}(p,\gamma)^{28}\text{Si}$ reaction. Proton beams were scanned from 3.2 MeV down to 0.8 MeV

energy with average step of 60 keV and hit $^{10,11}\text{B}$ targets. The beam spot was collimated to 3 mm diameter leading to less than 3 keV energy spread. The beam current was monitored by a Faraday cup (FC) placed at 4.7 cm downstream which was developed for nA scale beam monitoring. During the operation, the FC suppressor was applied by -350 V to avoid the current loss caused by the secondary electrons' escape. The total charge (or number of protons) is equal to the integral of the FC current over the measuring time. A natural boron target and two enriched ones were used. The first one was prepared by evaporating a $47 \mu\text{g}/\text{cm}^2$ natural boron layer (composed of 19.9% ^{10}B and 80.1% ^{11}B) onto an $1.95 \mu\text{m}$ aluminum substrate. While, the enriched targets reached 90% for ^{10}B and 99% for ^{11}B with the thicknesses of 67 and $76 \mu\text{g}/\text{cm}^2$, respectively, on a $4 \mu\text{g}/\text{cm}^2$ formva ($\text{C}_3\text{H}_6\text{O}_2$) substrate. All the setups in Fig.1 were placed inside a NEC RC43 scattering chamber. This chamber's vacuum was maintained at 10^{-6} torr to avoid particle energy loss. The detectors were S3590-09 Hamamatsu Silicon PIN diodes placed 6.4 cm far from the target. Their reverse voltages were set to +100 V. An 8 mm diameter collimator was mounted in front of each detector to avoid edge effect and its resolution is less than 0.5% of energy. The electronics for pulse shaping and data acquisition (DAQ) was developed with 8 channels in maximum. The beam current was controlled to keep the DAQ rate around 5 kHz. The DAQ dead time was estimated to be about 10% at this rate. The energy calibration for the detectors was done by using an ^{241}Am alpha source.

Firsly, experiments were performed to measure the thickness of ^{10}B and ^{11}B targets using the α -transmission method. A ^{241}Am source provided α particles of 5.486 MeV energy. The results were compared with the Istituto Nazionale di Fisica Nucleare (INFN) supplier's values, showing a good agreement in thickness for the ^{11}B target, while the results for the ^{10}B target were reasonable within the uncertainty range, and accepted for publication in Nuclear Science and Technology Journal.

A Faraday cup (FC) suitable for nA intensive beams has been developed. The FC operation was tested with proton beams of 0.8 and 2.63 MeV energies bombarding a $0.081 \mu\text{m}$ ^{197}Au target. By varying the high voltage (HV) applied to the FC's repeller ring, current increase due to negative charge loss as secondary electron escape was investigated. Saturation was observed at about -50 V in both experiment and simulation using the CST Studio Suite software. Subsequently, the HV was set to -350 V to ensure the measuring current's precision. Afterward, the FC was used in an experiment to measure the cross sections of $p+^{12}\text{C}$ elastic scattering with $E_p=0.95\text{-}3.2$ MeV at the laboratory angles of 50° , 106° , 120° , 130° , and 160° for its validation and further study for this reaction. Good agreement was obtained between our new data and those reported in the literature. The new data were analyzed with the R-matrix approach. The extracted level parameters are consistent with those of previous studies. The results were published in IEEE Transactions On Nuclear Science Journal.

Differential cross sections at α_0 -particles' eight outgoing angles of 50° , 70° , 90° , 106° , 120° , 130° , 150° , and 160° from $^{11}\text{B}(p,\alpha_0)^8\text{Be}$ reaction induced by 2.5 MeV proton beam bombarding on a natural boron target were measured. Fig. 2 presents the experimental results, fitted by sum of six Legendre functions, and in good agreement

with those from the literature. The importance of the data in a widely angular range is evidenced for the precise determination of the total integrated cross section. This result is published in Nuclear Physics A Journal.

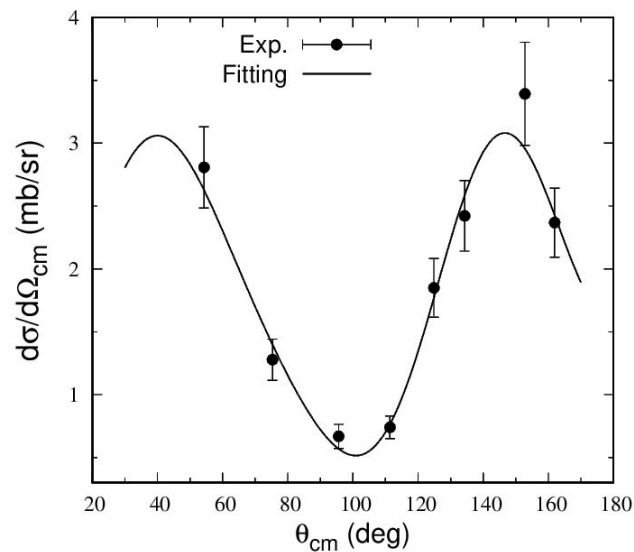


Figure 2. Experimental angular distribution of differential cross sections of $^{11}\text{B}(p,\alpha)^8\text{Be}$ reaction induced by 2.5 MeV proton beam, fitted by sum of six Legendre functions.

The angular differential cross sections dependent on the proton energy of 2.48, 2.54, and 2.72 MeV were measured at 160° and shown in Fig. 3. The obtained cross sections are in good agreement with previous studies, and accepted for publication in Nuclear Science and Technology Journal.

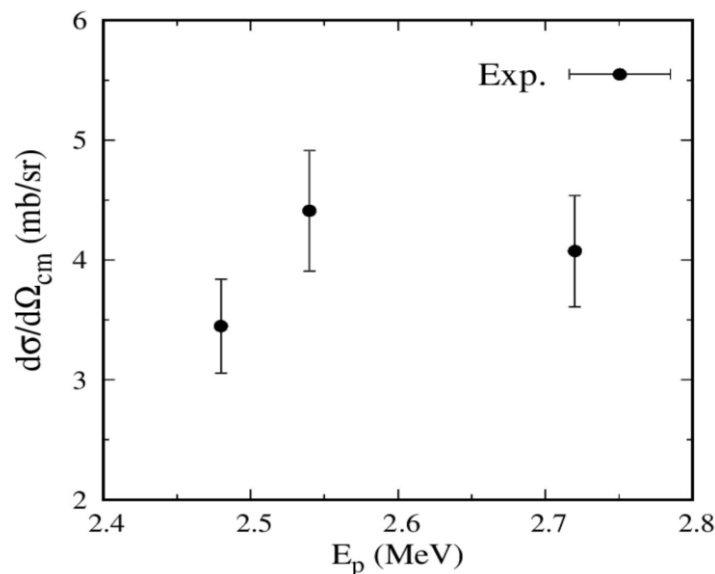


Figure 3. Angular differential cross sections of $^{11}\text{B}(p,\alpha)^8\text{Be}$ reaction measured at 160° with $E_p=2.48, 2.54,$ and 2.72 MeV.

Future work will involve analyzing the data from the present project including the experiments between p and the enriched ^{10}B and ^{11}B targets which is still not completed. Another experiment between $p+^6\text{Li}$ is planned using the same experimental conditions.

Beside scientific results, the education for students and young researchers is also aimed at by this series of experiments.

2.2. RESEARCH REACTOR, NUCLEAR POWER TECHNOLOGY, NUCLEAR SAFETY, NUCLEAR POWER ECONOMY

DEVELOPMENT AND IMPROVEMENT OF EXPERIMENTAL MEASUREMENT TECHNIQUES FOR NATURAL CONVECTION FLOW

Thanh Tung Duong, Thanh Tram Tran, Tri Vien Tran, Hoang Tuan Truong, Chi Thanh Tran, Tat Thang Nguyen, Hiroshige Kikura

Nuclear Training Center, 140 Nguyen Tuan Street, Thanh Xuan District, Hanoi, Vietnam

Project information:

- **Project name:** “Development and Improvement of Experimental Measurement Techniques for Natural Convection Flow”

- **Code:** CS/24/10-01

- **Managerial Level:** Institute

- **Implementation time:** 12 months (Jan. 2024- Dec. 2024)

- **Contact email:** duongtung@gmail.com

- **Published papers related to the project:**

1. Thanh Tung Duong, Thanh Tram Tran, Tri Vien Tran, Tan Hung Hoang, Hoang Tuan Truong, Chi Thanh Tran, Tat Thang Nguyen, Hiroshige Kikura “FUNDAMENTAL INVESTIGATION OF NATURAL CONVECTION INDUCED BY VERTICAL HEATED ROD USING ULTRASOUND VELOCITY PROFILER”, *Journal of Nuclear Science and Technology*, Nucl. Sci. and Tech., Vol.4, 2024.

2. Thanh Tung Duong, Tan Hung Hoang, Hoang Tuan Truong, Chi Thanh Tran, Tat Thang Nguyen, Hiroshige Kikura “Investigation of Natural Convection Induced by Vertical Heated Rod Using Ultrasound Velocity Profiler”, Vietnam Conference on Nuclear Science and Technology, VINANST-15, Nha Trang, Vietnam, August 2023.

3. Trinh The Nghia, Le Mai Linh, Pham Thanh Tung, Duong Thanh Tung, Tran Tri Vien, Tran Thanh Tram, Truong Hoang Tuan, Tran Chi Thanh, Hiroshige Kikura “Study on the Influence of Spacer Grids on Natural Convection in Reactor Fuel Rods”, The 8th Nuclear Science and Technology Conference for Young Researchers Hanoi, 10/2024.

Natural convection is a fundamental phenomenon observed in various industrial, nuclear energy, power generation, and electronics cooling applications. In nuclear reactors, natural convection plays a crucial role in residual decay heat removal following reactor shutdown incidents or accidents. The design of fuel elements and fuel assemblies significantly influences flow rates, impacting natural circulation. Understanding natural convection requires analysis of the spatiotemporal velocity profile, which provides valuable insights into flow behavior. Therefore, the Ultrasonic Velocity Profiler (UVP) emerges as a suitable tool for observing natural convection flow behavior. However, since sound velocity in a fluid is temperature-dependent, it might affect the accuracy of velocity measurements. Hence, confirming the applicability of UVP becomes essential. In this study, a vertical heated rod with a diameter of 12 mm and a length of

225 mm is immersed at the center of a vertical acrylic pipe with a diameter of 144 mm and a height of 500 mm. The ultrasonic transducer is positioned outside the pipe to enable long-term flow behavior measurement. Utilizing the UVP technique, one-dimensional velocity profile behavior inside the pipe is measured and validated using Particle Image Velocimetry (PIV). Consequently, the spatiotemporal velocity profile is depicted in color scale to comprehend the natural flow behavior induced by a single heater rod.

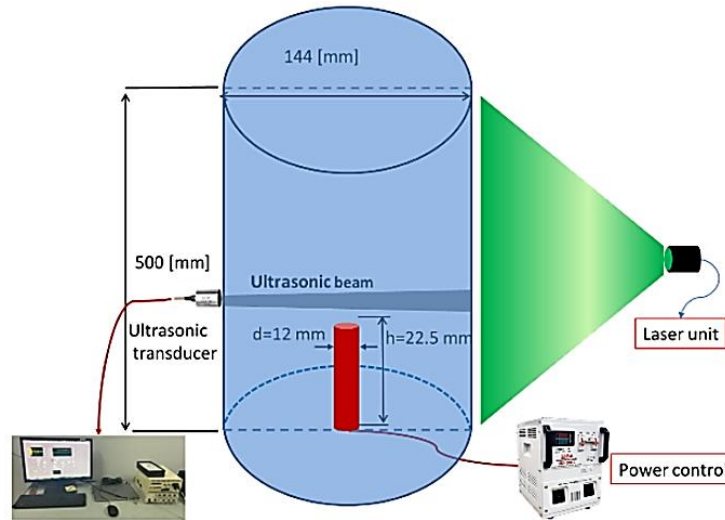


Figure 1. Sketch of experimental apparatus

The principle of the UVP method is based on the echography of ultrasound. The ultrasonic pulse is emitted from a transducer and reflected by solid particles suspended in fluids and received with the same transducer. For deriving instantaneous velocity profile, position information is given by a time delay between pulse emission and reception of the echo. The velocity information can be obtained from an instantaneous frequency of the echo at each time instant. The transducer for the velocity measurements was mounted on the outside of the sidewall, and the ultrasonic waves passed through the container wall.

The information of position in each channel is extracted from the time delay T_{PRF} or pulse repetition frequency $f_{PRF} = 1/T_{PRF}$ as follows:

$$x = \frac{c \times T_{PRF}}{2} \quad (1)$$

where c is sound speed in the medium.

The local instantaneous velocity, $V(x)$, can be determined from the Doppler shift frequency at each time and position by analyzing the echo signal to compute the instantaneous frequencies at various time intervals after emission (known as the Doppler frequency), as follows:

The instantaneous local velocity, $V(x)$ is derived from Doppler shift frequency (f_D) at the time and position as:

$$V(x) = \frac{cf_d}{2f_0 \cos(\theta)}$$

(2)

where f_0 is the basic ultrasonic frequency, θ is inclined angle between ultrasonic sensor and pipe.

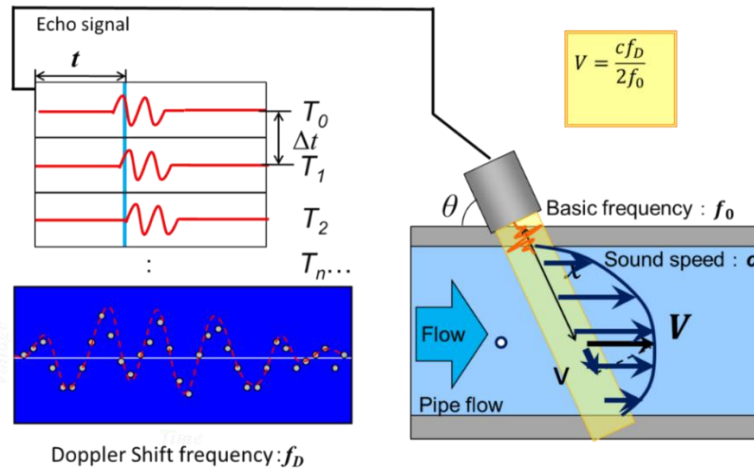


Figure 2. Principle of Ultrasonic Velocity Profile (UVP)

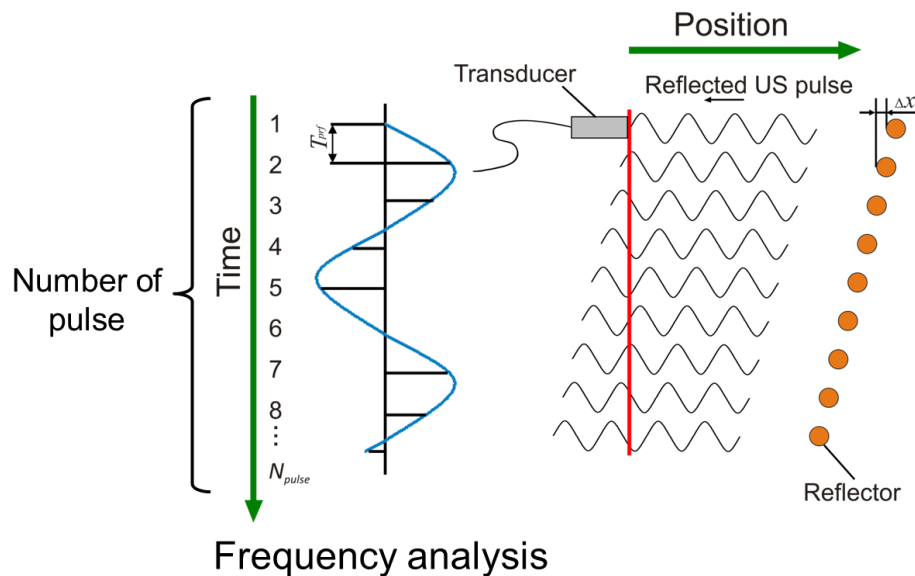


Figure 3. Principle of detection of Doppler shift frequency using UVP method

The signal processing for Doppler frequency is basically based on the FFT (Fast Fourier Transform). It is well known that the frequency resolution depends on the sampling frequency and the data length. The Auto-correlation approach is the method to calculate the Doppler frequency with the auto-correlation function. In case of the auto-correlation, the frequency can be theoretically obtained by only two pulses. In the Fig. 3, a pulsar/receiver is used to emit and receive the ultrasonic waves through same sensor. The received echo signals contain both carrier and shifted signals. The quadrature detection where echo signals are multiplied by sine and cosine components is applied to separate signals. Then low pass filter is used to eliminate the carrier waves. The

complex envelope signal $z(t)$ after the low pass filter is explained as following:

$$z(t) = I(t) + jQ(t) \quad (3)$$

where, $I(t)$ and $Q(t)$ are the in-phase signal and the quadrature phase signal with the received signal, respectively. The autocorrelation function R_f is expressed as following:

$$R_f = (T_{PRF}, t) = \int z(t) \times z^*(t - T_{PRF}) dt = R_x(T_{PRF}, t) + jR_y(T_{PRF}, t) \quad (4)$$

where, T_{PRF} is the time interval of the pulse emission, z^* is the conjugate complex signal of $z(t)$, R_x and R_y are the real and imaginary part of R_f , respectively. The phase shift between consecutive echo signals is expressed as following:

$$\varphi(T_{PRF}, t) = \tan^{-1} \frac{R_x(T_{PRF}, t)}{R_y(T_{PRF}, t)} \quad (5)$$

Doppler shift frequency is estimated as follows:

$$f_D = \frac{1}{2\pi T_{PRF}} \tan^{-1} \frac{R_x(T_{PRF}, t)}{R_y(T_{PRF}, t)} \quad (6)$$

The primary advantage of employing UVP is its capability to measure spatiotemporal velocity profiles, enabling the observation of long-term flow behavior. The magnitude of the vertical velocity along the measurement line is represented using a color scale: yellow to red ($0 < \text{velocity} < 0.025$ m/s) denoted velocity directed towards the transducer (downward in the figure), while green to blue ($-0.025 < \text{velocity} < 0$) indicated velocity moving away from the transducer (upward in the figure), with black representing zero velocity.

The spatiotemporal velocity profile obtained using UVP for natural convection induced by a single heated rod is illustrated in Fig. 4. The vertical axis denotes the distance from the transducer, while the horizontal axis represents the elapsed time from the start of the measurement (1000 s in this instance). The flow behavior measured by the UVP technique clearly revealed that upward flow occurred at the center of the pipe where the heater rod was located, while flow near the pipe wall remained low. This information proved valuable for estimating the efficiency of natural convection phenomena in specific scenarios, such as those encountered in nuclear fuel applications.

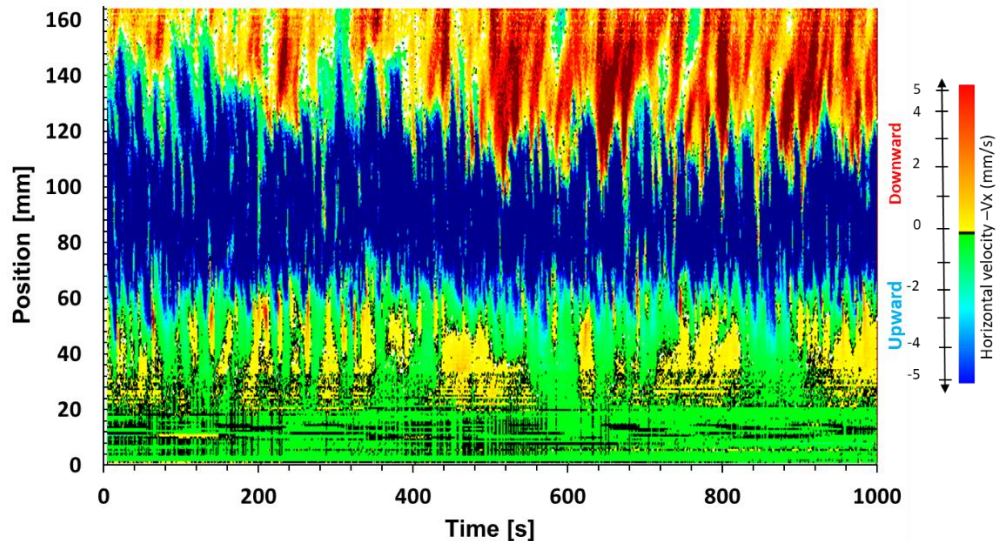


Figure 4. The spatio-temporal of vertical velocity profile using UVP for 1000 s

In this project, the characteristic of convective flow induced by a single heater rod was investigated experimentally. The in-house developed Ultrasound Velocity Profiling (UVP) technique is employed for measuring the natural convection flow. The influence of temperature on the velocity profile measurement using UVP is examined and deemed negligible under the experimental conditions. Accordingly, in case of simple natural convection by using single heater rod, the UVP technique clearly revealed that upward flow occurred at the center of the pipe where the heater rod was located, while flow near the pipe wall remained low. This information proved valuable for estimating the efficiency of natural convection phenomena in specific scenarios and this technique could be applicable for more complex geometry of natural convection flow.

STUDY ON PHYSICAL DESIGN, THERMAL-HYDRAULIC ANALYSIS, AND SAFETY ASSESSMENT OF A SMALL MODULAR REACTOR FOR A FLOATING NUCLEAR POWER PLANT

Nguyen Thi Thanh Thuy¹, Vo Thi Huong¹, Duong Thanh Tung², Hoang Tan Hung¹,
Le Tran Chung¹, Tran Thanh Tram², Nguyen Thi Dung¹, Cao Dinh Hung¹, Pham
Nhu Viet Ha¹

¹ Institute for Nuclear Science and Technology, 179 Hoang Quoc Viet, Cau Giay, Hanoi, Vietnam

² Nuclear Training Center, 140 Nguyen Tuan, Thanh Xuan, Hanoi, Vietnam

Project information:

- **Project name:** Study on physical design, thermal-hydraulic analysis, and safety assessment of a small modular reactor for a floating nuclear power plant
- **Code:** DTCB.14/22/VKHKTHN
- **Managerial Level:** Ministry
- **Implementation time:** 30 months (Jun 2022- Nov 2024)
- **Contact email:** nguyenthuy@vinatom.gov.vn/ pthuytien@yahoo.com
- **Published papers related to the project:**

1. Thi Thanh Thuy Nguyen, Thi Huong Vo, Dinh Hung Cao, Nhu Viet Ha Pham, A study on friction factor correlation considering the torsion effect in helical pipe flow, *Annals of Nuclear Energy*, Volume 217, July 2025.

2. Duong Thanh Tung, Tran Thanh Tram, Hoang Tan Hung, Nguyen Thanh Thuy, Investigation of quenching phenomena during the reflooding phase against the FLECHT-SEASET experiment by using RELAP5/MODE3.3, *Nuclear Science and Technology*, Vol. 14 No. 2 (2024), 1-10.

3. Viet Ha Pham Nhu, Benchmark Analysis of a Prismatic Type-high Temperature Gas-cooled Reactor with the ENDF/B-VII.0, ENDF/B-VII.1 and ENDF/B-VIII.0 Nuclear Data, *VNU Journal of Science: Mathematics - Physics*, [S.l.], Vol. 40, No. 3 (2024).

4. Thanh Tung Duong, Thanh Tram Tran, Tan Hung Hoang, Thanh Thuy Nguyen, Verification of the reflooding model of RELAP5/MOD3.3 with FLECHT-SEASET Experiment, *Vietnam Conference on Nuclear Science and Technology (VINANST14)*, Nha Trang, Vietnam, 9-11 Aug., 2023.

5. Nguyen T. Thanh Thuy, Vo Thi Huong, Cao Dinh Hung, Pham Nhu Viet Ha, Application scaling criteria for the force convection circulation to conceptual simulation reactor vessel design, *Vietnam Conference on Nuclear Science and Technology (VINANST14)*, Nha Trang, Vietnam, 9-11 Aug., 2023.

6. Nguyen Thi Dung, Tran Viet Phu, Calculation of core configuration selection and analysis of physical characteristics for a 200 MWt pressurized water reactor small modular reactor (SMR), *The 7th National Conference for Young Researchers on Nuclear*

In the context of the growing global demand for clean and sustainable energy, small modular reactors (SMRs) have emerged as a promising solution thanks to their compact and flexible design. These reactors are particularly suitable for regions with constrained electrical grid infrastructure and can be seamlessly integrated into the energy grid with other renewable energy sources. Notably, SMRs can be designed for deployment in marine environments, typically located on floating platforms such as ships or barges, which enables them to provide a stable power supply to coastal and island regions. However, the marine environments pose significant challenges to nuclear safety under extreme environmental conditions. Given the limited access to design parameters of the existing SMRs in the world, this study proposes a preliminary design of a 200 MWt SMR utilizing pressurized water reactor (PWR) technology. The primary objectives of the study include: (1) optimizing the core configuration; (2) conducting a thermal-hydraulic analysis for cooling performance assessment; (3) modeling and simulating the nuclear steam supply system (NSSS); and (4) performing steady-state simulations by RELAP5/mode 3.2 for the operational efficiency evaluation under normal conditions.

The optimization of the SMR core configuration was carried out through the analysis of 1,260 core arrangements, in which the positions of fuel assemblies with different enrichment levels were adjusted for minimization of the non-uniformity of power distribution. The PIJ module for fuel cell simulation and the COREBN module for 3D core burnup analysis of the SRAC2006 code were used for those calculations. Due to the direct influences of core configuration on thermal performance, a thermal-hydraulic analysis was conducted for evaluation of the key parameters such as temperature distribution, flow velocity, heat transfer efficiency, as well as pressure loss, based on the conservation equations of mass, momentum, and energy. These analysis results facilitated the assessment of cooling capability and provided essential input for the NSSS design.

In this study, the NSSS was established with fundamental components, including a reactor vessel, a helical coil once-through steam generator (OTSG), a pressurizer, and a coolant pump. The thermal structure of the OTSG was characterized by three distinct heat transfer regions: subcooled preheating, saturated boiling and evaporation, and superheating. The pressurizer was calculated using the mass and energy balance method, with the steam-to-water volume ratio derived from the reference ratios of the existing SMR designs. The reactor coolant pump (RCP) is a centrifugal pump, with its power and rotational speed estimated by torque and pressure differential. Additionally, a passive safety system, with an accumulator (ACC) and a core makeup tank (CMT), was developed based on the Bernoulli and Darcy-Weisbach equations to predict flow velocity, water level, and cooling duration in emergencies. For the verification of the system model, the calculation results were compared with the simulation results by RELAP5. As part of this validation, the FLETCH-SEASET experiment was selected as a

reference for assessment of the consistency between theoretical calculation and simulation results.

The schematic diagram of the 200 MWt SMR is presented in Figure 1. The calculation results showed that the optimal core configuration reached a peak power factor (PPF) of 1.36, with a fuel cycle length of 848 days, contributing to the reduction in local hot spots and uniform power distribution (as in Figure 2).

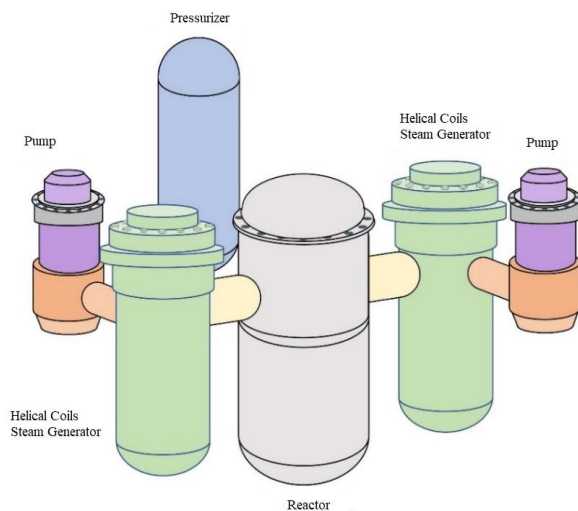


Figure 1. The schematic diagram of the SMR

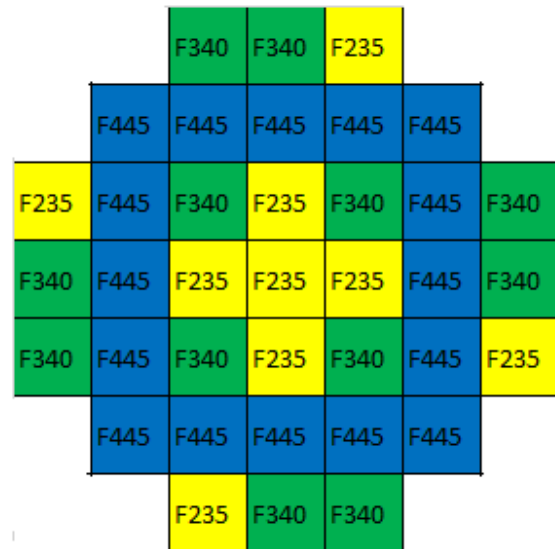


Figure 2. The optimal configuration

The thermal-hydraulic analysis of the core indicated that the temperatures of the fuel, cladding, and coolant were all within the safe operation limits, with the peak fuel temperature not exceeding 2800°C. The core configuration, with a diameter of 1.67 m and a height of 2.2 m, along with the heat flux distribution estimated based on the core height, ensured the departure from nucleate boiling ratio (DNBR) values of ≥ 2.0 , exceeding the safety threshold of 1.5 (as in Figure 3). The reactor vessel, with an inner diameter of 2.2 m and an overall height of 6.78 m, achieved an L/D ratio of approximately 3.1, which is consistent with current SMR designs. The OTSG, with an outer diameter of 1.409 m and 240 heat exchange tubes arranged in 19 layers (as in Figure 4), demonstrated high heat transfer efficiency and enabled the steam output to reach 290°C.

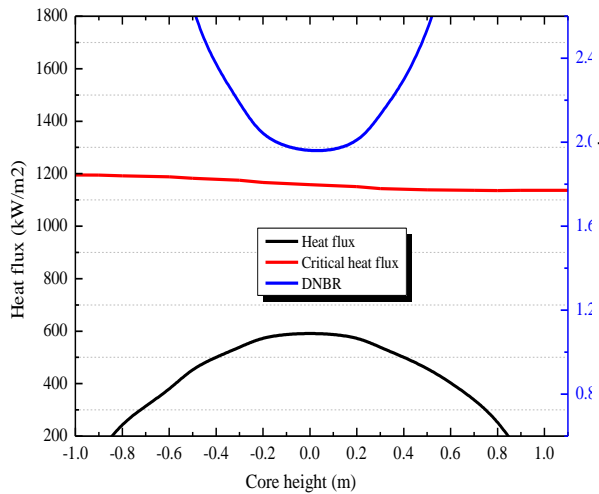


Figure 3. Heat flux distribution, maximum heat flux, and DNBR along core height

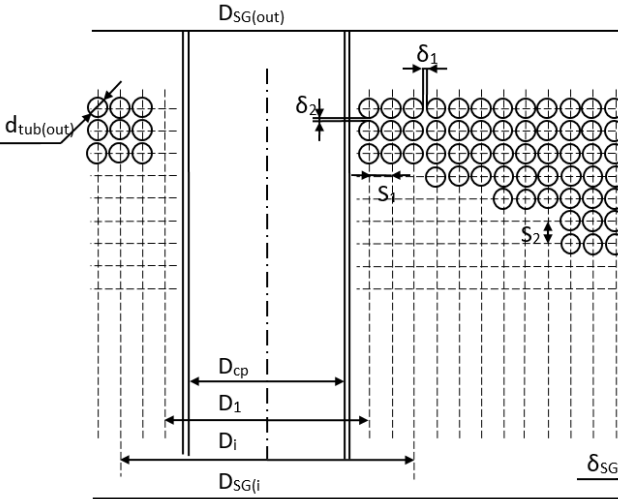


Figure 4. Arrangement of heat exchange tube layers in the OTSG

In addition, the passive safety system was evaluated through the analysis of CMT and ACC. The CMT, with an initial water level of 4.0 m and flow rate of 0.73 kg/s, provided gravity-driven core cooling for up to 4 hours. The ACC was analyzed using isothermal and isentropic gas expansion models. The results revealed that the discharge rate stood at 0.73 kg/s initially and then decreased with pressure drop. The isothermal model offered better pressure maintenance and longer cooling duration, compared to the isentropic model. These findings have underscored the necessity for selecting an appropriate gas expansion model for optimal ACC performance.

The simulation results by RELAP5/mode3.2 illustrated that the SMR systems attained a steady state after approximately 200 seconds, with the coolant temperatures of 326.85°C at the outlet and 301.80°C at the inlet of the reactor. The pressure differential across the core was maintained at 14.431 kPa, showing stable operation of the system. Nevertheless, the pressure drop across the OTSG from the simulation was underestimated compared to the calculation value (72.0 kPa), which requires adjustment of the friction factor for the OTSG model.

In summary, this study presented the preliminary design for the 200 MWt SMR using PWR technology. The optimized core configuration achieved a favorable power distribution, with an extended fuel cycle. Thermal-hydraulic analysis confirmed that important safety parameters like fuel temperature and DNBR value remained within acceptable limits. The designs of the NSSS and passive safety systems showed promising performance in maintaining stable operation and core cooling at the steady-state. However, discrepancies in the pressure drop across the OTSG were observed from the simulation and calculation results, thereby necessitating further refinement of the model, especially regarding the friction factor. In general, the research provides valuable input and serves as a technical foundation for safety assessment of SMRs.

Future studies are expected to consider the integration of structure components such as grid spacers, control rod systems, piping, and auxiliary equipment, which may

affect flow distribution, pressure loss, and heat transfer efficiency. It is also recommended that accident scenarios should be analyzed for performance evaluation of the passive safety system under varying thermal-hydraulic conditions. Furthermore, the integration of SMRs with renewable energy sources should be stimulated for enhancement of applicability, flexibility, and operational efficiency of the reactors.

2.3. INSTRUMENTATION, NUCLEAR ELECTRONICS

STUDY AND DEVELOPMENT OF A GAMMA CAMERA USING SILICON PHOTOMULTIPLIERS AND A YSO(Ce) SCINTILLATOR ARRAY

Lai Viet Hai, Nguyen Thi Minh Hien, Dang Quoc Trieu

Centre for Applications of Nuclear Technique in Industry (CANTI),
01 DT 723, ward 12, Dalat city, Lamdong province

Project information:

- **Project name:** Study and development of a gamma camera using silicon photomultipliers and a YSO(Ce) scintillator array.
- **Code:** CS/24/06-02
- **Managerial Level:** Institute
- **Implementation time:** 12 months (Jan 2024- Dec 2024)
- **Contact email:** hailv@canti.vn
- **Published papers related to the project:**
 1. Lai Viet Hai et al., Development of an Arduino-Based Bias Power Module for Silicon Photomultipliers, Conference on Nuclear Science and Technology for Young Researchers, Ha Noi, Vietnam, 2024 (in Vietnamese).
 2. Lai Viet Hai et al., Developing an Arduino-Based Peak Detector Circuit for Gamma Spectrum Measurement”, 24th IEEE Real Time Conference, Quy Nhon, Binh Dinh, Vietnam

Along with remarkable advances in radiation application technology, gamma camera devices have been concurrently developed to serve various fields such as healthcare, security, and nuclear energy. In the medical field, gamma cameras are a key component of imaging systems like SPECT and PET, assisting in the detection and monitoring of conditions such as cancer, cardiovascular diseases, thyroid disorders, and musculoskeletal issues. In the nuclear energy sector, to ensure the safety of personnel working with radiation, gamma cameras are used to identify and locate sources of radioactive materials in contaminated areas. Following the incident at the Fukushima nuclear power plant, these devices not only aid in monitoring polluted areas but also contribute to the decontamination and decommissioning processes of nuclear facilities. In the security domain, gamma cameras help detect the locations of illegal radioactive sources or materials that could potentially be used for terrorist purposes. To enhance our understanding and gradually localize nuclear imaging technology, we propose the study and construction of a gamma camera using silicon photomultipliers and a YSO(Ce) scintillator array.

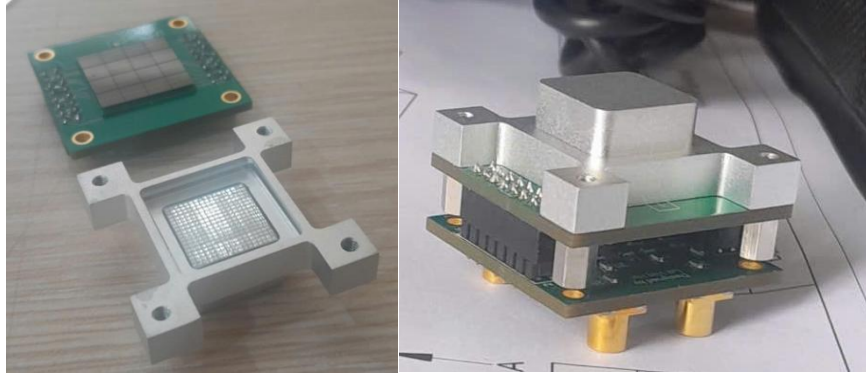


Figure 1. SiPM array, YSO(Ce) scintillator array, and the complete detector module

In this study, we used a 4×4 SiPM array combined with a 17×17 YSO(Ce) scintillator array through a 2mm-thick glass light guide. The entire SiPM and scintillator assembly was housed in an aluminum enclosure to shield it from external light and EMI noise. For signal processing, we developed channel-matched circuits, amplifier circuits, peak detection circuits, ADC circuits, as well as programming for control, image reconstruction, and display **interfaces**.

We performed gamma camera image calibration in two steps: spatial linearity calibration and uniformity calibration. Spatial linearity was calibrated using a uniformly distributed ^{131}I disk source along with the non-linear interpolation method Thin Plate Splines (TPS). Uniformity was also calibrated using the same ^{131}I disk source; the measured results were used to calculate the probability of photon interaction at each image pixel, combined with a binomial distribution model to obtain an accurate correction coefficient.

To evaluate energy resolution, we measured the energy spectra of ^{241}Am and ^{131}I sources, yielding the results of $\text{FWHM}(\%)@60 \text{ keV} = 14.67\%$ and $\text{FWHM}(\%)@364 \text{ keV} = 19.53\%$.

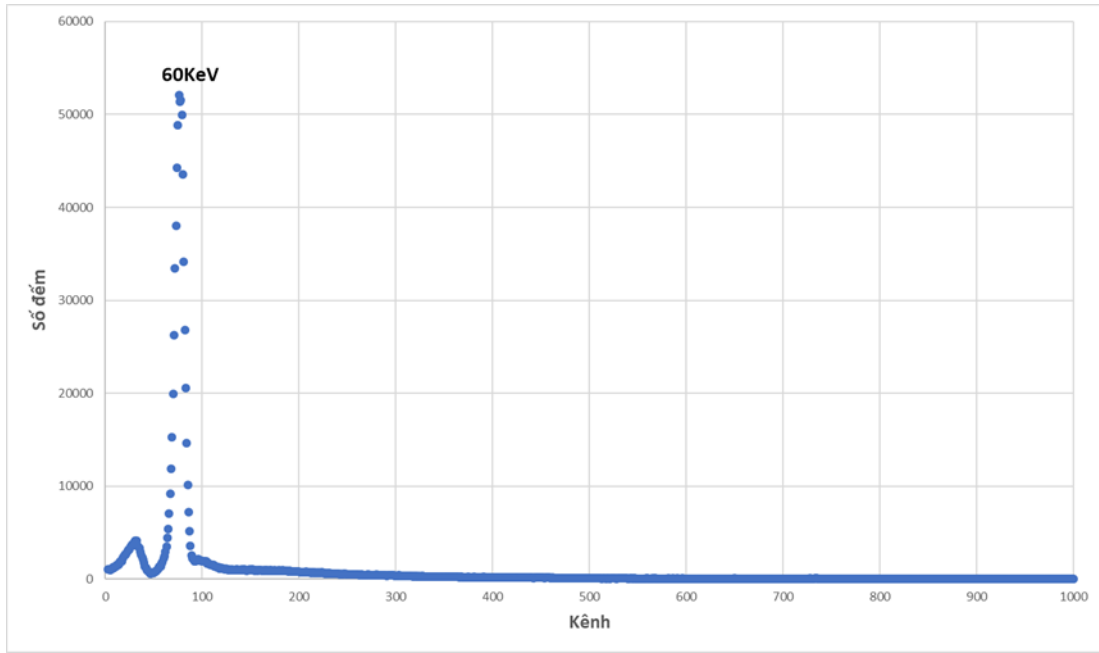


Figure 2. Energy spectrum of the ^{241}Am source

To evaluate the intrinsic spatial resolution of the gamma camera, we used a slit placed on a uniform disk source, resulting in an FWHM of 0.68 mm.

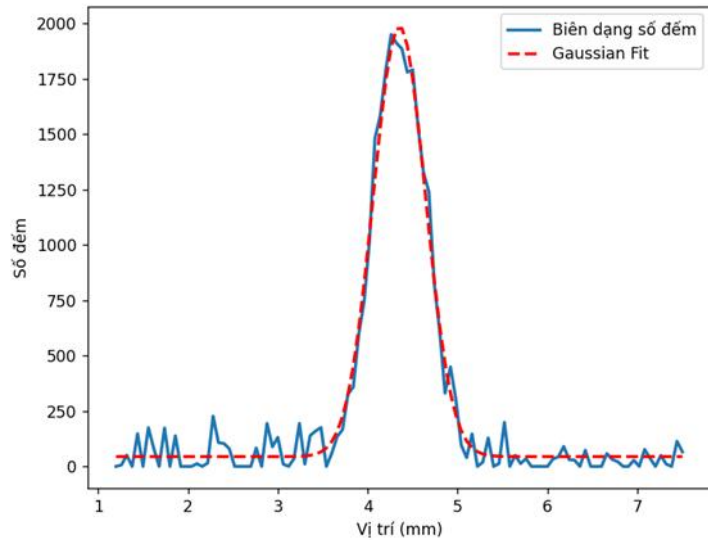


Figure 3. Image profile of the slit

Thus, we have successfully researched and fabricated a basic gamma camera system capable of capturing images of gamma-emitting sources, with energy resolution and intrinsic spatial resolution meeting the **established** criteria. This achievement serves as a foundation for further development of nuclear imaging technology applications in Vietnam.

STUDY ON DEVELOPMENT OF AN ENVIRONMENTAL RADIATION MONITORING SYSTEM USING A NaI-SiPM SCINTILLATION DETECTOR COMBINED WITH THE INTERNET OF THINGS (IoT)

Vu Van Tien, Mai Văn Dien, Nguyen Duc Tuan, Vu Trung Tan, Đinh Anh Tuan, Bui Duc Ky, Vuong Thu Bac, Nguyen Hai Ninh, *Nguyen Thanh Hung

Institute for Nuclear Science and Technology, 179 Hoang Quoc Viet, Cau Giay, Hanoi, Vietnam

*Hanoi Irradiation Center, Km 12, Street 32, Minh Khai, Bac Tu Liem, Hanoi, Vietnam

Project information:

- **Project name:** Study on development of an environmental radiation monitoring system using a NaI-SiPM scintillation detector combined with the internet of things (IoT)
- **Code:** ĐTCB.04/23/VKHKTHN
- **Managerial Level:** Ministry
- **Implementation time:** 24 months (1/2023 to 12/2024)
- **Contact email:** ngdtuan108@gmail.com
- **Published papers related to the project:**

1. Nguyen Duc Tuan et al., Design and operation of VinaERMS-INST for the national environmental radiation monitoring network, Proceedings of the 15th Vietnam Conference on Nuclear Science and Technology (VINANST 15), Nha Trang, Vietnam, 2023.

2. Nguyen Duc Tuan, Mai Van Dien, Vu Van Tien, Dinh Anh Tuan, Vu Trung Tan, Nguyen Hai Ninh, Nguyen Thanh Hung, Design and operation of VinaERMS-INST for national environmental radiation monitoring network, submission accepted on October 25, 2024 by Nuclear Science and Technology (NST).

Up to now, the Institute for Nuclear Science and Technology (INST) has installed and put 12 environmental radiation monitoring systems into operation, including 7 Fuji systems (Japan) and 5 Sara systems (Envinet, Germany) at 11 online environmental monitoring stations in Lang Son, Hai Phong, Mong Cai, Bai Chay, Lao Cai, Cao Bang, Nghe An, Son La, Da Nang, Hanoi and on Bach Long Vi island. However, the number of ERMSs currently in place remains limited and does not fully meet the domestic demand for monitoring and management in Vietnam. An ERMS using a NaI-SiPM scintillation detector combined with the Internet of Things (IoT) was designed and manufactured within the framework of the project managed by the Ministry of Science and Technology in order to address the domestic demand for the establishment of a national environmental radiation monitoring network and local monitoring stations in some provinces and cities. The system consists of 2 main measuring channels: a **spectrometric channel** based on a scintillation detector and a *wide range dosimetric*

channel based on an energy compensated Geiger-Muller detector combination. These channels were designed and manufactured on the basis of the STM32 family of 32-bit microcontrollers to control the real-time data measurement, acquisition and storage. In addition, the system was integrated with weather sensors such as temperature, humidity, atmospheric pressure, rainfall and a GPS global positioning satellite signal receiver. The system used the IoT technology for the data transmission to the Monitoring Center on a cloud server via 4G LTE network connections with the popular HTTP protocol through the methods such as GET, POST and PUT. The data generated from the ERMS included *date/time of data acquisition, low/high range radioactive pulse counting rate, battery voltage, air temperature, relative humidity, atmospheric pressure, rainfall, gamma spectrum, GSM strength, and GPS coordinates*, which were saved as a database on the server. The system was fully powered by solar cells combined with a backup lithium battery (12V-30Ah) which enables its continuous outdoor operation. All radiation detectors and functional electronic units were placed in an IP-67 protected enclosure. The fully developed ERMS, named VinaERMS.Spect-INST, as shown in Figure 1, was mounted on a rack at a height of 1m above the ground. The achieved technical specifications and features of the system are shown in Table 1.

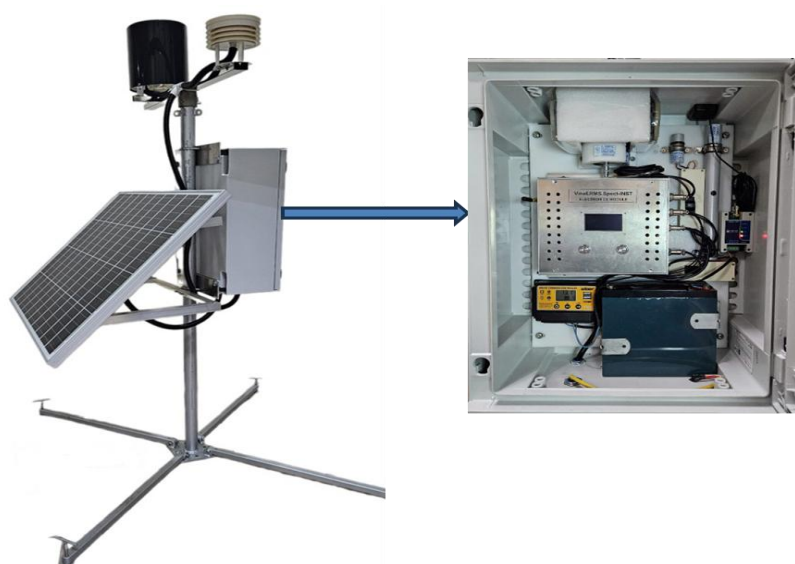


Figure 1. The complete VinaERMS.Spect-INST system

Table 1. Technical specifications and features of VinaERMS.Spec-INST system

Specifications	
Scintillation detector	SiPM+NaI: 51B51/SIP-E3-X (Scionix) Dimension: 2x2 inch Energy resolution 7.5% (at 662 keV)
Multi-channel analyzer (MCA)	4096 channels
Geiger-Muller detector	Energy compensated tubes, Qty: 02 - Vacutec 70031A for Low Dose Rate - Vacutec 70018A for High Dose Rate
Radiations	Gamma, X-ray

Quantity	H*(10) (Ambient dose equivalent rate)
Energy range	38 keV to 1.3 MeV ($\pm 25\%$) 35 keV to 2.5 MeV (-29% to $+67\%$)
Dose rate range, H*(10)	10 nSv/h – 1 Sv/h
Accuracy	$\pm 5\%$ (calibrated with Cs-137 and Co-60)
Operating temperature and humidity range	-10°C to 50°C, 100% RH
Complying with the international standards	IEC 60846, IP 67
Data communication	4G LTE, IoT: http protocol Interface: USB, GPS
Weight and size	~30 kg, 530 x 430 x 210 mm
Power supply	100W solar cells and 12V-30Ah backup batteries
Features	
Spectrometric channel: Based on a NaI-SiPM scintillation detector coupled with a compact multichannel analyzer for environmental gamma spectrum measurement, isotope identification, and dose rate conversion for ultra-low dose rates with high sensitivity from nSv/h.	
Wide range dosimetric channel: Based on the combination of two energy compensated Geiger-Mueller detectors complying with the IEC-60846 standard capable of measuring the ambient dose equivalent rate H*(10) with the sensitivity from environmental background levels to Sv/h.	
Meteorological monitoring channel: Measures parameters such as temperature, humidity, atmospheric pressure, and rainfall for synchronization and analysis with radiation monitoring data.	
GPS module: Enables precise location identification during the installation and supports environmental radiation mapping applications.	
Data acquisition and transmission: Collected data on spectra, gamma radiation intensity, environmental parameters, and system status are periodically transmitted wirelessly via a 4G-LTE modem to a cloud server for storage, management, evaluation, visualization, and analysis.	
Automated operation: Fully automated and operates independently based on the pre-set cycles without the need for manual intervention, in accordance with an IoT system/device.	
Outdoor operation: Powered by a combination of solar energy and a lithium battery and designed to meet the IP67 standard.	
User-friendly software: Provides operators and end-users with access to real-time environmental radiation data via a Web-based platform and an Android mobile application.	

At the Monitoring Center, a web-based software interface serves as the display platform for the ERMS, as shown in Figure 2. The interface includes a dosimetric and

spectroscopic channel function tab for wide-range dose rate and environmental gamma spectrum channel charts, a meteorological monitoring channel for weather parameter charts, and a data logger for real-time specific data tables. Additionally, the system features a map displaying the installation location of the system according to GPS coordinates, along with the latest updated radiation dose parameters.

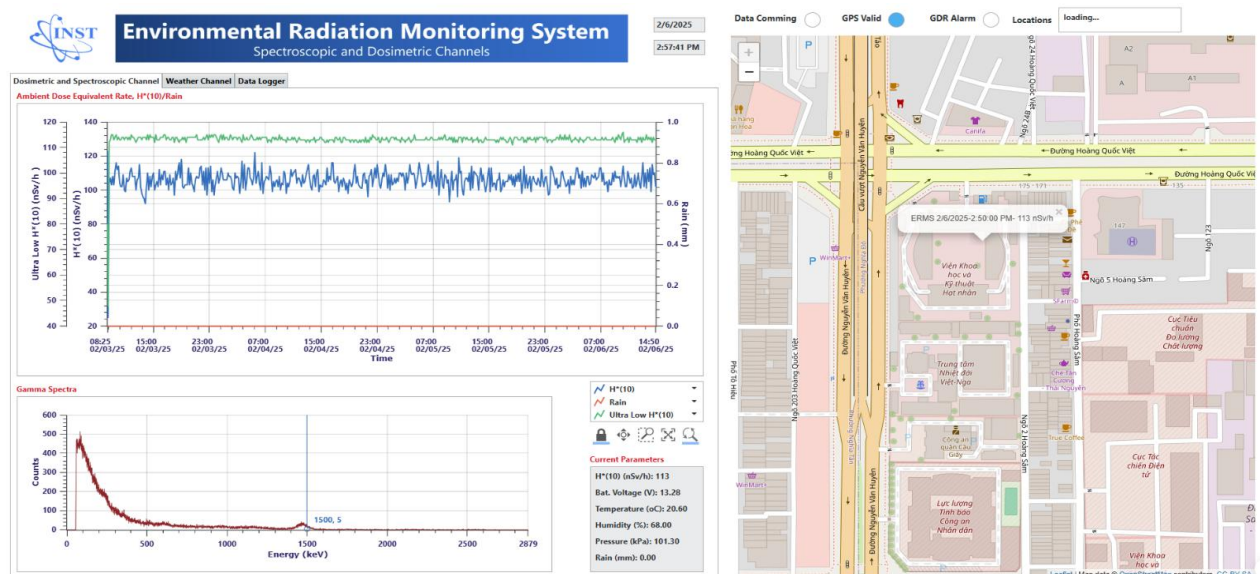


Figure 2. Web-based user software of the VinaERMS.Spect-INST at <http://eradmon.nuclearelectronics-inst.com/>

The VinaERMS.Spect-INST consists of a NaI-SiPM scintillation detector and two GM detectors that have been calibrated based on the Gamma ray irradiator system (GC-60-10-A, Hopewell, USA) of the Secondary Standard Dosimetry Laboratory (SSDL) of the INST to obtain full certification.

The system has been installed in the field to conduct monitoring and testing in the actual conditions of continuous environmental radiation for many days. One of the typical datasets measured at the site of the INST is shown in Figure 3. The average value shows the correlation between the measuring devices, with a notable rainfall event occurring from 15:00 to 17:00 on October 15, 2024 due to the increase in airborne radon levels, resulting in a peak in the dose rate measurement with simultaneous spikes across all devices.

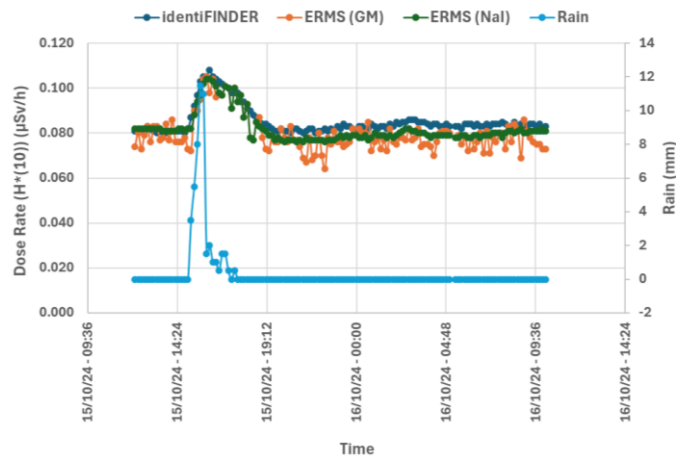


Figure 3. Data of VinaERMS.Spect-INST system at the INST

In summary, the system was designed and developed with a compact structure. The hardware specifications and software features met the requirements of an environmental radiation monitoring system. The VinaERMS.Spect-INST, based on industrial standards for hardware and IoT network protocols, is a reliable stand-alone system that helps to improve nuclear emergency preparedness and response by supplying real-time radiation data. Mastering the technology to successfully manufacture the system shows advantages in cost, greater autonomy in the operation, maintenance, and repair of the national environmental radiation monitoring network. The research results of the project serve as the foundation and prototype for a project on producing some other systems in the near future to supplement and replace malfunctioning systems in the national environmental radiation monitoring network.

2.4. INDUSTRIAL APPLICATIONS

RESEARCH AND APPLICATION OF LOW VOLTAGE TECHNIQUES TARGET TO DETECT AND LOCATE LEAKS IN WATERPROOF MEMBRANES ON THE CONCRETE SURFACE

Dinh Quoc Dat ¹, Nguyen Duc Huyen ¹, Nguyen Xuan Thao ¹, Nguyen Tien Phong ¹, Luong Thi Hong ¹

¹ Center for Non-Destructive Evaluation, 140 Nguyen Tuan, Thanh Xuan, Hanoi

Project information

- **Project name:** Research and application of low voltage techniques target to detect and locate leaks in waterproof membranes on the concrete surface.

- **Code:** CS/23/09-01

- **Managerial level:** Institute

- **Duration:** January 2023 - December 2023 and extended to June 2024

- **Phone:** 0362697083 **Email:** quocdatdinh@gmail.com

- **Published papers related to the project:**

1. Dinh Quoc Dat, Nguyen Duc Huyen, Nguyen Xuan Thao, Nguyen Tien Phong, Luong Thi Hong, "Research and application of low voltage techniques target to detect and locate leaks in waterproof membranes on the concrete surface". The 8th Conference on Nuclear Science and Technology for Young Researchers in Hanoi, Vietnam, 2024.
2. Dinh Quoc Dat, Nguyen Duc Huyen, Nguyen Xuan Thao, Nguyen Tien Phong, Luong Thi Hong, "Research and application of low voltage techniques target to detect and locate leaks in waterproof membranes on the concrete surface". Journal of Nuclear Science and Technology Information, No.2/2024 (in Vietnamese).

In civil and industrial construction, the issues of seepage and waterproofing to protect concrete floors are always of primary concern. In Vietnam, with a tropical monsoon climate, heavy rain and high humidity, the quality of concrete is reduced; concrete structures can crack, corrode, mold, leak, and thus the life of the project will be reduced. To increase the durability and life of the concrete floor, it is necessary to implement specialized waterproofing measures. Therefore, the inspection, detection and evaluation of waterproof surfaces will gradually be applied in the inspection and maintenance process of construction works. At the Center for Non-Destructive Evaluation, the research team of the Technology Research and Development Department has conducted initial physical effects studies on the detection of electrical leakage through non-conductive coatings on concrete floors.

In order to study characteristics of low voltage technique to detect and locate seepage through the coating on concrete base and according to ASTM D7877-14 standard, Research Team has successfully designed and manufactured each part and assembled it into a complete device system. The technical parameters of the device system are as follows:

- Operating voltage: 220V - 240V
- Output voltage in range: 9VDC – 90VDC
- Frequency: 50 – 60 Hz
- Matching impedance not less than 1 MΩ.
- Ammeter: digital: Digital measures voltage in the range up to 100V, measures current from 1μA to 1A.
- Overall dimensions (length x width x height): 230x150x90 (mm)
- The measuring head is designed with 3 copper brushes (width x length): 200 x 230 (mm)



Figure 1. DC power supply and low voltage test probe

The device system is evaluated for accuracy and stability of the output current by connecting a multimeter and resistor in series. The stability and reliability of the device system is assessed to be over 95%, ensuring the requirements for use in measuring and recording voltage values on experimental concrete samples according to the instructions of ASTM D7877-14.

The experimental test sample set includes:

- Reinforced concrete sample (length x width x height): 4500x300x150 (mm) and unreinforced concrete sample (length x width x height): 3500x300x150 (mm). Both samples are coated with a waterproof paint on the surface. The thickness of non-conductive waterproofing paint layer ranges from 50 μm to 3500 μm.



Figure 2. Experimental tested concrete sample

Before being put into use, the system must be checked for internal short circuits to ensure the device operates safely without electrical leakage. Following the ASTM D7877-14 guidelines, the research team used a low voltage test method to conduct the experiment. First, we used an electric wire to connect the circuit to a steel stake pre-mounted on the concrete sample (grounded). The positive pole of the circuit was connected to a probe, scanning this probe across the surface of the concrete sample. The entire surface area of concrete sample was then wetted with water, allowing the electric current moved freely across all surface of the waterproof paint layer and was creating a uniform positive charge. In this circuit, the waterproof paint layer acted as an insulator between the positively charged concrete sample surface and the concrete substrate. When the coating was punctured, there had been being a circuit on the surface of concrete sample. Using a voltage meter, the current value generated will be displayed on the meter, from which the location of the puncture was be determined (Figure 3). Low voltage testing allows detection of small changes in current intensity,

while still ensuring electrical safety factors, does not require special measures, and is suitable for manufacturing and testing capacity at Center of Non-destructive Evaluation.

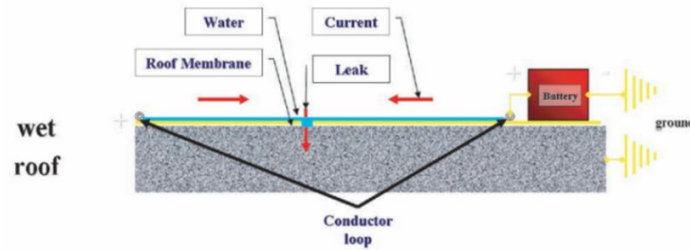


Figure 3. Working principle of low voltage technique

The project team conducted the tests on dry concrete samples and wet concrete samples (spraying water on the concrete surface), which aims to evaluate the change in impedance in concrete when the concrete is dry and wet. We conducted the experimental measurements on the waterproofing insulating paint film when the paint surface was intact and when the paint surface was punctured, to record the initial background noise current value and the current values that changed when the paint film was punctured. From there, the locations of seepage through the coating on the concrete surface were detected and determined. The results recorded after conducting the experiment and are shown in the following charts:

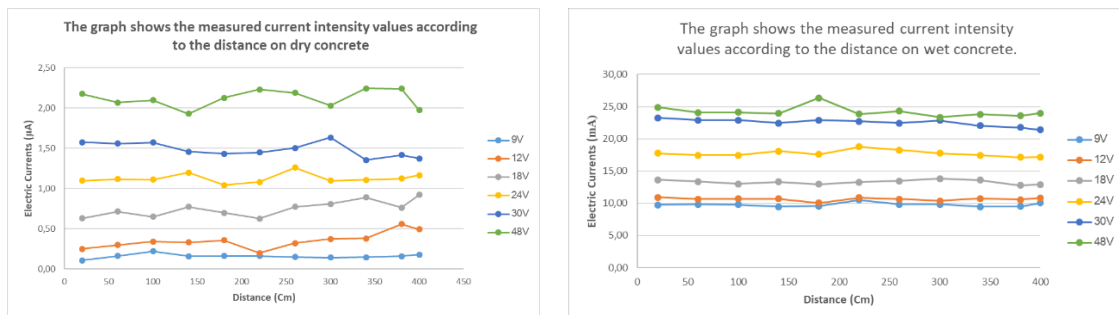


Figure 4. The graph shows the current values measured on dry and wet concrete

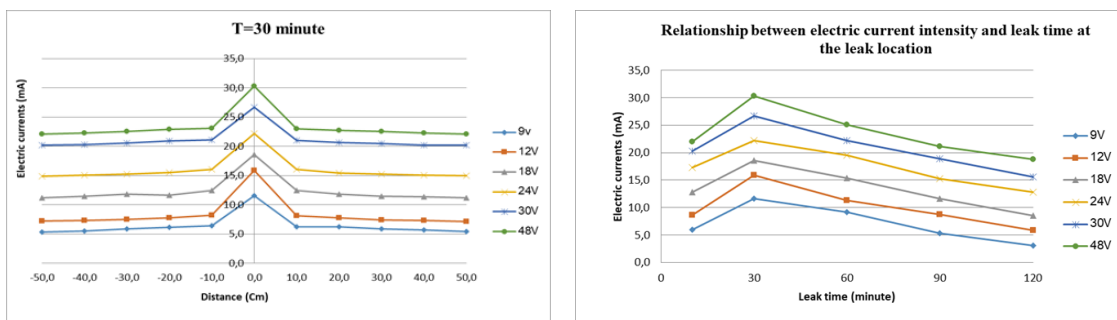


Figure 5. The graph shows the measured current value at the punctured paint layer according to the water penetration time into the concrete

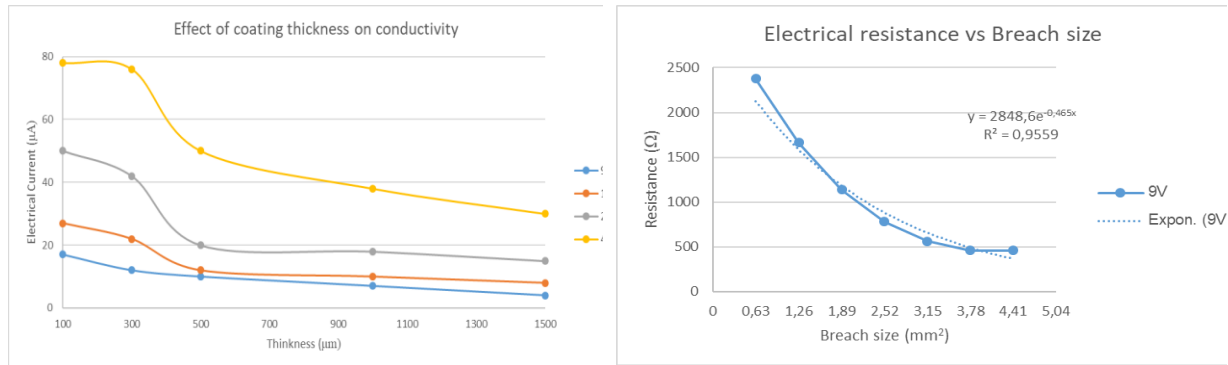


Figure 6. The graph shows the effect of coating thickness and breach size on the sensitivity of the method

From the data recorded during the experiment, the research team found that the method of applying the low voltage technique has good physical effects. It can clearly detect and accurately locate the position of the seepage point through the waterproof coating membrane. The method's duration to record the most optimal value is 30 minutes as of the time of water injection. In addition, the method can detect small seepage spots with a diameter of 0.63 mm. The survey range for concrete is up to 4 m (limited by the test concrete sample).

The device system that the research team built is simple and the recorded values have some fluctuation. They fully meet the technical requirements according to ASTM D7877-14 standard, which applies the low voltage technique in detecting and locating the seepage position on the membrane of non-conductive waterproof coating on concrete floors.

With the above results and the capacity of the research team, the team can conduct a full study on the characteristics of the method, manufacture testing device system and basic coating types. This enables the research team to approach the completion of device system manufacturing, establish the technical processes for detecting leaks in waterproofing layers with laboratory models and explore a new research direction for applying low voltage techniques to detect electrical leaks through waterproofing coatings on concrete floors in the future.

**DEVELOPMENT OF THE TRAINING PROGRAM
ON ULTRASONIC TESTING METHODS FOR CARBON STEEL CASTINGS IN
ACCORDANCE WITH THE REQUIREMENTS OF SNT-TC-1A BY THE AMERICAN
SOCIETY FOR NON-DESTRUCTIVE TESTING**

Pham Thanh Tung, Dao Dinh Dang, Nguyen Minh Duc, Nguyen Van Du, Ngo Thi Kieu Oanh

Center for Non-Destructive Evaluation, 140 Nguyen Tuan, Thanh Xuan, Hanoi

Project Information:

- **Project name: Development of the training program on ultrasonic testing methods for carbon steel castings in accordance with the requirements of SNT-TC-1A by the American Society for Non-Destructive Testing**
- **Code: CS/24/09-01**
- **Managerial level: Institute**
- **Duration: January 2024 - December 2024**
- **Contact email: thanhtung.epu.evn@gmail.com**
- **Published papers related to the project:**

1. Pham Thanh Tung, Dao Dinh Dang, Nguyen Minh Duc, Nguyen Van Du, Ngo Thi Kieu Oanh, "Development of the training program on ultrasonic testing methods for carbon steel castings in accordance with the requirements of SNT-TC-1A", Proceedings of the 8th Conference on Nuclear Science and Technology for Young Researchers in Hanoi, Vietnam, 2024.

Ultrasonic testing is a widely used non-destructive testing method in which a high-frequency ultrasonic beam is transmitted into the test object. Energy reflected from interfaces or discontinuities can be used to determine the size and location of discontinuities or the thickness of the test material. For casting products, the surface roughness of the tested material, the size and complexity of the material structure, the grain size, as well as the orientation of the discontinuities are not perpendicular to the direction of the ultrasonic beam, which can cause difficulties and hinder the interpretation of discontinuities. Establish the training program of ultrasonic testing for carbon steel castings according to SNT-TC-1A to develop specialized training programs applicable to castings products.

Based on reference documents and standards combined with the actual survey, the team developed the training programs, training materials, and question banks that meet the requirements of international standards and in accordance with the conditions applied in Vietnam.

The objectives of the project are to develop a training program for Level II ultrasonic testing methods for carbon steel castings, meeting the requirements of the

SNT-TC-1A document, to support training, research, and practical application in ultrasonic testing for carbon steel castings.

From the survey results and practical conditions in Vietnam, the NDE Center established a training program under the internal certification system by following the training program requirements of the SNT-TC-1A and ANSI/ ASNT CP-105 document, researching the technical specifications included in the standards ASTM A609 and ISO 4992-1. The products of the project consist of the followings:

(1) A training program was designed to span 80 hours to meet the requirements of the recommended practice No. SNT-TC-1A which is given for personnel to study directly at Level II.

No.	Contents	Training Hours	
1	Overview of casting and related discontinuities	4	
2	Introduction to Nondestructive Testing (NDT)	4	
3	The basic principles of acoustics	4	
4	Basic testing methods	4	
5	Pulse-echo equipment system	8	
6	Pulse-echo equipment calibration	12	
7	Ultrasonic testing applications for castings	24	
8	Standard code or specification	4	
9	Testing practice	16	
Total:		80	

(2) A manual that covers the entire content of the training program.

(3) A question bank comprises 145 multiple-choice questions with four options which focus on ultrasonic testing of castings, and cover the topics such as casting technology, associated discontinuities, equipment specifications, probes, cables, calibration blocks, and other related subjects.

(4) A practical Manual for Ultrasonic Testing of Carbon Steel Castings in Compliance with ASTM A609 - Procedure A using Flat Bottom Holes (FBH).

(5) A report on the Trial Implementation of Ultrasonic Testing Training Program Level II for Technicians of the NDE Center and at VINACOMIN Machinery Manufacturing Joint Stock Company (VMC).



Địa chỉ: 140 Nguyễn Trãi, Thanh Xuân, Hà Nội, Việt Nam
ĐT: +84 243 5577881 – 310 Email: info@nnde.com.vn Website: nnde.com.vn

Figure 4: The training material



Figure 5. Applying the ultrasonic testing training program for castings at NDE and VMC Company

The report “Development of the training program on ultrasonic testing methods for carbon steel castings in accordance with the requirements of SNT-TC-1A” was presented at the 8th Conference on Nuclear Science and Technology for Young Officers of the Atomic Energy Industry.

The project has successfully developed the training program for ultrasonic testing of carbon steel castings, complying with the requirements of the SNT-TC-1A. This program has been tested at the NDE Center and several industrial facilities, and gathered the feedback from related organizations and trainees. Based on the feedback, the training program will be further adjusted and refined to better meet practical needs in Vietnam.

**A STUDY ON THE APPLICATION OF NON-DESTRUCTIVE TESTING (NDT)
METHODS TO ASSESS THE CURRENT STATUS OF SOME IMPORTANT SAFETY
COMPONENTS OF THE DALAT NUCLEAR REACTOR**

Tran Dang Manh⁽¹⁾, Doan Phuc-Thuan⁽¹⁾, Mai Thai Nam⁽¹⁾, Vu Duc Vinh⁽¹⁾, Vu Xuan Thanh⁽¹⁾, Nguyen The Man⁽¹⁾, Pham Minh Tuan⁽²⁾, Pham Quang Huy⁽²⁾, Nguyen Kien Cuong⁽²⁾

¹*Center for Non-Destructive Testing (NDE), 140 Nguyen Tuan, Thanh Xuan, Ha Noi*

²*Dalat Nuclear Reseach Institute, 01 Nguyen Tu Luc, Da Lat, Lam Dong*

Project Information:

- **Project name: A study on the application of non-destructive testing (NDT) methods to assess the current status of several important safety components of the Dalat Nuclear Reactor**
- **Code: ĐTCB.14/23/TTNDE**
- **Managerial level: Ministry**
- **Duration: January 2023 - December 2024**
- **Contact email: dangmanhus@yahoo.com**
- **Published papers related to the project:**

1. Tran Dang Manh, Nguyen An Trung, Nguyen The Man, Vu Duc Vinh, Mai Thai Nam, Vu Huu Cuong, Vu Xuan Thanh, “Establishing a program to test and assess the current status of a number of important components for the safety of the da lat reseach reactor using non-destructive testing (NDT) method”, Proceedings of the 15th Vietnam Conference on Nuclear Science and Technology, Nhatrang, Vietnam, 2023 (in Vietnamese)

2. Dang-Manh TRAN, Phuc-Thuan DOAN, Thai-Nam MAI, Huu-Cuong VU, Minh-Tuan PHAM, Quang-Huy PHAM, Kien-Cuong NGUYEN, “Assessing The Current Condition of Aluminum Tank and Weld Inner Surface of Horizontal Beam Tube Number 3 of The Dalat Nuclear Research Reactor Using Non-Destructive Inspection”. Journal of Nuclear Science and Technology - Vietnam Atomic Energy Institute, 2025 (in English)

The Dalat Nuclear Reactor, built in the 1960s and renovated in the 1980s, is the only and oldest nuclear research facility in Vietnam. After more than 60 years of existence and nearly 40 years of operation after renovation, important components such as the reactor vessel, horizontal beam tubes (horizontal channels), cooling system I and protective concrete block are all at risk of aging and quality deterioration. In the absence of any systematic research applying non-destructive testing (NDT) techniques to this reactor, the project entitled "A study on the application of non-destructive testing (NDT) methods to assess the current status of several important components for the safety of the Dalat Nuclear Reactor" has been implemented to provide a scientific basis for assessing and maintaining operational safety. The project focused on researching and

selecting appropriate NDT methods, as well as developing and experimentally applying non-destructive testing procedures for metallic and concrete objects in the furnace. The selected techniques for metal objects include: ultrasonic testing (UT), penetrant testing (PT), digital radiography (RT-D), and visual inspection (VT). The selected techniques for concrete objects include: ultrasonic pulse velocity measurement, core drilling, rebound hammer testing, carbonation depth measurement, electromagnetic testing of steel reinforcement, measurement of steel rust potential, and measurement of moisture content by neutron scattering.

In order to ensure testing efficiency and radiation safety, the research team has manufactured a special mechanical arm that allows the attachment of an ultrasonic probe and camera, remote operation, supporting operations in high-radiation areas that are inaccessible to personnel. The mechanical arm is flexibly designed with multiple degrees of freedom using a jointed structure to access hidden locations in the furnace. In addition, the simulation model of the furnace and the horizontal channel was designed and manufactured using materials equivalent to those in the actual reactor (aluminum 6061, stainless steel), to simulate the structural configuration, geometry, clearances and access conditions. The model was used for equipment testing, calibration and training, thus minimizing risks in actual inspection. In addition, standardized control samples according to ASTM E428 and ASTM E127 standards were also manufactured to evaluate the sensitivity and accuracy of the measuring equipment. The results of the inspection, assessment of the current status and analysis of the root causes for important components of the Da Lat nuclear reactor show that after decades of operation in an environment of ionizing radiation, high temperature - humidity and special historical conditions, several metallic and concrete components have shown signs of material quality deterioration, local damage and potential risks to the long-term safety of the project.

Metallic components such as the reactor vessel and horizontal channel (aluminum alloy 6061) show the appearance of mechanical scratches, spot corrosion, and the risk of degradation due to electrochemical corrosion, especially at locations of collision or exposure to uncontrolled environments. For the cooling pipeline system (stainless steel), defects in the welds such as concave legs, burned legs and lack of penetration were detected, requiring close monitoring to ensure the tightness and mechanical strength of the system.

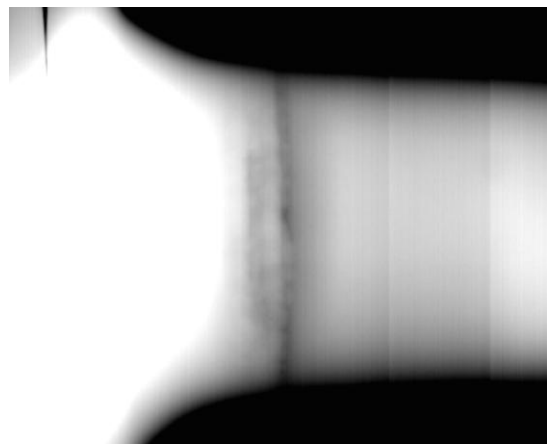


Figure 1. Control samples and simulated models

The concrete structures of the reactor building and the reactor shielding layer showed cracks in the protective mortar layer, surface peeling, water seepage, and strength inconsistency in certain areas. The analysis of the causes revealed the combined effects of carbonation, long-term moisture seepage, uneven construction, mechanical impact, and lack of maintenance in the long period before the renovation. However, most of the main structures retained their structural integrity, with no signs of serious deterioration in bearing capacity or radioactive leakage. The application of non-destructive testing (NDT) and experimental testing methods has provided a reliable technical database to guide maintenance work and support the extension of the facility's service life.



2a. Corrosion hole on beam tube No. 3

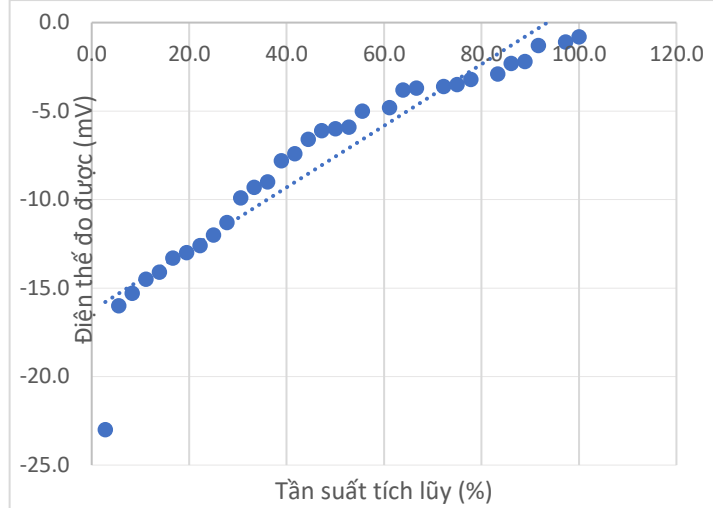


2b. Discontinuity on digital radiograph of round I cooling pipe weld

Figure 2. Metal item test results



3a. Cracks on the concrete column



3b. Cumulative frequency graph (showing the frequency of steel corrosion)

Figure 3. Concrete item test results

In addition to the results achieved, the study has not yet been able to comprehensively measure the wall thickness of the horizontal channels in the area inside the reactor, where many corrosion spots were visibly present on the surface, using the ultrasonic thickness measurement (UTM) method and creating a corrosion map. This limitation is mainly due to the horizontal channels are mainly located in locations hidden by pipes, supports, and other structural elements making access very difficult. The newly manufactured tools were designed primarily for access from the inside of the furnace, thus only partially addressing the inspection work. While they enable pointwise thickness measurements, they cannot access from the outer side of the channels or accurately locate the inspection points for corrosion mapping.

Based on the research results, the authors recommend reinforcing, waterproofing and restoring the protective concrete layers in the damaged areas; integrating NDT testing into the periodic maintenance program according to international standards; and conducting further research to develop appropriate tools for corrosion measurement and mapping of the channel walls, assessing concrete carbonation and periodic steel reinforcement corrosion status. In addition, it is necessary to develop a technical profile for managing the life and risk of each component, aiming at a decision support system for operating and renovating, or upgrading the reactor. In addition, the research team also proposes to carry out further research topics to measure and comprehensively evaluate the thickness of the horizontal channel wall inside the reactor vessel, using the UTM method and corrosion mapping techniques, focusing on studying the structure of the shielding layers placed in the horizontal channel and manufacturing suitable tools for access. Additional future research topics may include detailed assessment of corrosion depth, carbonation level, steel reinforcement status, analysis of concrete composition, and development of damage monitoring solutions based on sensors or digital technology.

2.5. APPLICATIONS IN ECOLOGY, ENVIRONMENT AND GEOLOGY

STUDY ON ESTABLISHING A PROCEDURE FOR DETERMINING STABLE ISOTOPE VALUES ($\delta^{13}\text{C}$, $\delta^{15}\text{N}$) IN MARINE FISH SAMPLES FROM COASTAL AREAS

Nguyen Duc Tam, Nguyen Tai Tue, Nguyen Thi Hong Thinh, Luu Viet Dung, Vu Hoai, Mai Dinh Kien, Vu Thi Hien, Phuong Hai Yen

¹*Institute for Nuclear Science and Technology, VINATOM, 179 Hoang Quoc Viet, Cau Giay, Hanoi, Vietnam*

²*Key Laboratory of Geoenvironment and Response to Climate Change, Hanoi University of Science, Vietnam National University, 334 Nguyen Trai, Thanh Xuan, Hanoi, Vietnam*

Project information:

- **Project name: Study on establishing a procedure for determining stable isotope values ($\delta^{13}\text{C}$, $\delta^{15}\text{N}$) in marine fish samples from coastal areas.**

- **Code: CS/24/04-01**

- **Managerial Level: Institute**

- **Implementation time: 12 months (Jan 2024- Dec 2024)**

- **Contact email: tam.nguyen.1225@gmail.com**

- **Published papers related to the project:**

1. N.D. Tam, N.T.H.Thinh, V.Hoai, M.D.Kien, Vu.T.Hien, P.H.Yen, *Establishing a procedure for determining stable isotope values $\delta^{13}\text{C}$ and $\delta^{15}\text{N}$ in fish samples from Lach Huyen coastal areas*, Conference on Nuclear Science and Technology for Young Researchers in Atomic Energy, 03-04/10/2024, Hanoi.

2. N.D. Tam, N.T.Tue, N.T.H.Thinh, L.V.Dung, V.Hoai, M.D.Kien, Vu.T.Hien, P.H.Yen, et al., *Establishing a procedure for determining stable isotope values $\delta^{13}\text{C}$ and $\delta^{15}\text{N}$ in fish samples from Lach Huyen coastal areas*, Nuclear Science and Technology, accepted.

In Vietnam, stable isotope composition analysis techniques have been widely applied in various studies of coastal ecosystems to determine the assimilation potential of food sources and the trophic levels of invertebrates and fish in recent years. Research by Dung et al., 2023 also highlighted stable isotope signatures of carbon ($\delta^{13}\text{C}$) and nitrogen ($\delta^{15}\text{N}$), along with TEs from invertebrates and fish to evaluate the food web structure in the coastal areas of Ha Tinh province, Central Vietnam. However, there is still a lack of studies on trophic structure and nutrient transfer of TEs in marine food webs in the northern coastal regions. This study focuses on developing a procedure for isotopic composition analysis ($\delta^{13}\text{C}$, $\delta^{15}\text{N}$) in white dorsal muscle tissue of fish which primarily consists of protein and has a low lipid content compared to other tissues like red muscle or liver. The advantage of white muscle tissue is its low impurity content and structural homogeneity, making it easy to separate from other fish parts (such as skin, bones, and viscera), thereby simplifying the sample preparation process prior to analysis.

The study area is located in Lach Huyen, Hai Phong City, a coastal region with a deep-water port, industrial zones, and soft-bottom ecosystems, making it suitable for environmental research. In the study area, fish samples were collected by using net fishing methods. The collected samples included five different natural fish species. The collected samples were placed in clean PE zip-lock bags, labeled, packaged, and stored in ice-cooled refrigerators. They were then transported to the laboratory and stored in deep freezers at a minimum temperature of -20°C for further processing steps which are presented below.

The first stage was to check the IRMS system. The system was supplied with stable power. The normal operating values of the pumping speed of the primary and secondary pumps at vacuum pressure were required to stand at the range of $<1\text{e-}2$ mbar, $<1\text{e-}6$ mbar respectively when the analysis system was closed and Helium was continuously pumped through the system. We observed the Helium pressure value on the computer screen to ensure that it was consistent with the system value. CO_2 and N_2 standard gases were used for steps for finding the ion current (beam) of each stable isotope by scanning the mass range of CO_{2+} and N_{2+} ions. The mass value sets of 44, 45, 46 and 28, 29 were applied to CO_2 and N_2 gases respectively.

The second stage was to establish the $\delta^{13}\text{C}$, $\delta^{15}\text{N}$ standard curve. We conducted a minimum of three analyses and calculated the average values of the standard samples: IAEA CO-8 ($\delta^{13}\text{C}_{\text{VPDB}}$: -5.75‰), IAEA CO-9 ($\delta^{13}\text{C}_{\text{VPDB}}$: -47.1‰), IAEA-CH-3 ($\delta^{13}\text{C}_{\text{VPDB}}$: -24.72‰), IAEA-N1 ($\delta^{15}\text{N}_{\text{vsAir}}$ = $+0.4\pm 0.2\text{‰}$), IAEA-NO-3 ($\delta^{15}\text{N}_{\text{vsAir}}$ = $+4.7\pm 0.2\text{‰}$), and IAEA-N2 ($\delta^{15}\text{N}_{\text{vsAir}}$ = $+20.3\pm 0.2\text{‰}$). We constructed a calibration curve correlating the $\delta^{13}\text{C}$ and $\delta^{15}\text{N}$ values of the standard samples with the measurements of pure CO_2 and N_2 reference gases ($\delta^{13}\text{C}_{\text{CO}_2 \text{ ref}}$, $\delta^{15}\text{N}_{\text{N}_2 \text{ ref}}$) obtained on the IRMS. These were then compared to the certified values of the standards, which are referenced to the Vienna Pee Dee Belemnite standard ($\delta^{13}\text{C}_{\text{VPDB}}$) and atmospheric nitrogen standard ($\delta^{15}\text{N}_{\text{vsAir}}$).

The third stage was sample selection which included the following steps.

Step 1: The fish samples were descaled, eviscerated, and then rinsed thoroughly with deionized water and dried using lint-free tissue paper.

Step 2: The fish skin was removed with a scalpel to collect the entire white muscle tissue. A small piece of white muscle (approximately 2grs) was cut with a sterile scalpel and placed in a 2mL Eppendorf tube with a lid, labeled with the sample designation.

Step 3: The test tube containing the sample was dried at 60°C for 24-36 hours in a drying oven until a constant weight was achieved.

Step 4: The dried fish muscle sample was ground into a fine powder using a mortar and pestle, then sieved through a stainless steel mesh with pore sizes of $<200\ \mu\text{m}$.

Step 5: The sieved fish muscle sample was placed into a 2mL Eppendorf centrifuge tube or a tightly sealed glass vial. The sample was stored in a vacuum chamber until analysis.

Step 6: An appropriate amount of the sample, approximately 200 µg, was weighed into a tin cup measuring 4×6 mm, then compressed into small pellet-sized pieces, and placed in a sample tray in the designated order for analysis using the EA-IRMS isotope ratio mass spectrometer.

The fourth stage was calculation of δ¹³C value. The prepared sample was combusted using the EA-IRMS system. The system software calculated the δ¹³C, δ¹⁵N values of both the standard sample and the sample to be analyzed in comparison with pure CO₂ gas (δ¹³C_{CO2 ref}), N₂ gas (δ¹⁵N_{N2 ref}) according to formula 1 below:

$$\delta^{13}\text{C}_{\text{CO}_2} / \delta^{15}\text{N}_{\text{N}_2} (\text{‰}) = \left(\frac{R_{\text{sample}}}{R_{\text{standard sample}}} - 1 \right) * 1000 \quad (1)$$

Where: R_{sample}: The isotopic ratio of ¹³C/¹²C, ¹⁵N/¹⁴N of the sample to be analyzed,

R_{standard sample} : The isotopic ratio of ¹³C/¹²C of the standard CO₂ gas, ¹⁵N/¹⁴N of the standard sample

The analysis procedure for δ¹³C and δ¹⁵N isotopic composition was applied to 15 fish samples from 5 species collected by the research team in Lach Huyen, Hai Phong. The results of the analysis are presented in the table below:

Sample ID	Species	N(%)	C(%)	δ ¹³ C (‰)	C/N	δ ¹⁵ N (‰)
LH-01.01	Cheilinus chlorourus (Bloch, 1791)	14.12	45.26	-16.83	3.21	9.04
LH-01.02	Cheilinus chlorourus (Bloch, 1791)	14.15	44.73	-16.78	3.16	8.84
LH-01.03	Cheilinus chlorourus (Bloch, 1791)	14.07	44.71	-16.76	3.18	8.40
LH-02.01	Alepes kleinii (Bloch, 1793)	13.88	44.52	-19.73	3.21	10.52
LH02.02	Alepes kleinii (Bloch, 1793)	13.61	43.63	-16.99	3.21	11.46
LH-02.03	Alepes kleinii (Bloch, 1793)	13.88	45.05	-20.29	3.25	9.99
LH-03.01	Netuma thalassina (Rüppell, 1837)	14.09	45.06	-18.03	3.20	11.60
LH-03.02	Netuma thalassina (Rüppell, 1837)	14.31	45.83	-18.30	3.20	11.50
LH-03.03	Netuma thalassina (Rüppell, 1837)	14.19	45.74	-17.83	3.22	11.45
LH-04.01	Siganus fuscescens (Houttuyn, 1782)	12.89	42.48	-17.28	3.30	9.87
LH-04.02	Siganus fuscescens (Houttuyn, 1782)	12.97	42.60	-16.11	3.28	9.98
LH-04.03	Siganus fuscescens (Houttuyn, 1782)	13.73	44.76	-17.46	3.26	10.50

LH-05.01	<i>Synodus variegatus</i> (Lacepède, 1803)	14.43	45.48	-16.23	3.15	9.58
LH-05.02	<i>Synodus variegatus</i> (Lacepède, 1803)	12.92	41.78	-16.17	3.23	10.32
LH-05.03	<i>Synodus variegatus</i> (Lacepède, 1803)	14.12	45.44	-16.71	3.22	9.96

The study serves as an initial step in applying nuclear analysis techniques, specifically stable isotope analysis, to ecological research, particularly in coastal marine ecosystems. Therefore, the research team is eager to continue maintaining, developing, and applying nuclear analysis techniques in future studies, such as tracing the origins of food, assessing food web structures, and monitoring environmental impacts.

EXPERIMENTAL STUDY TO IDENTIFY THE ORIGIN OF TUYEN LAM LAKE SEDIMENTS USING ISOTOPIC TECHNIQUES

Le Xuan Thang¹, Nguyen Thi Huong Lan¹, Phan Son Hai¹, Nguyen Minh Dao¹, Vo Tran Quang Thai¹, Nguyen Huu Nghia¹, Tran Tuan Anh¹, Tran Quang Thien¹, Phan Quang Trung¹, Vo Thi Mong Tham¹, Tuong Thi Thu Huong¹, Chau Thi Nhu Quynh¹,
Nguyen Viet Duc¹

¹ Da Lat Nuclear Research Institute, 01 Nguyen Tu Luc, Da Lat, Lam Dong, 670000,
Vietnam

Project information:

- **Project name:** Experimental study to identify the origin of Tuyen Lam Lake sediments using isotopic techniques
- **Code:** ĐTCB 08/2023/VNCHN
- **Managerial Level:** Ministry
- **Implementation time:** 24 months (Jan 2023 - Dec 2024)
- **Contact email:** lexuanthang85@gmail.com
- **Published papers related to the project:**

1. Le Xuan Thang, Nguyen Thi Huong Lan, Phan Son Hai, Tran Tuan Anh, Tran Quang Thien, Nguyen Minh Dao, Nguyen Huu Nghia, Phan Quang Trung, Vo Thi Mong Tham, *Determination of $\delta^{13}\text{C}$ -TOC in sediment samples by using EA-IRMS*, Nuclear Science and Technology, 2024. (Accepted).

2. Tran Quang Thien, Le Xuan Thang, Nguyen Thi Huong Lan, Phan Son Hai, Tran Tuan Anh, Nguyen Minh Dao, Nguyen Huu Nghia, Phan Quang Trung, Vo Thi Mong Tham, *Development of a methodology for analyzing organic carbon and $\delta^{13}\text{C}$ in soil and sediment samples through EA-IRMS*, Proceedings of ISINN-29, JINR, E3-2023-58, Dubna, 2023, p,164 – 169.

Sediments play an important role in freshwater ecosystems, significantly affecting water quality, aquatic ecosystems, and even socio-economic activities such as agriculture, aquaculture, and tourism. Identifying the origin of sediment is essential for the sustainable management of land and water resources, particularly in watershed areas with high soil erosion and agricultural activities. However, in Vietnam, research on sediment origins remains limited and has yet to fully apply modern techniques such as stable isotope analysis. Given this situation, the project was carried out to establish procedures for analyzing the stable isotope ratios $\delta^{13}\text{C}$ and $\delta^{15}\text{N}$ using the isotope ratio mass spectrometry system from sediment samples, combining the compound-specific isotope analysis technique (CSIA) with the MixSIAR mixing model to test the origin of sediments in Tuyen Lam Lake in Da Lat. This is a pioneering step in applying stable isotope techniques in Vietnam, which aims to improve resource and environmental management.

The modern isotope ratio mass spectrometry system, LC-GC-EA-IRMS, has been equipped at the Dalat Nuclear Research Institute and comprises an elemental analyzer (Flash EA) and a gas chromatograph (GC IsoLink II) connected to an isotope ratio analyzer (IRMS) via the ConFlo IV interface, enabling EA-IRMS and GC-IRMS analyses. Additionally, a high-performance liquid chromatograph (LC IsoLink) was directly connected to the IRMS to enable the LC-IRMS analytical method.

Based on the IAEA-TECDOC-1870 guideline, the procedure for determining the total $\delta^{13}\text{C}$ and $\delta^{15}\text{N}$ stable isotope ratios in sediment samples was established. The EA-IRMS system performed simultaneous analysis of $\delta^{13}\text{C}$ and $\delta^{15}\text{N}$ with an accuracy of less than 0.25‰ for $\delta^{13}\text{C}$ and 0.3‰ for $\delta^{15}\text{N}$, respectively. For the procedure for determining $\delta^{13}\text{C}$ in total organic carbon ($\delta^{13}\text{C}_{\text{TOC}}$), the sediment samples were pre-treated with 0.5M HCl solution to remove carbonates before analysis on the EA-IRMS system, achieving an accuracy of less than 0.25‰ for $\delta^{13}\text{C}_{\text{TOC}}$. A process for fatty acid extraction from sediment samples and derivatives was carried out before analysis on the GC-IRMS system in order to ascertain the $\delta^{13}\text{C}$ isotope ratio in fatty acids ($\delta^{13}\text{C}_{\text{FAs}}$) was established. This approach was mostly based on the documents IAEA-TECDOC-1870 and IAEA-TECDOC-1881. This is the first of its kind in Vietnam to determine the $\delta^{13}\text{C}_{\text{FAs}}$ isotope ratio that commonly occurred in the sediment samples, specifically for fatty acids C14:0, C16:0, C18:0, C20:0, C22:0, and C24:0, achieving the accuracy of less than 0.55‰.

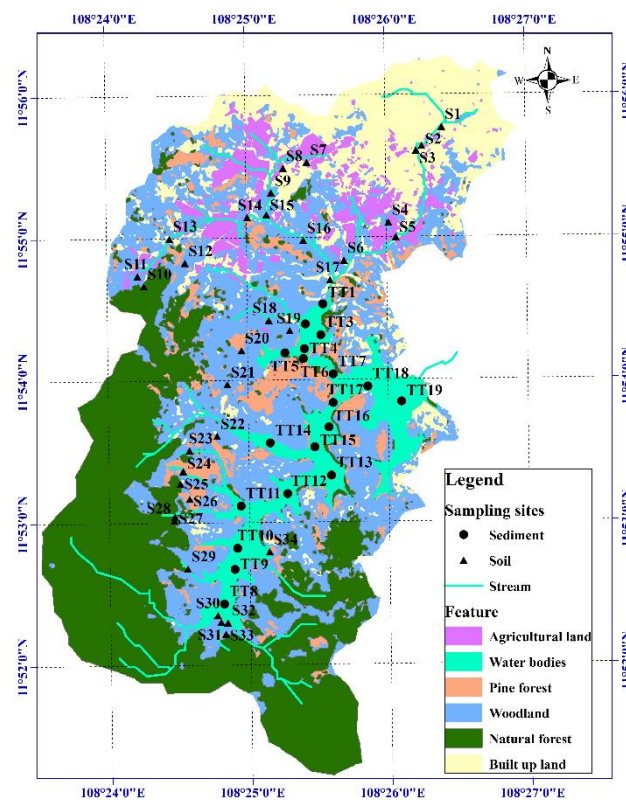


Figure 1. Land use map and sample locations in the Tuyen Lam Lake

Isotope analysis data were used to determine the origin of sediments based on four main types of land: agricultural and construction land, natural forests (mixed forests),

long-term pine forests, and woodland. The MixSIAR version 3.1 mixing model was applied using R software, utilizing satellite data from JAXA (ALOS 2020) and the measured isotope values. The results provide detailed information on the contribution ratio of each source type to the mixed sediment (Tuyen Lam Lake sediment).

The results from the MixSIAR model showed distinct variations in the contributions of various sources to Tuyen Lam Lake sediments, reflecting both natural and anthropogenic factors affecting the lake environment. Specifically, long-term pine forests, despite covering only a small portion of the study area, contributed the largest proportion to the sediment, accounting for $35.20\% \pm 3.21\%$. This contribution can be attributed to the high organic matter content of long-term pine forest soils (7.54% to 12.99%) and their susceptibility to erosion, particularly in areas with low vegetation cover and steep terrain. Forestry activities may have exacerbated soil erosion, leading to an increased organic matter contribution from old pine forest soils into Tuyen Lam Lake sediments.

Table 1. Contribution rate of different sources to Tuyền Lâm Lake sediment based on the MixSIAR model

Source	Source Characteristics	Watershed Area	Contribution to Sediment (%)
Source 1	Agricultural and construction land	7.190 km ²	23.20% \pm 2.85%
Source 2	Natural forests (mixed)	10.150 km ²	24.60% \pm 2.73%
Source 3	Long-term pine forests	2.110 km ²	35.20% \pm 3.21%
Source 4	Woodland	11.002 km ²	17.00% \pm 4.58%

Meanwhile, natural forests, which occupy a larger area, also contributed a significant proportion to the lake sediments, approximately $24.60\% \pm 2.73\%$. However, the organic matter content of natural forests was lower than that of long-term pine forests (from 3.76% to 6.18%). This indicates that the impact of natural forests on lake sediment is important but less significant compared to long-term pine forests. Some areas of natural forests may be affected by steep slopes or human activities, further increasing sediment input into the lake.

For woodland, although the area is the largest, covering up to 33.21%, its contribution to lake sediment remains modest, around $17.00\% \pm 4.58\%$. This may be due to the characteristics of woodland, which include newly planted pine forests and shrub areas with lower organic content and poorer sustainability in retaining sediments.

Finally, agricultural and construction land contributed the least to the lake sediments, with a contribution of $23.20\% \pm 2.85\%$. Although the area of this land is small, its low organic content and modern agricultural practices, such as the use of greenhouses, have minimized soil erosion and runoff, thereby limiting its contribution to sediment accumulation in the lake.

Overall, areas with high organic content, particularly long-term pine forests and natural forests soils, play a significant role in providing organic matter for Tuyen Lam

Lake sediments. This highlights the need to focus on managing and protecting long-term pine forests and natural forests to minimize organic pollution in the lake.

To improve the accuracy and effectiveness of sediment origin assessment, it is necessary to develop sediment source classification methods that integrate satellite data, land classification maps, and land-use information. Additionally, other analytical techniques such as ICP-MS, NAA, AAS, and multivariate statistical methods should be applied to analyze metal compositions and further support for determining the origin of sediments.

2.6. APPLICATIONS IN BIOLOGY, AGRICULTURE AND MEDICINE

SUMMARIZATION OF THE PROCESS OF DEVELOPING A SECONDARY STANDARD FOR RADIOACTIVITY OF I-131 IN VIETNAM

Dinh Xuan Hoang

Dalat Nuclear Research Institute, 01 Nguyen Tu Luc, Da Lat City, Lam Dong Province

Project information:

- **Project name:** Research on the development of a secondary standard for radioactivity in nuclear medicine through developing procedures for calibrating the dose calibrator and for preparing standard samples (I-131)

- **Code:** ĐTCB.04/22/VNCHN

- **Managerial Level:** Ministry

- **Implementation time:** 33 months (Jan 2022 - Sept 2024)

- **Contact email:** dinhxuanhoangnri@gmail.com

- **Published papers related to the project:**

1. Dinh Xuan Hoang et al., Determination of the Energy-Response curve of the ATOMLAB 500 dose calibrator by using MNCP5 code, Proceedings of the 15th Vietnam Conference on Nuclear Science and Technology, Nha Trang, Vietnam, 2023, p. 220-224.

2. Dinh Xuan Hoang, Truong Dinh Vu, Do Van Dan. Determination of the Energy-Response curve of the ATOMLAB 500 dose calibrator by using MNCP5 code, Journal of Nuclear Science and Technology, *accepted*.

3. Dinh Xuan Hoang, Truong Dinh Vu, Do Van Dan, Nguyen Thanh Nhan, Assessment of the Performance of the Dose Calibrator Used in Radioactivity Measurement, Indian Journal of Nuclear Medicine, *accepted*.

The accuracy of radioactivity measurement in nuclear medicine applications is one of the important factors to ensure the effectiveness and safety of the diagnostic and treatment procedures. If the radioactivity, corresponding to the prescribed dosage, is too high, it can result in radiation-induced harm and adverse effects on the patient. Conversely, if the radioactivity is too low, it will affect the effectiveness of the diagnostic and treatment process.

In Vietnam, the I-131 radioactive isotope is commonly utilized in nuclear medicine for the treatment of thyroid disease and certain types of thyroid cancer. Prior to administration to the patient, the radioactivity of the I-131 isotope is quantified using a dose calibrator. This device comprises a pressurized ionization chamber linked to a high-precision electrometer and electronic adjuncts (refer to Fig. 1). Upon entering the active volume of the chamber, ionizing radiation from the I-131 isotope generates an ionization current that is directly proportional to the sample's activity, subsequently being quantified and recorded.

According to the regulations of the Vietnam Atomic Energy Law, dose calibrators must undergo annual calibration to ensure their accuracy and reliability in measuring radioactivity. This calibration is typically carried out by a calibration laboratory that is traceable to a National

Metrology Institute (see Fig. 2). However, Vietnam currently lacks a national standard for radioactivity for the I-131 isotope. As a result, the calibration for the dose calibrators is usually performed using other standard sources such as Co-60, Ba-133, and Cs-137. Since these sources have different characteristics compared to the I-131 isotope, the calibration results may not be suitable and could lead to inaccuracies in the activity measurement results of the dose calibrators, ultimately affecting the quality of the treatment process.

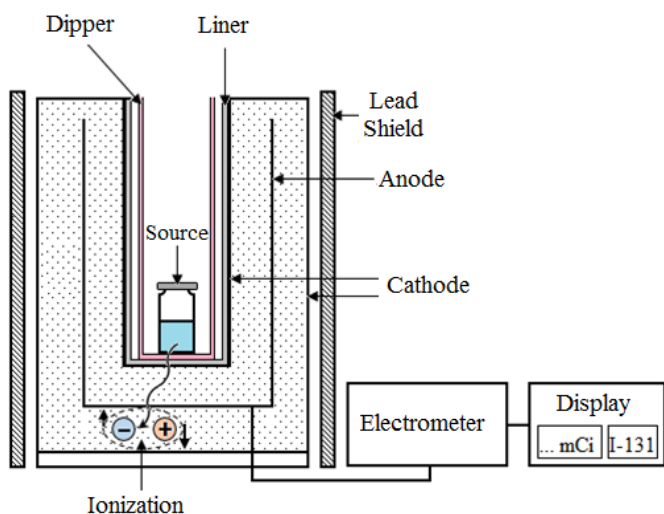


Figure 1. Illustration of dose calibrator.

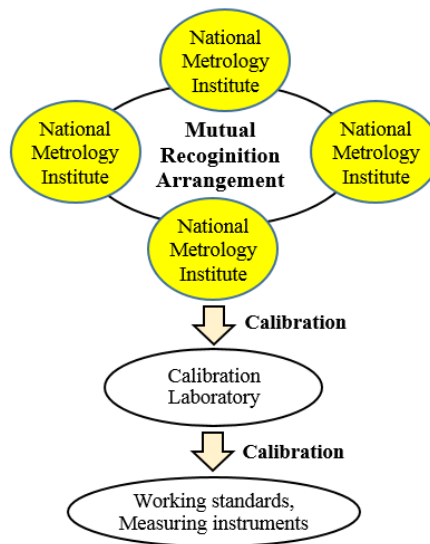


Figure 2. Radioactivity traceability system.

In order to address the circumstances mentioned above, the Ministerial project titled "Research on the development of a secondary standard for radioactivity in nuclear medicine through developing procedures for calibrating the dose calibrator and for preparing standard samples (I-131)" was proposed and completed by the Dalat Nuclear Research Institute (DNRI). This project involved calibrating the ATOMLAB 500 with a primary standard and preparing standard sources to calibrate the dose calibrators used in Vietnam.

Before calibrating the ATOMLAB 500 dose calibrator with the primary standard, it underwent acceptance tests for repeatability, linearity, and accuracy. Repeatability was assessed by measuring the activity of a Cs-137 standard source from Eckert & Ziegler on the dose calibrator, and the uncertainty due to repeatability was determined to be 0.38%. Following this, the uncertainty due to the device's linearity was determined to be 0.82% by measuring the activity of a Tc-99m solution produced at the DNRI and calculating the deviation between the measured and calculated activities in the range from 25 μ Ci to 867 mCi. Additionally, the accuracy of the dose calibrator was significantly improved by using a calibration factor determined from simulation results using the MCNP5 program, instead of the default calibration factor of the instrument, as shown in Table 1.

Table 3. Results for accuracy test of the ATOMLAB 500 dose calibrator for different calibration factors.

Isotope	Standard activity (μ Ci)	Default Calibration Factor		Calibration Factor determined from MCNP simulation	
		Measured activity (μ Ci)	Deviation (%)	Measured activity (μ Ci)	Deviation (%)

Cs-137	208,8	204,7 ± 0,3	-1,96	209,2 ± 0,3	0,19
--------	-------	-------------	-------	-------------	------

After evaluating the measurement uncertainty resulting from the inherent characteristics of the dose calibrator, we conducted studies to investigate the influence of geometric factors on the activity measurement results. This was done through experimental measurements combined with MCNP simulations. The survey results indicated that the combined uncertainties resulting from geometric factors, such as measurement position, sample volume, and the tolerance of the vial containing the radioactive solution, were approximately 0.2%.

To achieve the establishment of the secondary standard for radioactivity, the dose calibrators of the DNRI were calibrated by the National Institute of Advanced Industrial Science and Technology (AIST) using the remote calibration method (refer to Fig. 3). To perform this calibration, the AIST sent empty ampoules to the DNRI. Subsequently, the I-131 radioactive solution produced at the DNRI was dispensed into these sample bottles and measured on the dose calibrators. During the remote calibration, all measurement data was recorded by the AIST through the RemoteView remote control software. After completing the measurement, one of the measured ampoules was sent to Japan to determine the activity at the primary standard laboratory of the AIST. Based on the measurement results at AIST, calibration coefficients with an expanded uncertainty of 1.90% ($k = 2$) were issued to the dose calibrators of the DNRI.

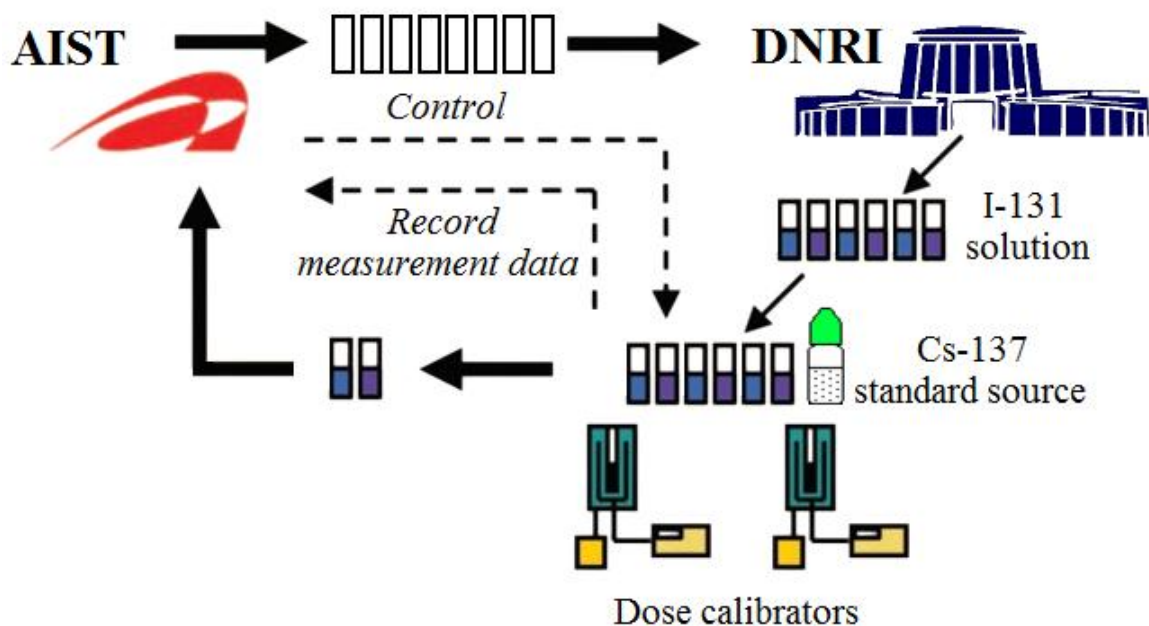


Figure 3. A schematic diagram depicting the remote calibration experiment carried out in collaboration between AIST and DNRI.

Upon receiving the calibration coefficients from the AIST, the DNRI proceeded to produce standard samples and assess their activities using calibrated dose calibrators. Based on the certified calibration uncertainty and the previously defined uncertainty components, the standard samples produced at the DNRI were determined to possess a combined standard uncertainty of 1.5%. Subsequently, these samples were employed to calibrate the dose calibrators in domestic facilities. The calibration results revealed that the majority of the dose calibrators met the accuracy criteria, with the deviation in the measurement results of the I-131 isotope activity being less than 5%, in comparison to the standard activity (see Fig. 4).

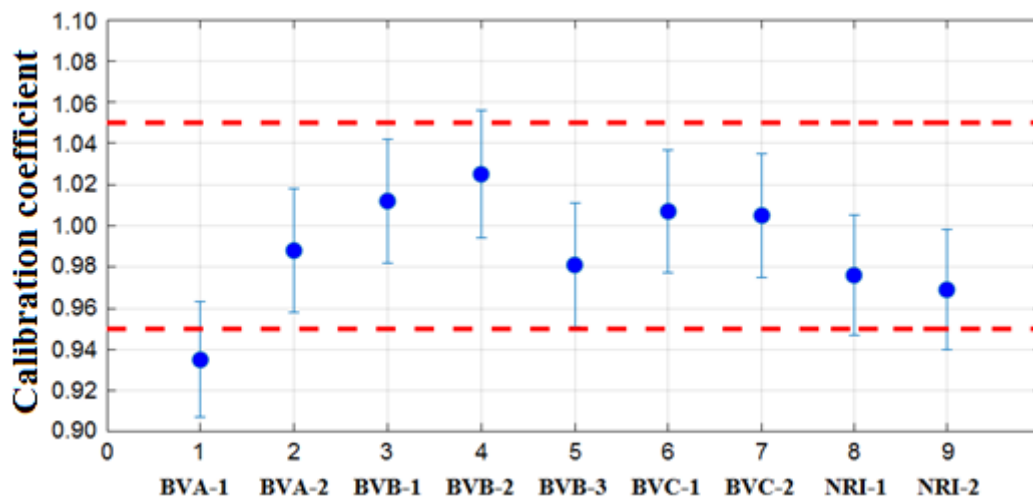


Figure 4. Calibration results for 9 dose calibrators.

The calibration results obtained for the domestic dose calibrators have completed the traceability system for radioactivity for the isotope I-131 in Vietnam, from primary standard to working standard. This will facilitate the regulatory authority in the control and management of the I-131 radiopharmaceutical quality at the radio-isotope production facility as well as in the diagnosis and treatment procedures at nuclear medicine facilities. The outcomes of this study will play an important role in the establishment of a national standard for radioactivity in Vietnam.

Further investigation is imperative to develop methodologies and techniques for accurately quantifying the activity of commonly utilized isotopes in nuclear medicine, including F-18, P-32, and Tc-99m, among others. The results of these studies will enable Vietnam to confidently participate in international comparison exercises for radioactivity quantity, thereby progressing towards active participation in mutual recognition agreements with regional and global counterparts, enhancing the country's standing in the field of radiation measurement.

PREPARATION OF ESSENTIAL OILS ENCAPSULATED LIPID NANOEMULSIONS FOR THE PREVENTION AND TREATMENT OF *BOTRYTIS CINEREA* CAUSING DISEASE IN STRAWBERRIES

Tran Thi Ngoc Mai, Le Xuan Cuong, Vu Ngoc Bich Dao, Nguyen Ngoc Thuy Trang, Le Van Toan

Center of Radiation Technology and Biotechnology, Nuclear Research Institute
01 Nguyen Tu Luc Street, Ward 8, Dalat, Lam Dong

Project information:

- **Project name:** Preparation of essential oils encapsulated lipid nanoemulsions for the prevention and treatment of *Botrytis cinerea* causing disease in strawberries
- **Code:** CS/24/01-02
- **Managerial Level:** Center of Radiation Technology and Biotechnology, Nuclear Research Institute
- **Implementation time:** 12 months (Jan 2024- Dec 2024)
- **Contact email:** tranthingocmai626@gmail.com
- **Published papers related to the project:**

1. Tran Thi Ngoc Mai et al., Investigation of inhibitory effect of nanocarriers encapsulating clove, mustard, garlic and lemongrass essential oil on *Botrytis cinerea* causing grey mold on strawberries in in-vitro condition, a report of the 8th Nuclear Science and Technology, Hanoi, Vietnam, 3-4 october 2024 (in Vietnamese).
2. Tran Thi Ngoc Mai et al., Investigation of inhibitory effect of nanocarriers encapsulating clove, mustard, garlic and lemongrass essential oil on *Botrytis cinerea*, Ho Chi Minh city university of education journal of science (in Vietnamese).

Gray mold disease on strawberry plants causes leads to an annual loss of over \$100 million globally in strawberry cultivation. Currently, due to the negative impacts of fungicides on human health and the environment, essential oils are being increasingly researched for antifungal treatments. However, their application remains limited due to poor solubility. Therefore, this study aims to develop a biological formulation using plant-derived essential oils that have been nano-encapsulated to improve their efficacy in inhibiting fungi.

Research comparing the efficacy of nine types of essential oils in nano form in controlling gray mold, including lemongrass, cinnamon, mustard, garlic, maychang, clove, chili, fennel, and oregano has not yet been conducted. Additionally, while combining two or three types of essential oils may provide higher prevention efficacy than their individual use, this approach has also not been studied for the gray mold pathogen. Therefore, this research was undertaken.

The research aims to develop a nano-biological formulation containing plant essential oils for the prevention and treatment of gray mold on strawberry plants. First, the pathogenic fungus causing for gray mold in strawberries was isolated and purified on potato dextrose

agar. Subsequently, the essential oils encapsulated lipid nanoemulsions was synthesized using a combination of homogenization and sonication methods. The efficacy of fungal inhibition under both *in-vitro* and greenhouse conditions was also evaluated.

The research results identified *Botrytis cinerea* as the fungal strain causing gray mold in strawberries. *In-vitro* experiments demonstrated that the nanoemulsions combining garlic essential oil and cinnamon essential oil (at a 1:1 v/v ratio) exhibited the highest antifungal activity at a diluted concentration of 900 times achieving 100% inhibition rate (Table 1). The nanoemulsions composed of garlic and cinnamon exhibits an average particle size of 82.6 ± 2.09 nm, a polydispersity index of 0.253 ± 0.013 , and a zeta potential of -46.1 ± 0.10 mV. It remained stable after two months of storage, with a particle size of 89.48 ± 1.84 nm, a polydispersity index of 0.248 ± 0.014 , and a zeta potential of -44.33 ± 1.27 mV (Figure 1). This research successfully developed an optimized synthesis process for the nanoemulsions of garlic and cinnamon at a 900 fold-dilution. Greenhouse experiments demonstrated that the formulation is effective in preventing and treating gray mold disease in strawberry plants.

However, further investigation is needed to evaluate higher concentrations under greenhouse conditions to determine the optimal concentration for this setting. Additionally, field trials should be conducted to compare the effectiveness of the formulation on strawberry plants in outdoor settings, thereby enhancing its practical applicability in real-world conditions.

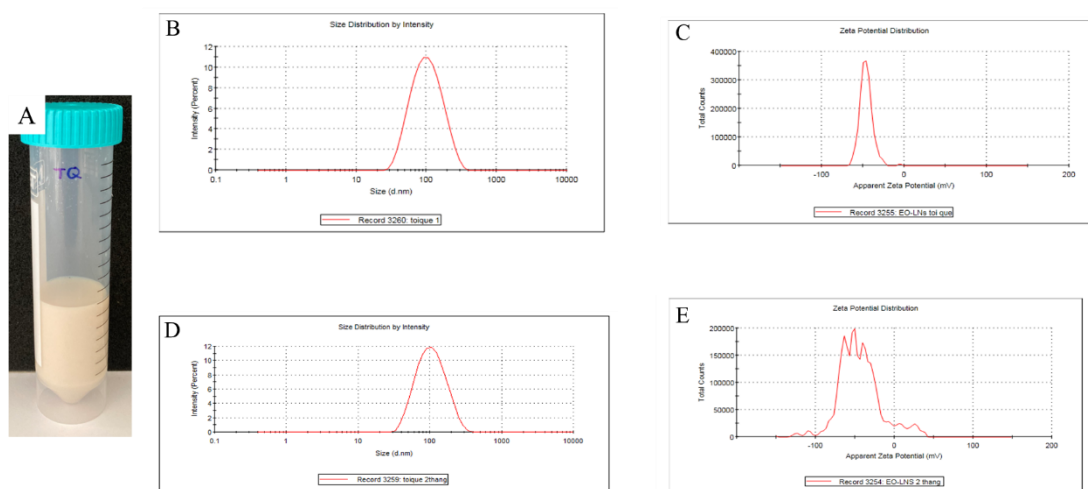


Figure 1. Garlic and cinnamon bioformulation (A) aqueous dispersion of the product (B) initial particle size distribution chart (C) initial zeta potential distribution chart (C) particle size chart after two months (D) zeta potential chart after two months

Table 1. The antifungal activity of essential oil encapsulated lipid nanoemulsions on *Botrytis cinerea* under *in-vitro* conditions

Essential oils encapsulated lipid nanoemulsions	Inhibitory effectiveness (%)			
	300 times dilution	400 times dilution	500 times dilution	600 times dilution

1	Garlic	100 ± 0 ^a	100 ± 0 ^a	100 ± 0 ^a	69.82 ± 3.4 ^a
2	Cinnamon	100 ± 0 ^a	100 ± 0 ^a	82.43 ± 1.35 ^b	40.99 ± 2.06 ^c
3	Lemongrass	100 ± 0 ^a	88.74 ± 2.06 ^c	39.19 ± 2.70 ^e	0 ± 0 ^e
4	Oregano	100 ± 0 ^a	100 ± 0 ^a	100 ± 0 ^a	61.71 ± 3.40 ^b
5	Maychang	100 ± 0 ^a	100 ± 0 ^a	62.16 ± 1.35 ^c	5.86 ± 2.81 ^d
6	Fennel	100 ± 0 ^a	90.99 ± 0.78 ^b	42.79 ± 1.56 ^d	0 ± 0 ^e
7	Mustard	97.75 ± 2.06 ^{ab}	69.82 ± 0.78 ^d	14.41 ± 1.56 ^f	0 ± 0 ^e
8	Clove	96.40 ± 1.56 ^b	43.69 ± 4.34 ^e	0 ± 0 ^g	0 ± 0 ^e
9	Chili	93.24 ± 2.34 ^c	38.74 ± 2.06 ^f	0 ± 0 ^g	0 ± 0 ^e
Inhibitory effectiveness of binary and ternary combination (%)					
	Essential oils encapsulated lipid nanoemulsions	700 times dilution	800 times dilution	900 times dilution	1000 times dilution
1	Garlic + Cinnamon	100 ± 0 ^a	100 ± 0 ^a	100 ± 0 ^a	94.59 ± 2.70 ^a
2	Garlic + Oregano	100 ± 0 ^a	91.44 ± 2.06 ^b	49.55 ± 3.12 ^b	0.45 ± 0.78 ^b
3	Cinnamon+ Oregano	100 ± 0 ^a	41.89 ± 1.35 ^c	1.80 ± 0.78 ^c	0 ± 0 ^b
4	Garlic + Cinnamon+ Oregano	61.26 ± 1.56 ^b	0 ± 0 ^d	0 ± 0 ^c	0 ± 0 ^b

PREPARATION OF NANOSTRUCTURED LIPID CARRIERS CO-ENCAPSULATING *HAEMATOCOCCUS PLUVIALIS* EXTRACT AND PALM OIL FOR SKIN PROTECTION AGAINST UV RADIATION

Vu Ngoc Bich Dao, Nguyen Minh Hiep, Tran Thi Ngoc Mai, Nguyen Vo Duy Tuan, Pham Ho
Thuat Khoa, Le Thi Thu Thuy, Pham Bao Ngoc

Center of Radiation Technology and Biotechnology, Nuclear Research Institute, 01 Nguyen Tu
Luc Street, Dalat City, Lam-dong Province, Vietnam

Project information:

- **Project name:** Preparation of nanostructured lipid carriers co-encapsulating *Haematococcus pluvialis* extract and palm oil for skin protection against UV radiation.

- **Code:** CS/24/01-01

- **Managerial Level:** Institute

- **Implementation time:** 12 months (Jan 2024- Dec 2024)

- **Contact email:** vungocbichdao@gmail.com

- **Published papers related to the project:**

1. Vu Ngoc Bich Dao, Nguyen Minh Hiep, Tran Thi Ngoc Mai, Nguyen Vo Duy Tuan, Pham Ho Thuat Khoa, Le Thi Thu Thuy, Pham Bao Ngoc. "Optimization of conditions for the preparation of nanostructured lipid carriers co-encapsulating *Haematococcus pluvialis* extract and palm oil". Oral report of the 8th Conference on Nuclear Science and Technology for Young Scientists, Ha Noi, Vietnam, 3-4 October 2024 (in Vietnamese).

Exposure to solar ultraviolet (UV) radiation is considered the main cause of accelerated skin aging due to the production of reactive oxygen species (ROS), leading to inflammation, decreased collagen synthesis, and the degradation of collagen and elastin. Compared to UVA and UVC radiation, UVB radiation causes the most damage to the epidermis, particularly to the basal layer. Therefore, developing products that protect the skin from the harmful effects of UVB radiation is essential.

A promising active compound for skin protection is astaxanthin (ATX) – a carotenoid abundant in the *Haematococcus pluvialis*. ATX exhibits strong antioxidant properties and has been studied for its ability to protect the skin from solar radiation, including reducing cellular oxidative stress, inhibiting enzymes that degrade collagen and elastin, and preventing collagen degradation. However, pure ATX is costly and challenging to apply in large-scale production. Therefore, in this study, *H. pluvialis* extract rich in ATX (10%) was utilized as a more practical alternative. Furthermore, a nanostructured lipid carrier (NLC) was employed in this study to enhance the bioavailability of ATX. The solid lipid component in NLC is palm oil, which also contains beneficial compounds for skin health.

To explore solutions for protecting the skin from UV radiation, the NLC contains *H. Pluvialis* extract and palm oil (NLC-A/P) that have been prepared and evaluated for their protective effects on cells under UVB radiation. Specifically, NLC-A/P was prepared using a T25 ULTRA TURRAX® device (IKA®-Werke, Staufen, Germany) for high-temperature homogenization combined with the Ultrasonic Liquid Processor VCX750 (Sonics & Materials,

USA) to generate ultrasound. The optimal formulation of NLC-A/P was investigated by adjusting the ratios of solid and liquid lipids, surfactants and lipids, and dispersion phase concentrations. The average particle size, polydispersity index (PDI), and zeta potential of NLC-A/P were determined by using a Zetasizer Nano ZS (Malvern, UK). The encapsulation efficiency was measured based on the ATX concentration using a high-performance liquid chromatography (HPLC) LC-20AD (Shimadzu, Japan). The antioxidant capacity of NLC-A/P was assessed by using the ABTS assay, with optical density measured by a mini-1240 UV-Vis spectrophotometer (Shimadzu, Japan). The cytotoxicity of NLC-A/P was evaluated by using the MTT colorimetric assay. The cellular protective effects of NLC-A/P on cells were determined by measuring reactive oxygen species (ROS) levels, senescent cells, and dead cells after exposure to UVB radiation at a dose of 40 mJ/cm². Analyses were performed by using a Nikon Eclipse 80i microscope (Nikon Corporation, Japan) and an AXIO Imager Z2 fluorescence microscope (Carl Zeiss, Germany).

The results showed that the optimal conditions for formulating the NLC-A/P system were a tween 80/lecithin ratio of 7/3, a palm oil/*H. Pluvialis* extract ratio of 1.5:1, lipids/surfactants ratio of 1:1.25, and a dispersion phase of 20%. These conditions were achieved through a combination of high-temperature homogenization and ultrasonic wave application for particle size reduction. NLC-A/P had an average particle size of 128.8 ± 6.7 nm, PDI of 0.227 ± 0.007, zeta potential of -40.9 ± 0.8 mV, and encapsulation efficiency of 92.4 ± 1.5%. Moreover, NLC-A/P exhibited strong antioxidant properties, as evidenced by its ABTS⁺ radical scavenging, which was approximately three times higher than that of Trolox (**Figure 1**).

Under *in vitro* conditions, NLC-A/P could be used at ATX concentrations from 0.1 to 1.5 µg/mL, as concentrations above 2 µg/mL negatively affected the viability of fibroblast cells (**Figure 2A**). The results also indicated that ROS levels were directly associated with the formation of senescent cells, as the proportion of senescent cells increased or decreased corresponding to ROS levels when NLC-A/P was applied at different concentrations (**Figures 2B, 2C**). Moreover, the results in **Figure 2D** showed that UVB exposure at 40 mJ/cm² increased the cell death rate from 5.5 ± 0.4% (negative control) to 11.4 ± 0.8%. When the cells were treated with NLC-A/P at ATX concentrations from 0.25 to 1.5 µg/mL, the UVB-induced cell death rate was reduced to less than 3%. Thus, at an ATX concentration of 0.5 µg/mL, NLC-A/P effectively protected fibroblast cells from the harmful effects of UVB by reducing ROS signals by over 84%, senescent cells by over 53%, and dead cells by over 27% compared to the positive control.

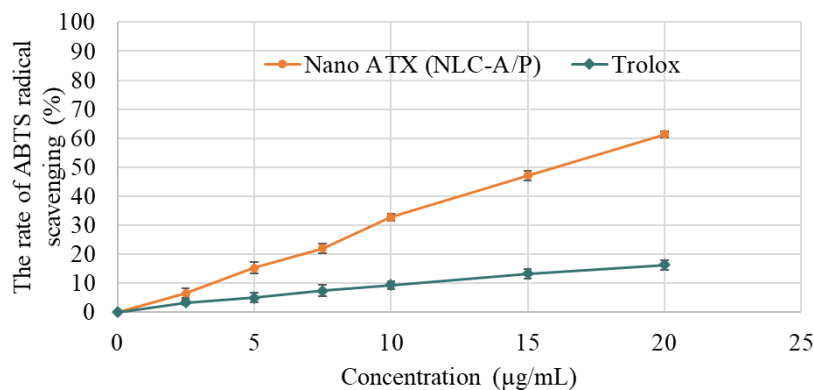


Figure 1. ABTS⁺ radical scavenging capacity of NLC-A/P.

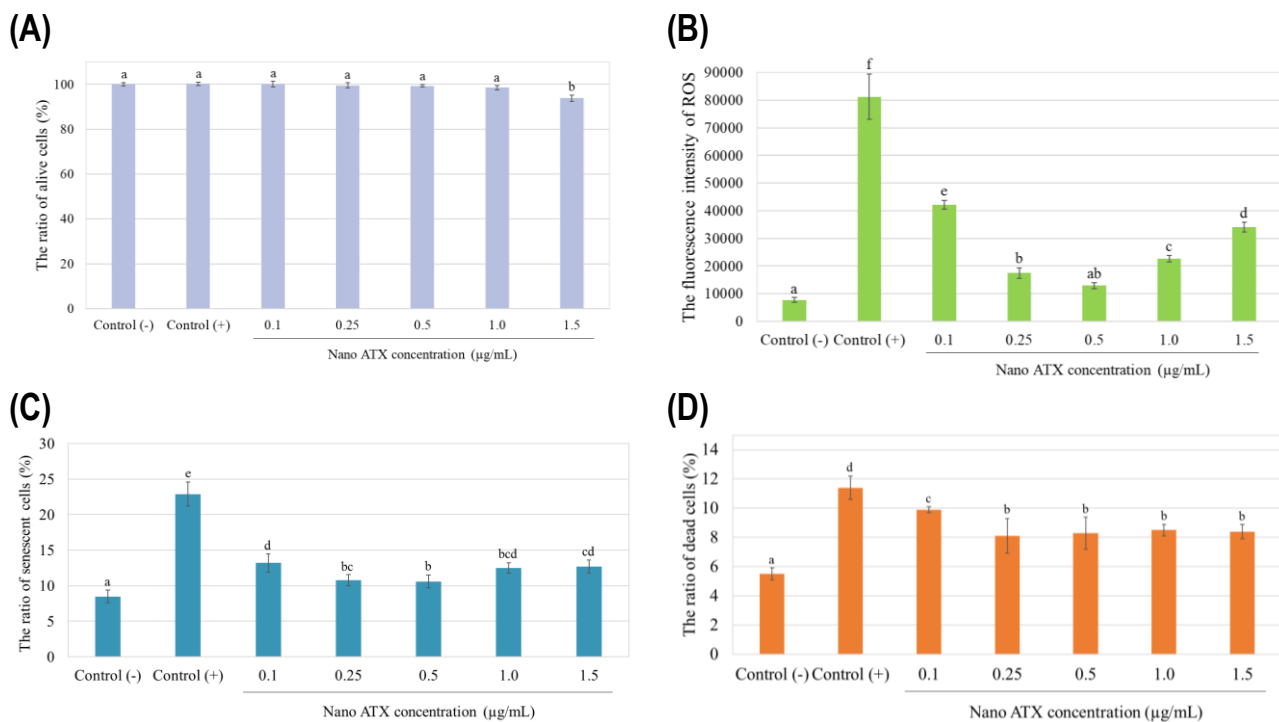


Figure 2. Cellular protective effects of NLC-A/P. **(A)** The cytotoxicity, **(B)** The reduction of ROS after UVB exposure, **(C)** The reduction of senescent cells after UVB exposure, **(D)** The reduction of dead cells after UVB exposure. Control (-): non-irradiated, Control (+): irradiated but untreated with NLC-A/P. Different alphabets indicate statistical differences by one-way ANOVA with post hoc Duncan's test, SPSS software, the significant level of p at 0.05.

In summary, the study successfully formulated the NLC-A/P with effective cell protection against UVB radiation. However, to advance the application of NLC-A/P for skin protection in the future, further investigation is needed to evaluate its protective effects more comprehensively, practically, and accurately. This includes conducting studies on mouse skin or human volunteer skin models to fully assess its potential for future applications.

STUDY ON THE DEVELOPMENT OF AN ANALYTICAL PROCEDURE TO DETERMINE THE TOTAL AND BIOAVAILABLE RARE EARTH ELEMENTS CONTENT IN ALLUVIAL SOIL SAMPLES USING ICP-OES

Tran Hoang Mai, Le Ba Thuan, Ngo Quang Huy, Luu Xuan Dinh, Nguyen Dinh Viet

Institute for Technology of Radioactive And Rare Elements, 48 Lang Ha, Ha Noi

Project information:

- **Project name: Study on the development of an analytical procedure to determine the total and bioavailable rare earth elements content in alluvial soil samples using ICP-OES**
- **Code: CS/24/03-01**
- **Managerial Level: Institute**
- **Implementation time: 12 months (Jan 2024 - Dec 2024)**
- **Contact email: tranhoangmai.khtn@gmail.com**
- **Published papers related to the project:**
 1. Tran Hoang Mai, Le Ba Thuan, Le Thi Giang, Ngo Quang Huy, Doan Thi Mo "Determination of total and bioavailable rare earth elements in alluvial soil samples for rice cultivation using ICP-OES", Journal of Analytical Sciences, ISSN-0868-3224 (in Vietnamese) (accepted).
 2. Tran Hoang Mai, Le Ba Thuan, Le Thi Giang, Ngo Quang Huy, Doan Thi Mo "Research on the sample decomposition method to determine total rare earth elements in alluvial soil samples using inductively coupled plasma atomic emission spectroscopy (ICP-OES)", reported in the 8th Conference of Nuclear Science and Technology for young researcher, 3-4, Oct. 2024, Hanoi, Vietnam.

Soil is an important bridge between plants and fertilizers. Soil is also a place to store and provide nutrients from fertilizers to plants. There is always a certain amount of rare earth elements (REEs) in soil, which is distributed in different fractions: water soluble, exchangeable and carbonate bound, organic matter bound, Fe-Mn oxide bound and residue. The total REEs content in five fractions mentioned above is called the total REEs content in soil. A small portion of the total REEs in soil, which exists in three fractions: water soluble, exchangeable and carbonate bound is known as the bioavailable REEs content in soil that can be used by plants. The REEs content in crops is often closely related to the bioavailable REEs content in soil. Although the total REEs content does not reflect the amount of REEs that can be absorbed by plants, they might affect the bioavailable REEs content in soil.

Therefore, to apply REEs effectively in fertilizers, minimize environmental pollution and protect land resource, the total and bioavailable REEs content in soil should be determined. Currently, fertilizers containing REEs have been widely used. So, developing a process for analyzing the total and bioavailable REEs content in soil was an urgent need. The study in this project aimed to evaluate the using ICP-OES in determining the total and bioavailable REEs

content in alluvial soil samples. The objects in this project were alluvial soil samples for rice cultivation taken in Thai Binh (n=10), representing soil samples of the Red River delta, Can Tho (n=2) and Dong Thap (n=10), representing soil samples of the Mekong delta. The REEs content in soil samples in these areas would be compared with those in soil samples using and without using fertilizers containing REEs, taken in Can Tho.

In this work, soil samples were digested with acid mixtures: aqua regia and HClO_4 , $\text{HNO}_3 + \text{HF} + \text{HClO}_4$; aqua regia; $\text{HCl} + \text{HF} + \text{HNO}_3$ to investigate the total REEs content, while the bioavailable REEs content were assessed by using different extractants at different pH: 0.1M CH_3COOH (pH=2.87); 0.05 M KCl (pH=7); 0.1 M HCl (pH=1); 0.1M $\text{CH}_3\text{COONH}_4$ (pH=7). As a result, using aqua regia and HClO_4 , $\text{HNO}_3 + \text{HF} + \text{HClO}_4$ were the best to recover the total REEs content. The bioavailable REEs content extracted by using 0.1 M HCl, was higher than others and was measured by ICP-OES. The bioavailable REEs content extracted by using 0.1M CH_3COOH , 0.05 M KCl, 0.1M $\text{CH}_3\text{COONH}_4$ were very low (< LOD of ICP-OES). that were measured by ICP-MS. The amount of REEs were extracted by 0.1 M $\text{CH}_3\text{COONH}_4$ and 0.1 M KCl belong to water soluble, exchangeable REEs fraction in the soil. The amount of REEs were extracted by 0.1M CH_3COOH and 0.1M HCl that reflected carbonate bound REEs fraction in the soil. The REEs content extracted by 0.1 M HCl reflecting the maximum and the amount of REEs extracted by KCl 0.05 M reflecting the minimum of the bioavailable content in rice alluvial soil samples in two studied area. However, the choice of extractant needed to be appropriate to the actual conditions in which the plant grew and developed, depending on the type of plant and soil. Based on the pH of soil (pH=5-6) and the pH of the extractants, initially 0.1 M CH_3COOH should be selected to extract bioavailable REEs content in soil.

The alluvial soil samples were pretreated by two different processes. Prepared samples (0.5 ± 0.0001 g) were processed by ashing at 500-550°C for 1 hours before the digestion with aqua regia and HClO_4 or being decomposed by a mixture of HNO_3 , HClO_4 and HF acids to determine the total REEs content. To determine the bioavailable REEs content, the alluvial soil samples were also pretreated by two different processes: prepared samples (7 ± 0.0001 g) were extracted in 100 mL of 0.1 M HCl or 100 mL of 0.1 M CH_3COOH in a triangular jar, which was shaken for 15 hours at room temperature at the speed of 150 times/min. The sample solutions after decomposition were evaporated or extraction until dry then dissolved in 2% HNO_3 solution and were filtered through a 0.45 μm membrane. The sample solutions was made up to the volume of 50 mL.

The determination of total and bioavailable REEs content, in which bioavailable REEs content was applied by using 0.1 M HCl, was carried out using inductively coupled plasma optical emission spectrometry (ICP-OES) with an Ultima 2 (Horiba, Japan) spectrometer. The following optimized instrumental parameters were used for determination of REEs: RF power 1200w, pump of speed: 20 times/min. The determination of the bioavailable REEs content in which bioavailable REEs content was applied by using 0.1 M CH_3COOH , was directly measured using inductively coupled plasma mass spectrometry (ICP-MS).

The results of correlation coefficient (R), the method detection limit (MDL), the method quantification limit (MQL) and the recovery, and the relative error were shown in Table 1.

Table 1. The correlation coefficient (R), method detection limit (MDL), method quantification limit (MQL) and the recovery, relative error

Element, emission wavelength (nm)	Correlation coefficient	MDL (mg/kg)	MQL (mg/kg)	Relative standard deviation (%)	Spike recovery (%)	Certified reference material (mg/kg)	Analysis results (mg/kg)	Relative Error (%)
Sc 335.373	0.9999	0.27	0.86	5.0	108.4		27.1	
Y 324.228	0.9999	0.85	2.71	1.0	97.6	59.9	55.1	-7.9
La 387.163	0.9999	0.71	2.26	3.5	106.1	1369.5	1344.2	-1.8
Ce 418.660	0.9999	0.77	2.44	4.7	103.0	179.0	1817.2	1.1
Pr 529.263	0.9998	0.77	2.46	5.1	91.3	243.4	214.7	-11.8
Nd 406.109	0.9999	0.62	1.98	5.3	91.8	780.9	813.9	4.2
Sm 359.260	0.9998	0.52	1.64	7.1	107.8	107.8	112.2	4.2
Eu 282.078	0.9999	0.76	2.43	7.6	106.9	22.7	19.4	-14.4
Gd 342.246	0.9999	0.59	1.88	3.2	109.3	50.3	54.0	7.2
Tb 350.917	0.9998	0.39	1.23	8.7	88.2	4.8	4.8	-1.8
Dy 340.780	0.9999	0.47	1.48	9.3	106.4	19.9	19.4	-2.2
Ho 345.600	0.9999	0.26	0.81	8.1	81.2	2.8	3.1	10.1
Er 369.265	0.9999	0.54	1.73	6.3	83.3	6.0	5.2	-14.2
Tm 317.281	0.9994	0.29	0.92	8.3	109.4	0.7	<1.0	
Yb 211.667	0.9999	0.28	0.90	9.1	98.2	3.9	3.6	-7.9
Lu 261.542	0.9999	0.27	0.85	3.6	104.1	0.5	<1.0	

The correlation coefficients of REE calibration curves ranged from 0.9994 to 0.9999 and they met the quantitative requirements. The method detection limit (MDL) were in the range of 0,27-0,85 mg/kg, the method quantification limit (MQL) were in the range of 0.85-2.71 mg/kg. Relative standard deviation (RSD) ranged from 1.0-9.3%. The recovery efficiency of each REE calculated by spiking REE standards into the matrix of soil sample was from 81.2 to 109.4 %

and they met the requirements within the research concentration level (80-110%). The relative error was obtained between -14.4% and 4.2% by the certified reference material (CRM-OREAS-460). All parameters met the requirement of the Association of Official Analytical Collaboration (AOAC) guideline for method validation. ICP-OES method was thus sufficient for the analysis of total and bioavailable REEs content in alluvial soil samples, in which bioavailable REEs content was applied by using 0.1 M HCl.

The analysis results of the total and 0.1 HCl fraction extracted bioavailable REEs content in alluvial soil samples were described in table 2.

Table 2. The total and bioavailable REEs content in alluvial soil samples

REE	Content (mg/kg)					
	Total rare earth elements		Bioavailable rare earth elements		Soil sample	
	Soil sample in Thai Binh	Soil sample in Dong Thap and Can Tho	Soil sample in Thai Binh	Soil sample in Dong Thap and Can Tho	With REEs containing fertilizers total(bioavailable)	Without REEs containing fertilizers total(bioavailable)
Sc	9.32±0.59	8.87±1.81	0.44±0.06	0.54±0.15	12.50(0.64)	10.94(0.40)
Y	16.98±4.56	15.65±1.90	8.42±2.14	6.40±1.07	15.13(7.54)	14.51(6.84)
La	27.26±5.20	26.92±11.50	5.36±2.04	5.73±4.05	35.93(7.19)	26.67(6.88)
Ce	68.47±7.30	64.36±26.98	14.89±4.08	15.44±2.30	85.00(17.27)	59.77(13.75)
Pr	18.25±9.23	9.71±5.51	2.67±1.06	2.88±0.87	12.69(2.40)	6.40(2.36)
Nd	28.63±3.71	29.76±10.13	7.00±1.54	6.86±0.80	30.92(7.69)	24.43(7.28)
Sm	4.84±2.22	5.29±2.21	2.01±0.38	1.78±0.29	5.78(1.98)	3.28(1.96)
Eu	3.25±2.34	3.56±1.68	0.64±0.11	0.66±0.25	4.59(0.84)	3.24(0.83)
Gd	9.35±1.37	8.20±1.59	2.41±0.38	2.05±0.29	7.30(2.11)	5.50(2.09)
Tb	2.84±2.19	2.16±1.51	0.47±0.10	0.35±0.12	1.65(<MDL)	<MDL
Dy	3.78±0.90	3.55±1.35	1.70±0.31	1.70±0.87	4.05(1.57)	3.68(1.56)
Ho	0.83±0.59	0.97±0.57	0.30±0.07	0.28±0.08	2.03(0.27)	0.55(0.3)
Er	2.27±0.73	2.34±0.64	0.73±0.14	0.67±0.14	2.68(0.72)	0.89(0.71)
Tm	2.22±1.23	1.86±1.80	0.24±0.13	0.48±0.49	5.50(0.29)	4.50(<MDL)
Yb	1.13±0.25	1.19±0.37	0.49±0.07	0.44±0.08	1.40(0.51)	1.39(0.46)
Lu	1.33±0.25	1.28±0.34	0.14±0.02	0.14±0.04	0.82(<MDL)	0.61(<MDL)
Total REEs	200.17±24.88	186.52±59.67	47.83±11.8	46.39±7.19	227.96(51.02)	166.60(45.64)

The average content of rare earth elements in soil samples in the Thai Binh, Can Tho and Dong Thap decreased as follows:

Ce>Nd>La>Pr>Y>Gd>Sc>Sm>Dy>Eu>Tb>Er>Tm>Lu>Yb>Ho.

Ce and Nd were the two most common elements in alluvial soil samples. The content of light REEs (La, Ce, Pr, Sm, Eu, Gd, Sm) accounted for the majority with a ratio of 79.2% (soil

sample in Can Tho) and 80.0% (soil sample in Thai Binh), proving that the mineral composition was richer in light REEs than in heavy REEs .

The analysis results showed that REEs content was also detected in soil sample which did not use fertilizer containing REEs. It mean that the source water, the parent material, the types of fertilizers, weathering conditions... contributed to the amount of REEs in soil. Comparing with the soil sample without using fertilizers containing REEs, it was found that there was an increasing in REEs content in the sample using fertilizers containing REEs. The total (average 200.17 ± 24.88 mg/kg) and 0.1 M HCl fraction bioavaiable (average 47.83 ± 11.8 mg/kg) REEs content, in Thai Binh soil samples were higher than those (average 186.52 ± 59.67 mg/kg) and (average 46.39 ± 7.19 mg/kg), respectively in Can Tho and Dong Thap soil samples. The total (227.96 mg/kg) and bioavaiable (51.02 mg/kg) REEs content of the sample using fertilizers containing REEs higher than those (166.60 mg/kg) and (45.64 mg/kg), respectively of the sample without fertilizers containing REEs, and higher than the average content of the two studied areas, but these differences were not much.

In near future, further studies would be done to mapping the distribution of REEs in agricultural soils, creating foundation for the effective, safe and sustainable use fertilizers containing REEs in agriculture.

THE STUDY ON DETERMINING ORGANIC-GROWN DALAT STRAWBERRIES IS BASED ON $\delta^{15}\text{N}$ ISOTOPE COMPOSITION USING THE EA-IRMS SYSTEM

Nguyen Huu Nghia¹, Tran Quang Thien¹, Nguyen Minh Dao¹, Le Xuan Thang¹, Nguyen Thi Huong Lan¹, Vo Thi Mong Tham¹, Le Van Toan¹, Pham Dinh Hai²

¹Department of Nuclear and Isotopes Techniques, Nuclear Research Institute, 01 Nguyen Tu Luc Street, Ward 8, Dalat city, Lamdong province, Vietnam.

²Lamdong Department Of Agriculture And Rural Development, 36 Tran Phu street, Ward 4, Dalat city, Lamdong province, Vietnam.

Project information:

- **Project name:** The study on determining organic-grown Dalat strawberries is based on $\delta^{15}\text{N}$ isotope composition using the EA-IRMS system.
- **Code:** CS/24/01-03
- **Managerial Level:** Institute
- **Implementation time:** 12 months (Jan 2024- Dec 2024)
- **Contact email:** huunghia30195@gmail.com
- **Published papers related to the project:**

1. Nguyen Huu Nghia et al., Stable isotope composition $\delta^{15}\text{N}$ in organic and conventional strawberry fruit samples, Ho Chi Minh city university of education journal of science (in Vietnamese).
2. Nguyen Huu Nghia et al., Difference in stable isotope composition $\delta^{15}\text{N}$ in organic and conventional strawberry fruit samples, a report of the 8th Nuclear Science and Technology, Hanoi, Vietnam, 3-4 october 2024 (in Vietnamese).

In recent years, consumers have increasingly favored organic products, particularly organic strawberries. Studies have shown that strawberries are not only delicious but also provide numerous health benefits, such as reducing cholesterol, stabilizing blood pressure, fighting inflammation, and supporting heart health. This has contributed to the rising value of organic strawberries. However, the market has seen cases of fraud, where non-organic strawberries are falsely labeled as organic. The fundamental differences between organic and conventional strawberries lie in cultivation practices, care, and the use of fertilizers and pesticides. Among these, nitrogen is a critical nutrient for plant growth and development. Hence, the stable isotope composition $\delta^{15}\text{N}$ serves as an isotopic fingerprint to discriminate between organic and conventional strawberries. This study aims to differentiate organic strawberries from non-organic ones through $\delta^{15}\text{N}$ isotopic composition analysis using the EA-IRMS mass spectrometry system.

To achieve the study objectives, we first established a method for analyzing $\delta^{15}\text{N}$ stable isotope composition in strawberry samples using the EA-IRMS system, based on USGS 61, USGS 63 standards, and QC standards such as protein, gelatin, and USGS 62. We then collected strawberry samples from the market, including both organic and conventional varieties. Next, we designed an experimental model to cultivate strawberries using two types of

fertilizers: organic and inorganic, to evaluate the impact of each fertilizer type on the $\delta^{15}\text{N}$ isotopic composition in fruit strawberries. Finally, we analyzed the $\delta^{15}\text{N}$ values from the collected samples and applied statistical models and regression algorithms to classify between organic and conventional strawberries.

The results of the study successfully established a method for analyzing $\delta^{15}\text{N}$ stable isotope composition in strawberry samples using the EA-IRMS system, achieving repeatability with an SD < 0.30 ‰ and an uncertainty U < 0.30 ‰ at a significance level of $\alpha = 0.05$ and a statistical factor $k = 1.96$. ANOVA testing showed significant differences in $\delta^{15}\text{N}$ values among organic strawberries grown in Japan and strawberries grown hydroponically, conventionally, and in greenhouses in Dalat and Japan, with a p-value < 0.001 at $\alpha = 0.05$. Specifically, the average $\delta^{15}\text{N}$ value in organic strawberries grown in Japan (6.077 ‰) was higher than in hydroponic strawberries (5.060 ‰), conventionally grown strawberries in Dalat and Japan (0.020 ‰ and 0.741 ‰, respectively), and greenhouse strawberries in Dalat (0.188 ‰) (**Table 1**). These $\delta^{15}\text{N}$ differences reflect variations in nutrition and nitrogen metabolism, influenced by cultivation conditions (soil, water, fertilizers) and geographic factors (climate, rainfall, altitude). Additionally, the study shows that the use of organic fertilizers increases $\delta^{15}\text{N}$ values in strawberries; $\delta^{15}\text{N}$ values in strawberries fertilized with organic matter (0.778 ‰) were higher than those fertilized with inorganic (-2.380 ‰) and synthetic fertilizers (-0.664 ‰).

Table 1. ANOVA test results for collected strawberry samples

$\delta^{15}\text{N}$ (‰)	Organic (Japan)	Hydroponic (Dalat)	Greenhouse (Dalat)	Conventional (Japan)	Conventional (Dalat)
n	8	10	8	6	8
Mean	4,720	5,060	0,188	0,741	0,020
Minimum	4,405	4,519	-0,942	-1,267	-1,119
Maximum	10,155	6,620	0,561	2,981	2,626
SD	1,848	0,582	0,890	1,604	1,211
ANOVA test p-value ($\alpha = 0.05$)	1,79E-04				

n: number of analyzed samples

This study has made significant contributions to the analysis and verification of agricultural product quality. The research successfully classifies organic strawberries from conventional ones through $\delta^{15}\text{N}$ stable isotope composition, providing a basic scientific foundation for differentiating organic products. The study has high potential for application in establishing organic agricultural product quality standards, supporting clean agricultural branding, and protecting consumer rights. In the future, we aim to expand the study to explore environmental factors and improve analytical methods for application to other agricultural products. Future work directions could focus on combining $\delta^{15}\text{N}$ values with other isotopic compositions, such as $\delta^{13}\text{C}$, $\delta^2\text{H}$, and $\delta^{18}\text{O}$, to enhance the accuracy of organic agricultural product verification.

2.7. RADIATION SAFETY AND RADIOACTIVE WASTE MANAGEMENT

STUDY ON ESTABLISHMENT OF PHOTON REFERENCE FIELDS IN ACCORDANCE WITH THE NEW ICRU95 OPERATIONAL QUANTITIES

Bui Duc Ky, Nguyen Ngoc Quynh, Nguyen Huu Quyet, Tran Thanh Ha, Pham Bao Ngoc, Bui Thi Anh Dzung, Nguyen Dang Nguyen, Dang Thi My Linh, Duong Thi Nhung, Tran Van Trung, Dang Thi Minh Hue, Do Thi Hai

Institute for Nuclear Science and Technology, 179 Hoang Quoc Viet, Hanoi, Vietnam

Project information:

- **Project name: Study on establishment of photon reference fields in accordance with the new ICRU95 operational quantities.**
- **Code: ĐTCB.05/23/VKHKTHN**
- **Managerial Level: Ministry**
- **Implementation time: 30 months (Jan 2023 - Jun 2025)**
- **Contact email: duckyb2@gmail.com**
- **Published papers related to the project:**
 1. Bui Duc Ky, Nguyen Ngoc Quynh, Le Ngoc Thiem, Validation of ISO 4037 x-ray reference field following ICRU-95 operational quantities, Radiation physics and chemistry, Vol 234, 2025
 2. Bui Duc Ky, Nguyen Ngoc Quynh, Nguyen Huu Quyet, Dang Thi My Linh, Duong Thi Nhung, Nguyen Dang Nguyen, Dang Thi Minh Hue, Simulation of gamma reference field at Institute for Nuclear Science and Technology, Nuclear Science and Technology, Vol. 14, No. 2, pp.26-33, 2024
 3. Bui Duc Ky, Nguyen Ngoc Quynh, Nguyen Huu Quyet, Dang Thi My Linh, Duong Thi Nhung, Nguyen Dang Nguyen, Dang Thi Minh Hue, Simulation of gamma reference field at Institute for Nuclear Science and Technology, Vietnam Conference on Nuclear Science and Technology, 2023
 4. Bui Duc Ky, Nguyen Ngoc Quynh, Dang Thi My Linh, Duong Thi Nhung, Nguyen Dang Nguyen, Dang Thi Minh Hue, Tran Thanh Ha, Tran Van Trung, Duong Van Trieu, Establishment of X-ray radiation reference field with RQR series according to international standard IEC 61267, The 8th Youth Conference on Nuclear Science and Technology, 2024 (in Vietnamese).

The operational quantities introduced in ICRU 39 and ICRU 51 Reports have been widely used to approximate protection quantities. However, several studies have demonstrated that these quantities can lead to significant deviations, either overestimating or underestimating the actual protection quantities. To address this limitation, in 2020, the ICRP and ICRU jointly proposed a new set of operational quantities to enhance the accuracy of radiation protection assessments. In line with these international developments, this study focuses on establishing reference photon radiation fields for the newly introduced ICRU 95 operational quantities, H^* and H_p , in accordance with ISO 4037 standard. These include X-ray narrow-spectrum series, X-ray low air-kerma series, and gamma radiation fields using two standard radionuclide sources ^{137}Cs and ^{60}Co . Additionally, X-ray reference fields with RQR series are developed following the IEC 61267 standard.

The study employs an X-ray generator (model X80-160-kV-E) to produce X-ray radiation reference fields, and a multi-source gamma irradiator (model GC-60-10-A) to generate gamma radiation reference fields. The measurement system includes ionization chambers of various volumes (A3, A4, and A6) in combination with a SUPERMAX electrometer, all manufactured by Standard Imaging (USA). The A4 ionization chamber is calibrated by the Primary Standard Dosimetry Laboratory (PSDL) at VSL in the Netherlands, while the A6 chamber is calibrated by the IAEA dosimetry laboratory.

The conversion coefficients from fluence to personal dose, h_p , for X-ray narrow-spectrum series and gamma radiation were calculated through simulations using the MCNP and PHITS codes. The simulation results were then compared with those obtained by interpolation methods. The simulation approach utilized X-ray reference spectra published by the Primary Standards Dosimetry Laboratory PTB (Germany) to determine the effective dose E for the ICRP 110 voxel phantom. The interpolation method also uses the X-ray reference spectra published from PTB and the dataset of conversion coefficients from fluence to personal dose, h_p , as published in ICRU 95 and ICRP 116, to determine the average conversion coefficient from fluence to personal dose, h_p for X-ray radiation qualities within the series of standard spectra.

Table 1 presents the conversion coefficients from fluence to personal dose h_p , obtained using both MCNP and PHITS simulation codes, as well as those derived from the interpolation method. The discrepancy between the simulation and interpolation results was found to be less than 10%.

Table 1: Fluence to personal dose conversion coefficient, h_p

Radiation quality	h_p ($\mu\text{Sv.cm}^2$)											
	MCNP				PHITS				Interpolation method			
	AP	PA	LLAT	RLAT	AP	PA	LLAT	RLAT	AP	PA	LLAT	RLAT
N-40	0.32	0.11	0.11	0.09	0.31	0.11	0.11	0.09	0.33	0.12	0.12	0.10
N-60	0.36	0.19	0.14	0.12	0.35	0.18	0.14	0.12	0.36	0.20	0.15	0.13
N-80	0.40	0.25	0.18	0.15	0.39	0.24	0.18	0.15	0.40	0.26	0.18	0.16
N-100	0.46	0.31	0.21	0.19	0.45	0.30	0.21	0.18	0.46	0.31	0.22	0.19
N-120	0.53	0.37	0.26	0.22	0.51	0.36	0.25	0.22	0.53	0.37	0.26	0.23
N-150	0.61	0.44	0.30	0.27	0.59	0.42	0.30	0.26	0.61	0.43	0.31	0.27
^{137}Cs	3.16	2.64	2.11	1.97	3.16	2.64	2.12	1.97	3.17	2.62	2.14	1.98
^{60}Co	5.33	4.66	3.95	3.74	5.33	4.67	3.95	3.75	5.34	4.65	3.98	3.76

The Half-Value Layer (HVL) values of X-ray radiation qualities in both narrow-spectrum and low air-kerma rate series were recalculated using the latest conversion coefficients from fluence to air kerma, h_k . The experimentally determined HVL values for these X-ray spectra were then compared with the reference HVL values specified in ISO 4037.

The deviation between the experimentally measured HVL values and the reference HVL values remains within acceptable limits, allowing for the use of conversion coefficients from air kerma to the new operational quantities with a measurement uncertainty of $\leq 2\%$.

Consequently, the expanded measurement uncertainty for dose or dose rate values of the new ICRU 95 operational quantities is estimated to be less than 4.65%.

Table 2 presents the experimentally determined HVL values and their deviations from the corresponding reference values

Table 2: Comparison of experimental and reference HVL values of X-ray radiation qualities

Radiation quality	Distance (cm)	Material	Experiment		Reference		Deviation	
			HVL1 (mm)	HVL2 (mm)	HVL1 (mm)	HVL2 (mm)	Δ HVL1 (μ m)	Δ HVL2 (μ m)
N-40	100	Al	2.704	2.842	2.632	2.824	72	18
	250	Al	2.681	2.842	2.648	2.840	33	2
N-60	100	Cu	0.240	0.258	0.2342	0.2624	6	-4
	250	Cu	0.242	0.269	0.2352	0.2634	7	5
N-60	100	Al	5.967	6.493	5.851	6.203	116	290
	250	Al	6.000	6.526	5.868	6.218	132	308
N-80	100	Cu	0.592	0.631	0.577	0.6206	15	11
	250	Cu	0.594	0.639	0.5791	0.6225	15	16
N-100	100	Cu	1.079	1.197	1.096	1.156	-17	41
	250	Cu	1.066	1.200	1.098	1.158	-32	42
N-120	100	Cu	1.694	1.761	1.673	1.734	21	27
	250	Cu	1.632	1.710	1.675	1.735	-43	-25
N-150	100	Cu	2.337	2.464	2.298	2.406	39	58
	250	Cu	2.341	2.449	2.302	2.411	39	38
L-55	100	Cu	0.254	0.263	0.248	0.2609	6	2
	250	Cu	0.257	0.260	0.249	0.2613	8	-2
L-55	100	Al	6.247	6.553	6.139	6.293	108	260
	250	Al	6.285	6.609	6.147	6.300	-15	309
L-70	100	Cu	0.493	0.503	0.483	0.504	10	-1
	250	Cu	0.499	0.501	0.483	0.505	16	-4
L-100	100	Cu	1.215	1.242	1.218	1.257	26	16
	250	Cu	1.238	1.260	1.219	1.257	29	15
L-125	100	Cu	1.994	2.024	1.983	2.018	70	67
	250	Cu	2.012	2.057	1.985	2.022	52	62

Factors affecting the photon radiation reference fields, such as scattered radiation and the field uniformity, were also evaluated through experimental measurements in accordance with ISO 4037 standards. The results indicate that both the influence of scattered radiation and the uniformity of the reference radiation field meet the requirements specified in ISO 4037.

The reference dose rate values corresponding to each X-ray radiation quality in the spectral series were determined using the following formula:

$$H_R = K_{air,R} \cdot h_R \quad (1)$$

In this formula, $K_{air,R}$ represents the air kerma value for radiation quality R, and h_R is the corresponding conversion coefficient from air kerma to the operational quantity for that

radiation quality. The operational quantity either ambient dose, H^* or personal dose, H_p depends on the specific conversion coefficient h_R used.

The reference dose rate values for the new ICRU 95 operational quantities under gamma radiation fields using the radionuclides ^{137}Cs and ^{60}Co were determined experimentally based on air kerma measurements, as described by Equation (1). Air kerma values were measured at source-to-detector distances ranging from 80 cm to 400 cm.

The expanded measurement uncertainties for the reference dose rate values of the new ICRU 95 operational quantities in the gamma radiation fields using ^{137}Cs and ^{60}Co sources were 4.64% and 4.57%, respectively.

The reference radiation fields established for the new ICRU 95 operational quantities were applied to determine the response functions of survey meters currently used in Vietnam. A total of 35 instruments, representing 22 different types and detector configurations including Geiger-Muller counters, scintillation detectors, ionization chambers, and proportional counters were tested. When calibrated using ^{137}Cs gamma radiation, the instruments were capable of measuring ambient dose equivalent H^* with deviations of less than 30% across the photon energy range from 200 keV to 1250 keV. However, in the lower energy range (below 200 keV), most instruments exhibited deviations exceeding 30% compared to reference values.

In addition to the radiation qualities defined by ISO 4037, this study also established reference radiation fields for the RQR spectral series as defined in IEC 61267. The RQR radiation qualities established range from RQR2 to RQR10. The characteristics of the RQR spectral series radiation qualities are presented in Table 3.

For each radiation quality, the thickness of additional filtration was determined based on the method described in IAEA Technical Reports Series No. 457. The results for the additional filtration are also presented in Table 3. Furthermore, the experimentally determined HVL values for these radiation qualities are included in the same table.

The deviations between the measured homogeneity coefficients and the reference values were all less than 0.03, thereby meeting the requirements of IEC 61267

Table 3: Comparison of experimental and reference HVL of RQR series according to IEC 61267

Radiation quality	High voltage (kV)	Additional filtration (mm Al)	Experiment			IEC 61267 standard		
			HVL1 (mm Al)	HVL2 (mm Al)	Homogeneity coefficient	HVL1 (mm Al)	HVL2 (mm Al)	Homogeneity coefficient
RQR2	40	2.42	1.42	1.76	0.807	1.42	1.75	0.81
RQR3	50	2.42	1.76	2.31	0.764	1.78	2.34	0.76
RQR4	60	2.67	2.20	2.98	0.738	2.19	2.96	0.74
RQR5	70	2.85	2.60	3.62	0.716	2.58	3.63	0.71
RQR6	80	3.13	3.07	4.42	0.695	3.01	4.36	0.69
RQR7	90	3.36	3.60	5.26	0.685	3.48	5.12	0.68

RQR8	100	3.48	4.00	6.13	0.652	3.97	5.84	0.68
RQR9	120	3.97	5.07	7.72	0.657	5.00	7.35	0.68
RQR10	150	4.77	6.66	9.35	0.713	6.57	9.13	0.72

In summary, this study successfully established X-ray and gamma radiation reference fields in accordance with ISO 4037 for the new operational quantities defined in ICRU Report 95. The established reference fields meet all the requirements specified in ISO 4037. The expanded measurement uncertainty of the reference dose rate values is less than 5% (with a coverage factor $k=2$).

Additionally, RQR-series X-ray reference radiation fields were established following the IEC 61267 standard. These reference radiation fields provide a more accurate basis for radiation dose evaluation, better support the calibration of radiation measurement instruments, and align with recent international developments in dosimetry evaluation.

In the future, further research will be conducted to establish additional reference radiation fields for the new operational quantities introduced in ICRU Report 95, such as the absorbed dose to the lens of the eye, $D_{p \text{ lens}}$, the absorbed dose to local skin, $D_{p \text{ local skin}}$ as well as the new operational quantities for neutron reference radiation fields, to supplement and improve the existing reference radiation fields.

2.8. RADIATION TECHNOLOGY

STUDY ON FABRICATION OF MAGNETIC IRON OXIDE/CHITOSAN ADSORBENTS GRAFTED BY IRRADIATION FOR ENHANCED REMOVAL OF HEAVY METAL IONS FROM AQUEOUS SOLUTIONS

Nguyen Thi Kim Lan, Dang Van Phu, Nguyen Chi Thuan, Ngo Phu Trieu, Nguyen Ngoc Duy

*Research and Development Center for Radiation Technology
202A, Street 11, Linh Xuan Ward, Thu Duc City, Ho Chi Minh City*

Project information:

- **Project name: Study on fabrication of magnetic iron oxide/chitosan adsorbents grafted by irradiation for enhanced removal of heavy metal ions from aqueous solutions**
- **Code: CS/24/07-01**
- **Managerial Level: Institute**
- **Implementation time: 15 months (Jan 2024- Mar 2025)**
- **Contact email: lktnguyen345@gmail.com**
- **Published papers related to the project:**

Nguyen Chi Thuan, Nguyen Thi Kim Lan, Dang Van Phu, "Study on preparation maleic acid grafted chitosan by gamma irradiation", the 8th Conference for Young Researchers on Nuclear Science and Technology, Ha Noi, Vietnam, 2024, 7p (in Vietnamese).

The contamination of various water sources by heavy metals is a significant concern due to its toxic effects on human health and the safety of ecosystems. Removing heavy metal ions from water, particularly from industrial wastewater, is one of the most pressing environmental challenges that needs to be addressed today.

Various treatment methods have been developed to remove heavy metal ions, among which adsorption is considered an effective method for treating metal ions in the aquatic environment. Chitosan is the second most common polysaccharide in nature and is valued for its biocompatibility, biodegradability, and environmental friendliness. Furthermore, chitosan is considered an effective adsorbent because of the presence of amino and hydroxyl groups in its structure, which acts as complexation sites for most metal ions. However, the crystalline structure and poor acid resistance of raw chitosan often do not meet the application requirements, necessitating various modification methods. The goals of modifying chitosan in adsorption studies are to enhance the material's stability in acidic environments and improve its adsorption capacity, which is evident in its adsorption efficiency. Crosslinking is a common method used to strengthen chitosan's stability in acidic conditions. Another significant method is graft polymerization, which has garnered considerable interest among researchers. This process involves grafting various functional groups, including carboxyl, sulfate, phosphate, nitrile, etc., onto chitosan to create functional derivatives that enhance its adsorption capacity for metal ions. Each modification method has its unique advantages and disadvantages. Notably, graft polymerization of chitosan through radiation methods has distinct advantages

over traditional chemical methods, as it does not require chemical initiators, provides high efficiency, allows easy control of experimental conditions, and is not limited by polymer shape.

To address the challenge of material recovery after adsorption, combining chitosan with iron oxide not only enhances its mechanical properties but also facilitates efficient recovery using an external magnet. Therefore, this study on the fabrication of radiation-grafted polymerized iron oxide chitosan adsorbent for the removal of heavy metal ions in water was carried out.

The radiation-grafted polymerized iron oxide chitosan adsorbent was prepared by gamma irradiation. Specifically, Fe_3O_4 was dispersed in 20 ml of water. The Fe_3O_4 dispersion was then added to 80 ml of 2.5% CTS solution (prepared with 1.5% lactic acid) with Fe_3O_4 content in the range of 0.2% - 2%. The mixture was stirred for 30 minutes. Glutaraldehyde was added to Fe_3O_4 /CTS solution at a concentration of 0.2% - 0.6% (w/v) to form Fe_3O_4 /CTS gel. Then, 5g of Fe_3O_4 /CTS was soaked in 10 ml of maleic acid (MA) solution with a concentration of 0-30% at room temperature for 24 hours. The solution was then bubbled with nitrogen for 20 minutes and irradiated with doses between 0 kGy and 12 kGy from a Co-60 SVST gamma source at the Research and Development Center for Radiation Technology. After irradiation, the sample (Fe_3O_4 /CTS/PMA) was washed with water in a thermostatic bath at 50 °C for 48 hours, and the water was changed every 4 hours. Finally, the samples were dried at 60°C until they reached a constant weight. The grafting content (%) was calculated according to equation (1):

$$\text{Grafting content (\%)} = (w_g - w_i) / w_i \times 100 \quad (1)$$

Where w_g is the mass of Fe_3O_4 /CTS/PMA after grafting and w_i is the initial mass of Fe_3O_4 /CTS.

To investigate the recovery ability of the material after adsorption, 0.1 g of the Fe_3O_4 /CTS/PMA sample was placed into 100 mL of a Pb(II) ion solution with a concentration of 1000 mg/L and left for 24 hours. After adsorption, A magnet (Neodymium, N35) was then used to recover the Fe_3O_4 /CTS/PMA. The recovered Fe_3O_4 /CTS/PMA sample was dried and weighed. The recovery rate (%) was calculated using equation (2):

$$\text{Recovery rate (\%)} = (w_r - m_i) / w_o \times 100 \quad (2)$$

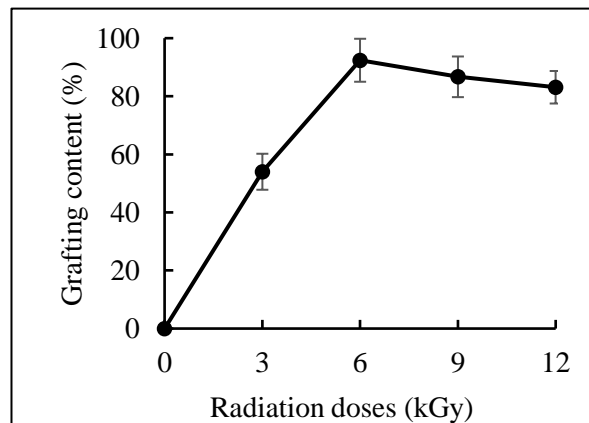
Where w_r is the mass of Fe_3O_4 /CTS/PMA recovered after adsorption, m_i is the adsorbed Pb(II) ion content and w_o is the initial mass of Fe_3O_4 /CTS/PMA.

To investigate the adsorption capacity of Pb(II) and Cd(II) ions of Fe_3O_4 /CTS/PMA material, the stock solution of Pb(II) and Cd(II) ions was prepared from $\text{Pb}(\text{NO}_3)_2$, $\text{CdCl}_2 \cdot 2.5\text{H}_2\text{O}$, respectively, achieving a concentration of 1000 mg/L for both ions. Different concentrations of Pb(II) and Cd(II) ion solutions were obtained by diluting the stock solution. The volume of the reaction solution was 50 ml, and the mass of the adsorbent material was 30 mg. The initial concentration of metal ions was 50-1000 mg/L. The experiments were carried out at room temperature, shaking speed was 100 rpm for 24 hours. After filtration, the remaining concentrations of Pb(II) and Cd(II) ions in the filtered solution were analyzed on an atomic absorption spectrometer AAS (AA 6601F, Shimadzu, Japan).

The grafting content of 20% MA onto Fe₃O₄/CTS under irradiation doses ranging from 0 to 12 kGy was shown in Figure 1. As the irradiation dose increased in the range of 0 to 6 kGy, the grafting content also increased. However, at radiation doses higher than 6 kGy, the grafting content did not change significantly. This indicates that a radiation dose of 6 kGy is optimal for grafting MA onto Fe₃O₄/CTS, with the grafting content achieved being approximately 92.4%. The radiation grafting process is initiated by free radicals generated during irradiation. Therefore, the grafting content depends on the number of free radicals formed in the reaction system. As the radiation dose increases, the number of free radicals also increases, facilitating the grafting reaction and consequently in a higher grafting content. However, when the radiation dose exceeds a certain level, the grafting content does not change significantly. This decrease may be attributed to high radiation doses causing residual free radicals to interact with the growing polymer chain or the recombination of free radicals with one another, which leads to the termination of the reaction chain.

Figure 1. Effect of radiation dose on graft content

The recovery of materials after adsorption was examined with varying concentrations of



Fe₃O₄, ranging from 0.2% to 2%. When the concentration of Fe₃O₄ increased from 0.2% to 0.5%, the recovery rate rose significantly, rising from 78.6% to 97.8%. However, further increases in Fe₃O₄ content to 1% and 2% did not result in a significant change in the recovery rate compared to the 0.5% concentration. Therefore, it can be concluded that a Fe₃O₄ concentration of 0.5% is optimal for producing materials that can be effectively recovered by magnets after adsorption.

Table 3.1. Langmuir and Freundlich coefficients

Metal ions	Langmuir isotherm			Freundlich isotherm		
	Q _m	k _L (L/mg)	R ²	n	k _f	R ²
Pb(II)	192,3	0,031	0,996	4,8	47,6	0,939
Cd(II)	95,2	0,010	0,992	7,8	21,5	0,953

The experimental results based on linear adsorption isotherm models and the calculated isotherm coefficients are summarized in Table 1. The correlation coefficients (R²) for the Langmuir isotherms of Fe₃O₄/CTS/PMA are higher than those obtained from the Freundlich isotherm. Therefore, the Langmuir model better represents the adsorption process in this study. This suggests that the adsorption occurs as a monolayer on the surface of a homogeneous adsorbent. The maximum adsorption capacity (Q_m) values according to the Langmuir model were 192.3 mg/g and 95.2 mg/g for Pb(II) and Cd(II), respectively.

The study investigated the fabrication of iron oxide chitosan grafted with maleic acid using gamma radiation for application as an adsorbent for lead and cadmium ions in water. The irradiation dose of 6 kGy is optimal for grafting MA onto Fe₃O₄/CTS, with the grafting content achieved being approximately 92.4%. The maximum adsorption capacities were 192.3 mg/g for Pb(II) and 95.2 mg/g for Cd(II). Magnetic iron oxide chitosan material grafted with maleic acid is a promising adsorbent for the removal of Pb(II) and Cd(II) ions from water.

STUDY ON ENHANCEMENT OF STRUCTURAL PROPERTIES AND PHOTOCATALYTIC ACTIVITY OF BiVO_4 THIN FILMS VIA PHOSPHOR (P^+) ION BEAM IRRADIATION
Luu Anh Tuyen, Pham Thi Hue, Nguyen Thi Ngoc Hue, Phan Trong Phuc, La Ly Nguyen, Lo Thai Son

Center for Nuclear Technologies Hochiminh City, 217 Nguyen Trai Str., Dis. 1, Hochiminh City

Project information:

- **Project name:** Study on enhancement of structural properties and photocatalytic activity of BiVO_4 thin films via phosphor (P^+) ion beam irradiation

- **Code:** ĐTCB.12/2023/TTHN

- **Managerial Level:** Ministry

- **Implementation time:** 24 months (Jan 2023 - Dec 2024), extended until Jun, 2025

- **Contact email:** lalynguyen279@gmail.com

- **Published papers related to the project:**

1. La Ly Nguyen et al., "Computing simulation of sample absorbed dose homogeneity for electron beam irradiated from the Cyclotron MT-25", *The 15th Vietnam Conference on Nuclear Science and Technology (VINANST-15, Nha Trang)*, 2023, Section B (Poster, in Vietnamese).

2. Luu Anh Tuyen, Nguyen Quang Hung, Le Van Hoang, Tran Dinh Phong, Pham Thi Hue, Nguyen Thi Ngoc Hue, "Enhancing the catalytic activity of nano-catalysts by using electron-beam irradiation", *The 2nd International Conference on Chemical Sciences (Ninh Binh City)*, 2024, Panel 7: Chemistry for Energy Conversion & Storage.

3. Nguyen Vu Minh Trung, Nguyen Van Tiep, Marcin Turek, Andrzej Drozdziel, Krzysztof Pyszniak, Alexey A. Sidorin, Oleg S. Orlov, La Ly Nguyen, Pham Thi Hue, Nguyen Thi Ngoc Hue, Tran Van Phuc, Hoang V. Le, Le Thi Ly, Tran Dinh Phong, Alexander. A. Donkov, Evgeni P. Popov, Samir F. Samadov, M.N. Mirzayev, Nguyen Quang Hung, Luu Anh Tuyen*, "Preliminary analysis of structural defects in thin BiVO_4 layer using the slow-positron-beam based facilities at JINR, Dubna", *Nuclear Science and Technology*, 14(3), 41-50, (2024).

4. La Ly Nguyen, Pham Thi Hue, Nguyen Thi Ngoc Hue, Luu Anh Tuyen*, "Optimization of experimental parameters for positron annihilation lifetime spectroscopy in nanomaterial research", *Nuclear Science and Technology* (accepted on 05/06/2025).

5. Nguyen Vu Minh Trung, Tiep Nguyen Van, Marcin Turek, Andrzej Drozdziel, Krzysztof Pyszniak, Alexey A Sidorin, Alexander. A. Donkov, Oleg S. Orlov, Nguyen La Ly, Hue Thi Pham, Hue Thi Ngoc Nguyen, Tran V. Phuc, Le Van Hoang, Ly T. Le, Semyon V. Mitrofanov, N. Ismayilova, S.H. Jabarov, N. Kirilkin, A.S. Abiyev, P. L. Tuan, T. Vershinina, Evgeni P. Popov, Samir F. Samadov, M.N. Mirzayev, Nguyen Thi Thao Van, Tran Ngo, Phong D. Tran, Nguyen Quang Hung, Tuyen Anh Luu*, "Evolution of point and complex defects in 100 keV P^+ implanted BiVO_4 thin-film explored by experimental and simulated positron annihilations using slow-positron beam", *ACS Applied Materials & Interfaces* (revised 06/2025).

6. Nguyen Vu Minh Trung, Anh Tien Dang, Tran Quoc Viet, Tran Dong Xuan, Nguyen Ngoc Anh, Le Tan Phuc, La Ly Nguyen, Pham Thi Hue, Le Hong Khiem, Luu Anh Tuyen, and Nguyen Quang Hung*, "Description of Temperature Evolution of Pore Size and Geometry in

In this study, the research team utilized 100 keV phosphor (P^+) ion irradiation to modify the microstructure of $BiVO_4$ thin films, aiming to enhance their charge-related structural characteristics and photocatalytic activity. For the first time, the evolution mechanism of point and complex defects in $BiVO_4$ was comprehensively explored by combining positron annihilation spectroscopy using a slow-positron beam (SPB) from an accelerator and theoretical simulations based on density functional theory (DFT). Specifically, $BiVO_4$ films were irradiated at various ion fluences (10^{13} – 10^{15} ions/cm²), with three characteristic depth regions in the film: (0–30 nm), (30–117 nm), and (117–225 nm).

The analysis results from PAS (Positron Annihilation Spectroscopy), TEM (Transmission Electron Microscopy), XRD (X-ray Diffraction), UV–Vis (Ultraviolet–Visible Spectroscopy), and PL (Photoluminescence Spectroscopy) revealed that the defect structures evolved in a complex manner depending on both depth and ion fluence. In the near-surface region (0–30 nm), alongside the gradual emergence of an amorphous phase with increasing fluence, oxygen (V_o) and bismuth (V_{Bi}) vacancies were formed at low fluence ($\sim 10^{13}$ ions/cm²), while V_{Bi} became dominant at higher fluence. In the second region (30–117 nm), where P^+ ions reached their highest concentration (around 80–100 nm), the defect evolution became more complicated, involving the substitution of oxygen by P (P_o), which then combined with V_{Bi} to form the complex defect $V_{Bi}+P_o$. At low fluence, the competitive formation of V_o , V_{Bi} , and $V_{Bi}+P_o$ occurred simultaneously, while at intermediate fluence ($\sim 10^{14}$ ions/cm²), phosphorus atoms occupied interstitial sites, which caused significant lattice expansion in $BiVO_4$.

In the deepest region (117–225 nm), the defect evolution was even more diverse. At low fluence, strong formation of V_{Bi} and $V_{Bi}+P_o$ continued to be observed, while at high fluence ($\sim 10^{15}$ ions/cm²), a new complex defect V_v+P_o , in which vanadium vacancy combined with P_o , was formed. This type of complex defect was identified for the first time and may play an important role in modulating the optical absorption spectrum.

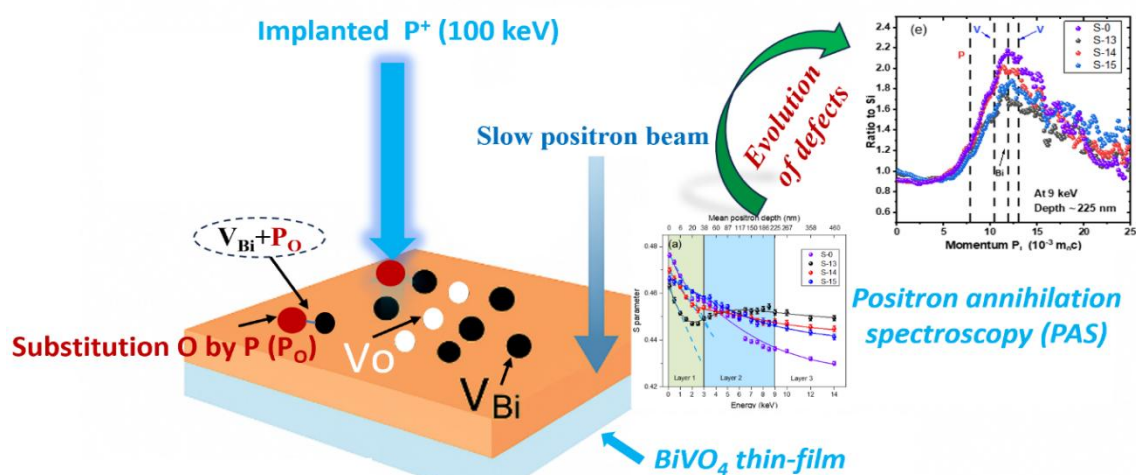


Figure 1. Illustration of the structural defect evolution that potentially enhances the photocatalytic activity of $BiVO_4$ thin films under P^+ ion irradiation.

The combined analysis using PAS, PL, and UV–Vis together with DFT simulations confirmed that defects such as V_o , V_{Bi} , and $V_{Bi}+P_o$ induced by P^+ ion irradiation can positively

modulate the electronic structure and optical properties of BiVO₄ thin films. These defects contribute to the narrowing of the band gap, enhancing visible-light absorption, and supporting charge separation and transport - key factors for improving photocatalytic efficiency.

The ability to control defect structures through low-energy ion irradiation combined with slow-positron analysis offers a novel approach for the design of semiconductor thin-film materials. These results provide unprecedented insights into the defect formation mechanisms in BiVO₄ and open up promising applications for heterostructured materials in water splitting, organic pollutant degradation, and dye-sensitized solar cells.

This research findings were published in the article titled "Evolution of point and complex defects in 100 keV P⁺ implanted BiVO₄ thin-film explored by experimental and simulated positron annihilations using slow-positron beam" in *ACS Applied Materials & Interfaces* (Q1 journal, Impact Factor 9.2). This work serves as a valuable reference work for the scientific community focused on photocatalytic materials and ion-beam modification techniques.

2.9. RADIOCHEMISTRY AND MATERIALS SCIENCE

STUDY ON HEAP LEACHING TECHNOLOGY PROCESS TO OBTAIN RARE EARTHS FROM ION-ADSORBED CLAY-KAOLINITE MINERALS

Nguyen Van Tung, Nguyen Thi Lien, Luu Xuan Dinh, Ngo Quang Huy, Nguyen Trong Hung, Bui Ba Duy, Le Quang Vu, Nguyen Thi Men

Institute for Technology of Radioactive and Rare Elements, 48 Lang Ha, Dong Da, Hanoi

Project information:

- **Project name:** Study on heap leaching technology process to obtain rare earths from ion-adsorbed clay-kaolinite minerals

- **Code:** ĐTCB.07/23/VCNXH

- **Managerial Level:** Ministry

- **Implementation time:** 24 months (January 2023 – December 2024)

- **Contact email:** tungnv.88@gmail.com

- **Published papers related to the project:**

1. Nguyen Van Tung, Bui Ba Duy, Cao Duy Minh, Nguyen Thi Lien, Luu Xuan Dinh, "Study on column leaching process of rare earths from ion adsorption clays by ammonium sulfate", Proceedings of the 15th Vietnam Conference on Nuclear Science and Technology (VINANST-15), Nha Trang, Vietnam, 2023.

2. Nguyen Van Tung, Bui Ba Duy, Cao Duy Minh, Nguyen Thi Lien, Luu Xuan Dinh, "Study on column leaching process of rare earths from ion adsorption clays by ammonium sulfate", Nucl. Sci. and Tech., Vol.14, No. 1 (2024), pp. 51-59.

3. Nguyen Van Tung, Cao Duy Minh, Bui Ba Duy, Nguyen Thi Lien, Ngo Quang Huy, Nguyen Thi Men, Luu Xuan Dinh, "Research on rare earth recovery from ion-adsorbed rare earth ores using different solvating agents", Journal of Analytical Chemistry, Physics and Biology - Vol. 30, No. 2A/2024 (in Vietnamese).

4. Bui Thi Thuy Uyen, Nguyen Thi Thu Ha, Nguyen Thi Lien, Nguyen Van Tung, "Research on rare earth precipitation and wastewater treatment of ion adsorption rare earth ore separation process", The 8th Conference on Nuclear Science and Technology for Young Researchers, Hanoi, Vietnam, 2024.

This study presents the results of heap leaching process to collect rare earths from ion-adsorbed clay-kaolinite minerals. The ion-adsorbed clay-kaolinite minerals, also known as ion-adsorbed rare earth ore, is a type of heavy rare earth elements enrichment ore with high economic value. In these deposits, rare earth elements exist in the form of ions adsorbed on the surface of kaolinite clay mineral particles. This type of ore is mainly distributed at latitudes of 26-28 degrees south, with exploration and mining activities conducted in countries such as China, Brazil, and Laos, etc. For these ores, the ion exchange method is the only viable approach for extracting and recovering rare earth elements. Currently, there are 02 main technologies to exploit this type of ore: heap leaching and in-situ leaching. Among these, heap leaching technology has higher recovery efficiency, better environmental control and the ability

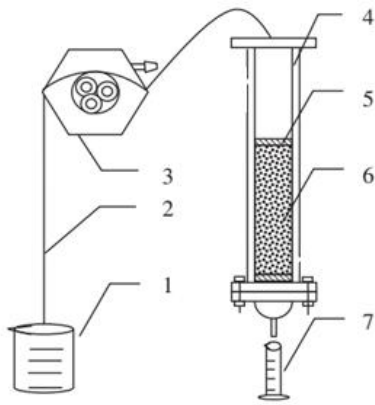
to process low-grade ores. Therefore, in this study, the heap leaching method was chosen as the research method.

In this study, ion-adsorped rare earth ore from Hua Phan area, Lao People's Democratic Republic was used as the research object. The composition of rare earth elements is shown in Table 1. The average total rare earth element content was 426.90 ppm, with heavy elements such as Dy, Tb accounting for 4.43% and 0.73% respectively, both of which have high economic value.

Table 1. Content and composition of rare earth elements in the initial ion-adsorbed rare earth ore

Element	Content (ppm)	composition (%)
Sc	6.09	1.43
Y	101.55	23.79
La	64.71	15.16
Ce	81.88	19.18
Pr	17.69	4.14
Nd	63.73	14.93
Sm	15.08	3.53
EU	2.05	0.48
GD	18.87	4.42
Tb	3.11	0.73
Dy	18.91	4.43
Cough	3.94	0.92
Er	12.53	2.94
Tm	1.94	0.46
Yb	12.94	3.03
Lu	1.89	0.44
TREEs	426.90	100.00

With the aim of obtaining technological parameters for the heap leaching process, a leaching column system was used to study and determine the technological parameters for the leaching process (Figure 1). The optimal technological parameters will be applied to the leaching process at a scale of 5000 kg/batch (performed at Phung facility - Institute for Technology of Radiocactive and Rare Elements) and the further adjusted to achieve the optimal recovery efficiency of rare earths.



(a) Experimental leaching column model
 1: Ammonium sulfate solution, 2: Pump line, 3: Metering pump, 4: Sample column, 5: Lining fabric, 6: Ore sample, 7: Solution collection tank



(b) Practical leaching column system

Figure 1. Experimental leaching column system.

The technological process diagram of heap leaching is illustrated in Figure 2, including the following specific technological steps and parameters:

- ✓ Heaping: Raw ore was crushed to a particle size of -5.0 cm and piled on a multi-layer bedding layer (the bedding layer serves to collect the leachate from the heap).
- ✓ Leaching: A leaching solution of $0.25\text{M } (\text{NH}_4)_2\text{SO}_4$ was pumped at a flow rate of 10 L/h onto the heap via a drip irrigation system. The leach solution-to-ore mass ratio was $0.8/1$ (mL/g). The leachate was collected.
- ✓ Washing: Wash water was pumped at a flow rate of 10 L/hr onto the surface heap through a drip irrigation system. The ratio of washing water volume/ore mass was $0.6/1$ (ml/g). The washing solution was collected into the lechate. The residual ore is backfilled into the mining area.
- ✓ Purification: A $0.25\text{M } \text{NH}_4\text{HCO}_3$ solution was added into the lechate (collected from the leching and ore washing process) to precipitate impurities at $\text{pH} = 5.0$. The rare earth solution was filtered and recovered, while the residues containing heavy metal elements were disposed of according to regulations.
- ✓ Precipitation: A $0.25\text{M } (\text{NH}_4)_2\text{CO}_3$ solution was added into rare earth solution to precipitate rare earth at $\text{pH} = 9$. The precipitate was filtered and collected, while the filtrate was retained for reuse.
- ✓ Recirculation of the filtrate for the next separation process: The pH of the filtrate after rare earth precipitation was adjusted to $\text{pH } 4.5$ by using $10\% \text{H}_2\text{SO}_4$ and $(\text{NH}_4)_2\text{SO}_4$ was added if necessary to form an initial $(\text{NH}_4)_2\text{SO}_4$ 0.5M leaching solution for the next separation process.
- ✓ Wastewater treatment: If the filtrate after rare earth precipitation is not reused, NH_4 recovery is performed using the M.A.P precipitation method with $1\text{M } \text{MgSO}_4$ and $1\text{M } \text{Na}_3\text{PO}_4$ at $\text{pH } 9.0$. The filtered wastewater is then collected and treated at a centralized wastewater treatment facility in compliance with environmental regulations before discharge.

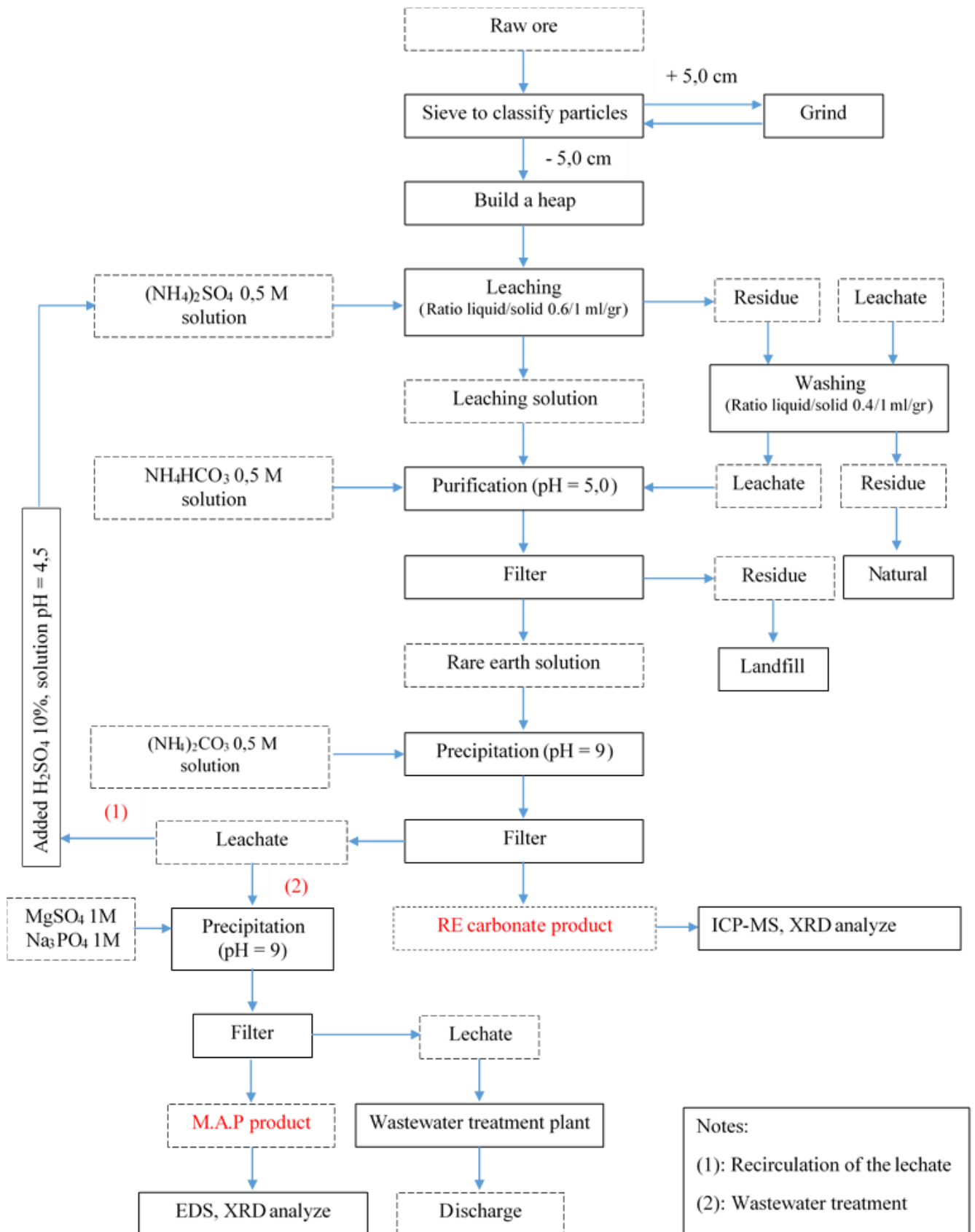


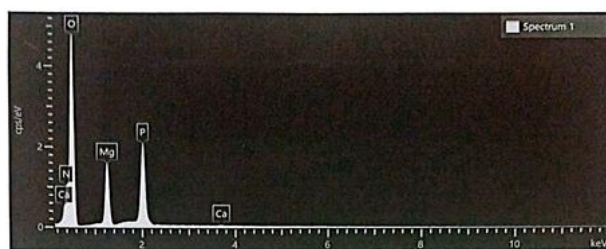
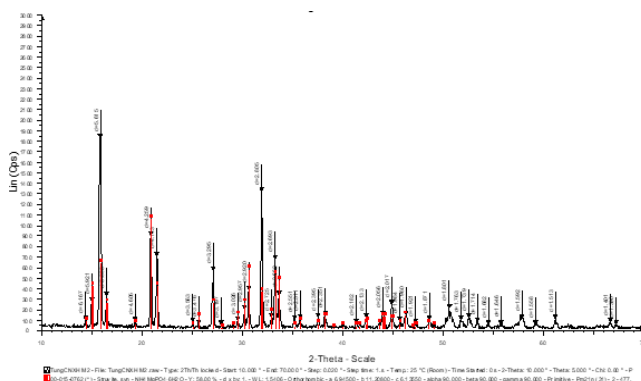
Figure 2. Flowchart of the technological process of heap leaching to recover rare earth from ion adsorption rare earth ore.

With the above technological parameters, the rare earth recovery efficiency reached 91.25% for trivalent rare earth elements. The obtained products include total rare earth carbonate and M.A.P precipitate. The total rare earth carbonate product was analyzed to

evaluate the purity and phase composition. The result was shown in Table 2. The results showed that the total rare earth carbonate product had a purity of over 94% (equivalent to the composition of rare earth elements reaching 57.74% in metallic form). The main impurities are Al, Mn, Fe. The M.A.P product was analyzed to determine the phase composition and element contents. The results are shown in Figure 3. The findings showed that the formation of M.A.P was crystalline phase and the main components were the elements of Mg, N, P and a small amount of Ca.

Table 2. Chemical composition of total rare earth carbonates.

Element	Composition by metal (%)	Composition by carbonate (%)
Y	16.51	31.55
La	12.09	18.92
Ce	5.62	8.77
Pr	2.67	4.16
Nd	9.06	13.99
Sm	2.23	3.39
EU	0.19	0.29
GD	2.49	3.72
Tb	0.45	0.67
Dy	2.68	3.95
Cough	0.54	0.79
Er	1.55	2.27
Tm	0.21	0.31
Yb	1.27	1.83
Lu	0.18	0.26
TREES	57.74	94.86
Al	0.65	2.68
Mn	0.78	0.12
Fe	0.05	0.57



Spectrum 1				
Element	Line Type	Weight %	Weight % Sigma	Atomic %
O	K series	65.48	0.44	71.21
Mg	K series	10.08	0.12	7.21
P	K series	12.74	0.14	7.15
Ca	K series	0.15	0.05	0.06
N	K series	11.56	0.54	14.36
Total		100.00		100.00

(a) XRD results

(b) EDS Results

Figure 3. XRD and EDS results of M.A.P products.

STUDY ON ENHANCING THE EFFICIENCY OF MONAZITE CONCENTRATE DECOMPOSITION BY ULTRASOUND-ASSISTED ALKALINE LEACHING TECHNOLOGY

Hoang Xuan Thi, Hoang Nhuan, Tran The Dinh, Tran Ngoc Ha, Hoang Van Duc, Ngo Van Tuyen, Luu Xuan Dinh, Le Hong Minh, Nguyen Thi Men, Hoang Thi Tuyen, Vuong Huu Anh, Nguyen Thanh Chung, Nguyen Van Tung, Vu Thi Phuoc

Institute for Technology of Radioactive and Rare Elements (ITRREs), No. 48, Lang Ha, Dong Da, Hanoi, Vietnam

Project information:

- **Project name:** Study on enhancing the efficiency of monazite concentrate decomposition by ultrasound-assisted alkaline leaching technology

- **Code:** CS/17/01-01

- **Managerial Level:** Ministry

- **Duration:** 24 months (Jan 2022 - Dec 2023) (extended by 9 months to Sep 2024)

- **Contact email:** hoangthi.hus@gmail.com

- **Published papers related to the project:**

1. Hoang Xuan Thi, Nguyen Thi Men, Hoang Thi Tuyen, Tran The Dinh, Ngo Van Tuyen, Hoang Nhuan "Ultrasound Chemical Devices Used in Laboratories, Pilot Production (Near-Industrial), and Industrial Applications," Poster Presentation at the 7th Nuclear Science and Technology Conference for Young Professionals in Nuclear Energy, 2022 (in Vietnamese);

2. Hoang Xuan Thi, Nguyen Thi Men, Hoang Thi Tuyen, Tran The Dinh, Ngo Van Tuyen, Hoang Nhuan "Analysis and Evaluation of the Effectiveness of Ultrasound Devices Supporting Chemical Technology Processes," Oral Presentation at the 7th Nuclear Science and Technology Conference for Young Professionals in Nuclear Energy, 2022 (in Vietnamese);

3. Hoang Xuan Thi, Hoang Nhuan, Nguyen Thi Men, Hoang Thi Tuyen, Nguyen Huu Duc, Ngo Van Tuyen "Research on the Impact of High-Intensity Ultrasound on the Efficiency of NaOH Alkaline Leaching of Monazite Concentrate," Oral Presentation at the 15th National Conference on Nuclear Science and Technology (VINAST15), 2023 (in Vietnamese);

4. Hoang Xuan Thi, Hoang Nhuan, Nguyen Thi Men, Hoang Thi Tuyen, Hoang Van Duc, Ngo Van Tuyen "Study on the Effect of High-Intensity Ultrasound on the Efficiency of NaOH Alkaline Leaching of Monazite Concentrate," *Journal of Chemistry and Applications*, 1(67)/12-2023 (in Vietnamese);

5. T. Hoang Xuan, N. Hoang, T. Ngo Van, A. Vuong Huu, and d. Nguyen Huu, "Advances in Monazite Decomposition Technologies: Proposed Potential Direction for the Sodium Hydroxide Leaching Context," *Recent Innovations in Chemical Engineering*, vol. 17, no. 4, pp. 256-280, 2024;

6. Hoang X.T., Hoang N., Nguyen T.M., Hoang T.T., Ngo V.T., Hoang V.D., Tran N.H., Vuong H.A., Nguyen H.D., Le H.S., Karelin V.A. "Application of ultrasound for leaching of Vietnamese monazite concentrate with NaOH solutions to obtain chlorides of rare earth

The global demand for rare earth elements is increasingly rising. However, in recent years, the Chinese government has implemented a policy to sharply reduce rare earth exports, driving up rare earth prices and creating supply shortages. Domestic market demand is also significant, with a target of producing 200 tons of total rare earths annually by Hung Thinh company. On the other hand, despite the considerable monazite deposits within Vietnam, monazite processing technologies remain limited. The largest and most complete production line has been a pilot-scale facility transferred from India to Vietnam in 1991. However, this technology has several limitations, including the need for a large excess of alkali (2→3:1) and extended durations (8-10 hours) under conventional hydrometallurgical conditions to achieve high leaching efficiency. These factors hinder large-scale production and consume substantial resources, fuel, and energy. Additionally, this technology requires fine grinding of monazite concentrate, which introduces issues of radioactive pollution, as monazite is a highly radioactive mineral.

To address these limitations, we initiated the project entitled **“Study on enhancing the efficiency of monazite concentrate decomposition by ultrasound-assisted alkaline leaching technology”**. The study had two main objectives: to assess the impact and influence of ultrasound on the decomposition of monazite concentrate, and to enhance the ore decomposition efficiency for recovery of total rare earth oxides using alkali and ultrasound-assisted chemical technology. Additionally, the study aims to train researchers in the use of this new ultrasound-assisted chemical technology.

The newly main equipment used in this study included: high-power ultrasound equipment FS-1800N 1.8kW (Figure 6); vacuum pump HBS 2XZ-6 0.75kW (Figure 7); ultrasound-assisted leaching vessel with a reaction volume of 5.5L, ultrasound power of 1.8kW, heating capacity of 3kW, and stirring capacity of 0.1kW (Figure 8); pH meter S220-K (Figure); Nabertherm furnace L 9/12 3kW (Figure 9); and other instrument, such as a planetary grinder, electric stove, etc.



Figure 6. High-Power Ultrasound Device FS-1800N



Figure 4. pH Meter S220 – K



Figure 7. Two-Stage Vacuum Pump HBS 2XZ – 6



Figure 9. Furnace

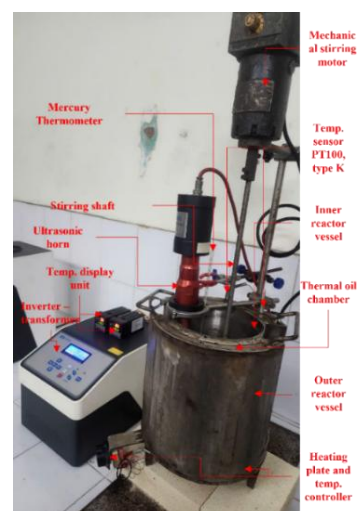


Figure 8. Ultrasound-Assisted Digestion Vessel (1 kg/batch)

The analytical methods used for solid samples included: gravimetric analysis, morphology (optical microscopy, transmission electron microscopy - SEM), crystal phase (X-ray diffraction - XRD), elemental composition (inductively coupled plasma optical emission spectroscopy ICP-OES, scanning electron microscopy combined with energy-dispersive spectroscopy SEM-EDS), and mineral composition (heavy mineral separation). For liquid solution samples, the analytical methods used include pH analysis, elemental composition (ICP-OES), radioactive activity by gamma spectrometer, and total α , β measurements.

Before conducting the experiments, the mineral content of input concentrate sample was analyzed by heavy mineral separation, and composition by ICP-OES. The results showed that the concentrate contained approximately 89.5% monazite, 7.33% zircon, and other accessory minerals such as xenotime and ilmenite; TREOs composition was approximately 50%, U and Th content was 0.35% and 4.76%, respectively. Monazite concentrate was then ground using a planetary grinder at 1200 rpm, with an optimal ore:balls:water mass ratio of 0.4:1:0.4/3, and a grinding time of 10 minutes. This yielded approximately 2 kg of particles in various sizes.

The overall experimental flow diagram is shown in **Figure 10**. The leaching of input concentrate was conducted on a scale of 50g/batch for different particle sizes: <45, 45-54, 54-63, 63-75, and >75 μm (unmilled concentrate). Other leaching conditions were studied including NaOH:concentrate mass ratios of 0.8, 1.0, 1.2, 1.4, 1.5, 2, NaOH mass concentration levels of 30, 40, 45, 50, 60, 70%, temperature ranges of 70, 100, 120, 130, 140, 150, 160, 170°C, leaching durations of 0.25, 0.5, 1, 2, 3, 4 hours, and ultrasound power levels of 0, 180, 360, 540, 720, 1080, 1440W. After leaching, the mixture was diluted with a volume of 1L distilled water, leaching 3 to 4 times over 30-60min. at 70-80°C to remove phosphates and excess alkali, and then fully dissolved in concentrated hydrochloric acid (HCl) at 90°C for 1.5 hours. The remaining insoluble residue (B) after dissolution was analyzed by XRD to determine the mineral composition and mass in order to calculate the concentrate leaching and monazite decomposition efficiency to the following formula:

$$\text{Concentrate leaching efficiency} = \left(1 - \frac{\text{Mass of residue B}}{\text{Mass of initial concentrate}}\right) \times 100\% \quad (1)$$

$$\text{Monazite decomposition efficiency} = \frac{\text{Concentrate leaching efficiency}}{\text{Monazite content the initial concentrate}} \times 100\% \quad (2)$$

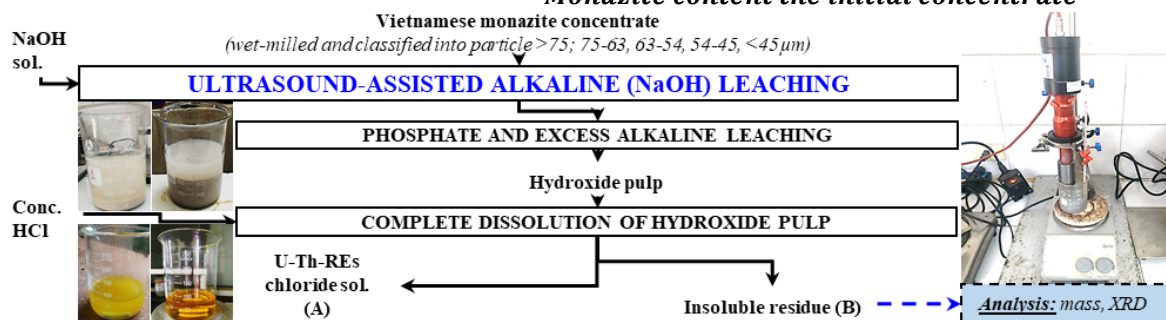


Figure 10. Experimental diagram and analysis of the ultrasound-assisted alkaline (NaOH) leaching process, with a scale of 50g/batch

The results of the influence of leaching conditions on monazite decomposition efficiency are shown in **Figure 11**.

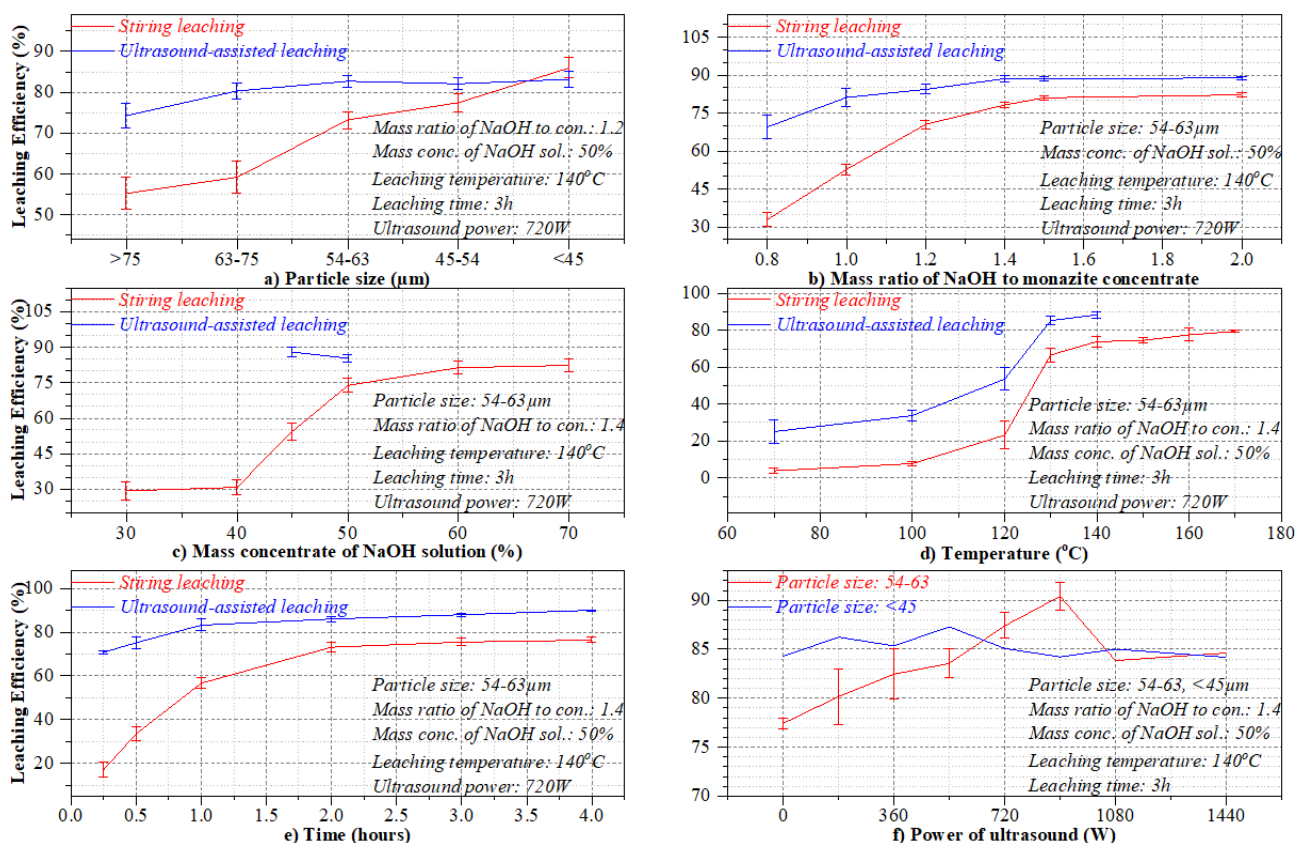


Figure 11. The influence of leaching conditions on monazite decomposition efficiency

From these results, optimal leaching conditions on a scale of 50g/batch were determined for two cases: conventional stirring and ultrasound-assisted, as indicated in **Table 4**. After determining the optimal ultrasound-assisted leaching conditions at a scale of 50g/batch, the leaching process was scaled up to 1kg/batch. The ultrasound-assisted leaching device (**Figure 12**) was designed and constructed with the following detailed components: 1) Inverter – transformer; 2) Support frame; 3) FS-1800N ultrasound transducer (1.8kW); 4) Mechanical stirring motor (0.1kW); 5) Mercury thermometer (200°C); 6) Resistance temperature detector (RTD) PT100, thermocouple K-type; 7) Outer casing of the reaction vessel; 8) Oil reservoir (4.5L); 9) Inner casing of the reaction vessel (5.5L); 10) Stirring shaft; 11) Stirring blade; 12) Electric heating (3kW heating plate); 13) Temperature display (REX-100).

Table 4: Optimal leaching conditions for a scale of 50g/batch for stirring and ultrasound assistance

Condition Leach. type	Stirring	US-assisted
Part. size (μm)	≤ 45	54-63
NaOH/ Conc. Mass Ratio	1.5-2	1.4
NaOH Conc. (%)	50	50
Temp. ($^{\circ}\text{C}$)	170	140
Time (h)	4-Mar	2
US Power (W)	0	720
Leach. Eff. (%)	~84	~89
Mnz. Decomp. Eff. (%)	~94	~99

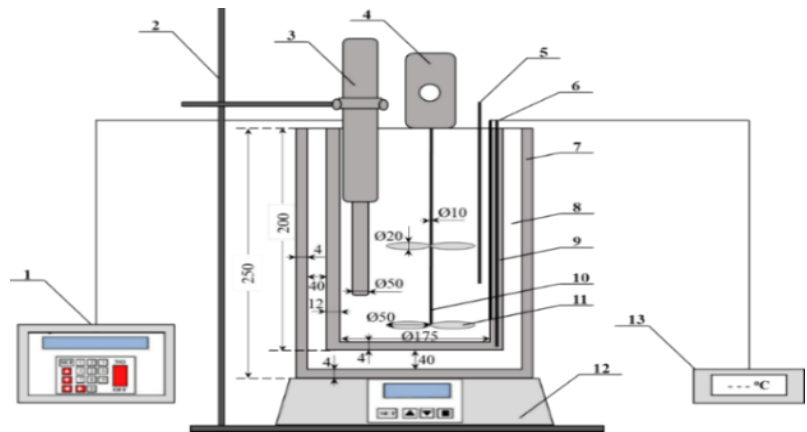


Figure 12. Overall design details of the ultrasound-assisted leaching device (1kg/batch)

Leaching at a scale of 1kg/batch was conducted on a newly constructed device for finely ground concentrate at 54-63 μm and unground concentrate $>75\mu\text{m}$. The results (Table 5) indicated that by increasing the ultrasound-assisted leaching time from 2 to 3.5 hours and increasing the ultrasound pulsing time to ON 5min, OFF 5min, the ultrasound-assisted leaching efficiency increased to 80.91%. When the monazite content in the original concentrate was 89.5%, the monazite decomposition efficiency reached ~90%.

Table 5. Optimization of leaching conditions for particle sizes of 54-63 and $>75 \mu\text{m}$ at a scale of 1 kg/batch

Scale (kg/b)	Part. size (μm)	NaOH / Conc. Mass Ratio	NaOH Conc. (%)	Temp. ($^{\circ}\text{C}$)	Time (h)	Stir. Leach. Eff. (%)	US-assisted Leach. Eff. (%)	US-assisted Monaz. Decomp. Eff. (%)	Note
0.1	54-63	1.4:1	50	140	2	76.84	88.71	99.12	
1	54-	1.4:1	50	140	2	53.91	75.23	84.06	

	63								
0.1	>75	1.4:1	50	140	2	50.74	63.96	71.46	
1	>75	1.4:1	50	140	2	27.93	55.86	62.41	
1	54-63	1.4:1	50	140	2	71.48	87.39	97.64	Redesign the stirring blade and relocate the stir. position; increase the stir. speed from 60 to 120 rpm; add steel balls (stirring assistance); increase the US power from 720 to 900W
1	>75	1.4:1	50	140	2	48.82	67.75	75.70	
1	>75	1.4:1	50	140	3.5	52.72	80.91	90.40	US pulse time to 5 minutes ON – 5 minutes OFF (US power of 900W)

The insoluble residue B was analyzed for its crystal phase composition by using the X-ray diffraction (XRD) method. **Figure 13** presented the X-ray diffraction (XRD) spectrum of residue B, where the sharp, high-intensity peaks were completely separated from the background and match the XRD spectrum of the standard zircon sample $ZrSiO_4$. This result indicated that zircon constituted a significant portion of the insoluble residue B.

The insoluble residue (B) obtained was analyzed by using ICP-OES to evaluate the conversion levels of rare earths, uranium, and thorium according to the following formula:

$$\text{Conversion efficiency of TREEs, U, Th} = \left(1 - \frac{\% \text{ TREEs, U, Th in residue B} \times \text{mass of residue B}}{\% \text{ TREEs, U, Th in initial concentrate} \times \text{mass of initial concentrate}} \right) \times 100\% \quad (3)$$

The results in **Figure 14** showed that the overall conversion efficiency of rare earths, uranium, and thorium under optimal ultrasound-assisted leaching conditions at a scale of 1 kg/batch for unground concentrate (>75 μm) achieved averages of 90.41%, 88.28%, and 91.93%, respectively.

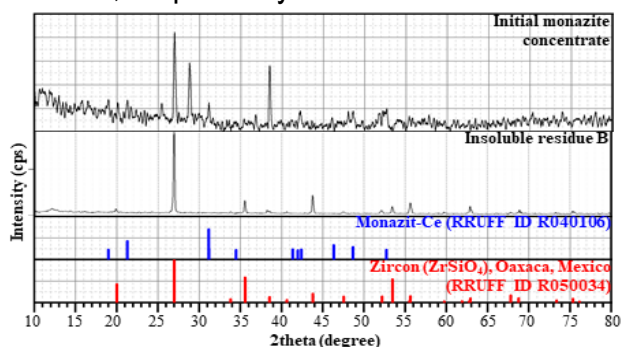


Figure 13. X-ray diffraction (XRD) spectrum of the insoluble residue B

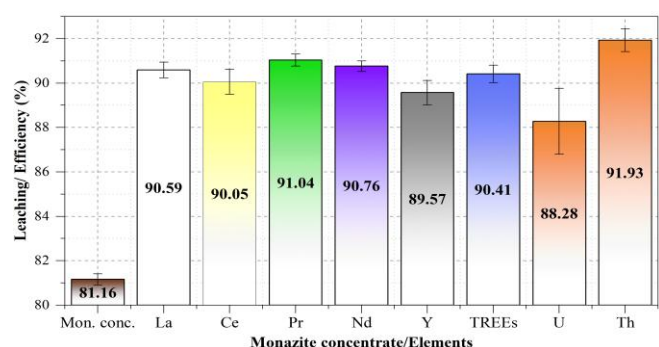


Figure 14. Monazite decomposition efficiency and rare earth, U, Th conversion at a scale of 1kg/batch

These results were compared with some other studies presented in **Table 6**. The comparison indicated several advantages of ultrasound-assisted technology, such as reducing alkali ratio, time, and temperature compared to open alkaline leaching and pressure alkaline leaching. Notably, this technology directly used unground concentrate, providing significant economic benefits by eliminating the grinding step and reducing the risk of radioactive emissions from the grinding process.

Table 6. Comparison of the technological parameters of traditional leaching of monazite (similar to xenotime) in previous studies with alkaline leaching assisted by ultrasound

Research Parameters	Alkaline leach. (India pilot)	Alkaline leach. under pressure	US-assisted leach. (this study)	
Year	1991	2001 – 2002	2022 - present	
Subject	Vietnamese monazite	Vietnamese xenotime	Vietnamese monazite	
Part. size (mesh)	+270 mesh ~54 μ m		54-63 μ m (preliminary grinding)	+200 \rightarrow -100 (>75 μ m uncr. conc.)
NaOH/ Conc. Mass Ratio	2 \rightarrow 3:1	2:1	1.4:1	
NaOH Conc. (%)	50-70	12.5M (~36%)	50	
Temp. (°C)	135-140	200 (10.5atm), 240 (20atm)	140	
Time (h)	8-10	4	2	3.5
Mixing method	Mech. Stir. + high-pressure steam (7atm)	Mech. Stir. + iron balls	Mech. Stir. + high-power US (900W, 20kHz, pulse ON 5s – OFF 5s)	Mech. Stir. + high-power US (900W, 20kHz, pulse ON 5min. – OFF 5min.)
Efficiency (%)	93 (8h)	90 (10.5atm), 94.7 (20atm)	~87 (conc.), ~98 (monazite);	81 (conc.), ~90 (monazite); 90.41 (TREES), 88.28 (U), 91.93 (Th)
Scale	250kg/batch (Pilot)	5kg/batch (pre-pilot)	1kg/batch (Lab)	

Ultrasound-assisted leaching for three batches of unground concentrate (>75 μ m) was conducted to recover rare earth chloride solutions as raw materials for the subsequent recovery of total rare earth oxide (TREO). The REsCl₃ solution obtained was purified to remove U and Th to concentrations below 1 ppm by adjusting the final pH of the rare earth chloride solution to 5.8. (**Figure 15**). Radium and other radioactive contaminants from REsCl₃ solution at pH 5.8 completely removed by using 250 mg/L Na₂S, 500 mg/L Na₂SO₄, and 500 mg/L BaCl₂, with a reaction time of 24 hours (**Table 7**). From the solution free from U, Th, Ra, and contaminants, oxalate precipitation and decomposition recovery yielded 1.2 kg of rare earth oxides with TREOs of 99.24%, U at 0.79 ppm, Th at 5.05 ppm, and Pb at 0.5%. The

overall recovery efficiency of total rare earth oxides from the entire ultrasound-assisted leaching process reached 78%.

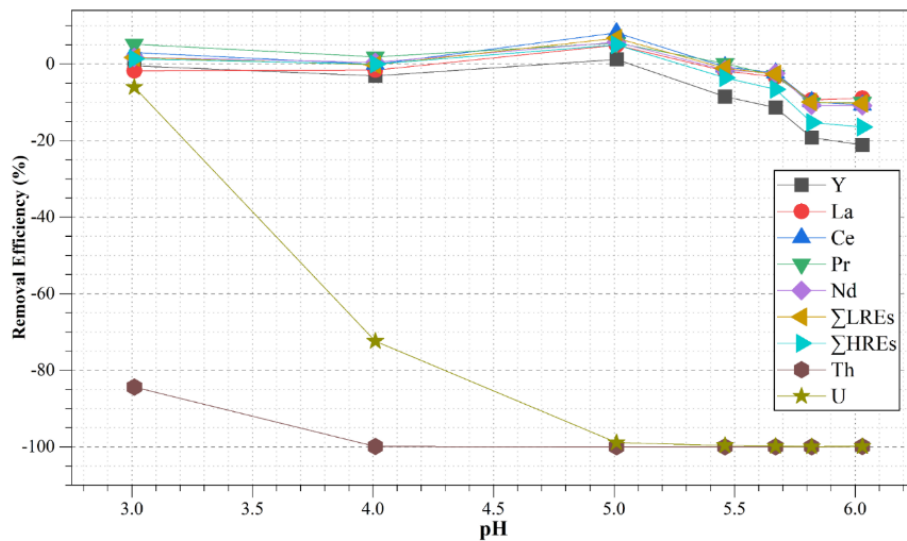


Figure 15. The separation levels of U, Th, and REE losses at different final pH values.

Table 7. Total γ radioactive of nuclides, total α , and total β radioactivity of the rare earth chloride solution before and after separation

Chloride rare earth solution			Affer removal of Ra and impurities								
			Before		Dosage: Na ₂ S (50mg/L), Na ₂ SO ₄ (50mg/L), BaCl ₂ (50mg/L); and reaction time: 30min.			Dosage: Na ₂ S (250mg/L), Na ₂ SO ₄ (500mg/L), BaCl ₂ (500mg/L); and reaction time: 24h.			
Nucleus			Bq/L	μ C i/L	Bq/L	μ C i/L	The var. of radioact. lev. (%)	Bq/L	μ C i/L	nC i/L	The var. of radioact. lev. (%)
Symb	Decay mode	Half-life	Bq/L	μ C i/L	Bq/L	μ C i/L	The var. of radioact. lev. (%)	Bq/L	μ C i/L	nC i/L	The var. of radioact. lev. (%)
Ra-226	α	1601 yr	2267.5	0.06	2279.5	0.06	0.53	6.64	0.00	0.18	99.71
Ac-228	β , α	6.13 h	7755.1	0.21	7688.7	0.21	0.86	86.38	0.00	2.33	98.89
K-40	β -, γ	1.251 BYA	22.74	0.00	10.92	0.00	51.98	5.15	0.00	0.14	77.35
Pb-214	β -	26.9 min	388.46	0.01	242.11	0.01	37.67	6.82	0.00	0.18	98.24
Bi-212	β - (64.05%) α (35.94%)	60.55 min	358.91	0.01	201.34	0.01	43.90	6.25	0.00	0.17	98.26
Pb-212	β -	10.64 h	5144.1	0.14	3854.7	0.10	25.06	5	0.00	0.14	99.90
Tl-	β -	3.053	1532.	0.0	1108.	0.0	27.65	1.35	0.0	0.0	99.91

208		min	6	4	9	3			0	4	
Total γ radioactivity of nuclides			17469	0.4 7	15386	0.4 2	11.92	17.4 7	0.0 0	0.4 7	99.90
Total α radioactivity			6211. 6	0.1 7	7371. 5	0.2 0	18.67	0.62	0.0 0	0.0 2	99.99
Total β radioactivity			12219	0.3 3	12433	0.3 4	1.75	1.22	0.0 0	0.0 3	99.99

In summary, the project evaluated the positive impact of ultrasound on the decomposition of monazite concentrate. Through a study conducted on a scale of 1 kg/batch using a self-fabricated device, the efficiency of the leaching process for obtaining purified radioactive rare earth oxides was improved: the leaching efficiency increased by 15.91% for preliminarily ground concentrate at 54-63 μm , reaching 87.39%, and the leaching efficiency increased by 28.19% for unground concentrate larger than 75 μm , reaching 80.91%. Considering that the monazite content in the initial concentrate was 89.5%, the monazite decomposition efficiency in the two cases was 97.64% and 90.40%, respectively. Further studies should be carried out at a larger scale (20-50 kg per batch) in the following proposed directions: 1) Changing from direct to indirect ultrasound to reduce damage to the ultrasound transducer, and 2) Using multiple high-power ultrasound transducers and optimize the design to ensure the ultrasound field evenly distributed in a larger volume.

STUDY ON THE PROCESSING TECHNOLOGY OF BINH THUAN MONAZITE CONCENTRATE BY PRESSURE ALKALI METHOD TO OBTAIN RARE EARTH CHLORIDES

Luu Xuan Dinh, Nguyen Dinh Viet, Bui Cong Trinh, Tran Hoang Mai, Nguyen Thanh Thuy, Nguyen Trong Hung, Le Ba Thuan, Le Thi Giang, Le Quang Vu, Ngo Quang Huy

Institute for Technology of Radioactive and Rare Elements, 48 Lang Ha, Dong Da, Hanoi

Project information:

- **Project name:** Study on the processing technology of Binh Thuan monazite concentrate by Pressure Alkali method to obtain rare earth chlorides

- **Code:** ĐTCB.15/23/VCNXH

- **Managerial Level:** Ministry

- **Implementation time:** 24 months (May 2023 - April 2025)

- **Contact email:** lx dinh79@gmail.com

- **Published papers related to the project:**

1. Luu Xuan Dinh, Nguyen Dinh Viet, Bui Cong Trinh, Le Hai Son, Research on the selective leaching process to remove thorium and uranium radioactive elements from rare earth chloride solution obtained from the decomposition of monazite concentrate by pressure alkali method, Chemistry and Application, 3(75)/06-2025 (in Vietnamese).

2. Bui Cong Trinh, Nguyen Dinh Viet, Le Hai Son, Le Thi Giang, Tran Hoang Mai, Nguyen Van Tien, Luu Xuan Dinh, Study on the technology for decomposition of Binh Thuan monazite concentrate by NaOH under high pressure, Chemistry and Application, 3(76)/06-2025. (in English)

3. H.S. Le, X.D. Luu, D.V. Nguyen, C.T. Trinh, V.A. Karelin, A.A. Smorokov, The decomposition possibility of Vietnamese monazite concentrate by the pressure alkali method, Bulletin of the Tomsk Polytechnic University, Geo Assets Engineering, T.336, No 3 (March), 2025 (in English).

4. Le Thi Giang, Le Hai Son, Nguyen Dinh Viet, Tran Hoang Mai, Luu Xuan Dinh, Nguyen Van Tien, Bui Cong Trinh, Research on the recovery of Na_3PO_4 from the alkaline decomposition of Binh Thuan monazite using NaOH, Научный журнал (Scientific Journal), № 11(375), V4, pp 20-25. 2025 (in English).

This report presents the research results on the technology for processing monazite concentrate using the pressure alkali method to obtain rare earth chlorides. The report also outlines the process and specific technological parameters for processing monazite concentrate by this method. These fundamental studies were conducted at the laboratory scale. Based on these results, an alkaline pressure decomposition apparatus with a capacity of 20kg/batch of monazite was designed, and the monazite processing technology was subsequently investigated using this equipment. The obtained products are rare earth chlorides ($\text{RECl}_3 \cdot 7\text{H}_2\text{O}$) and some by-products. The developed technological process demonstrates potential for large-scale implementation and offers an effective solution for monazite concentrate processing.

In terms of **analytical methods**, ICP-OES and ICP-MS were used to determine the elemental composition of the monazite concentrate, the hydroxide product after decomposition, the leach liquor, the residue after leaching, and the final product. XRD analysis was employed to identify the phase composition of the monazite concentrate and the hydroxide product. Laser diffraction was used to analyze the particle size distribution of the concentrate. The gamma dose rate method was applied to measure the gamma dose rate of the final product.



Figure 1. Laboratory-scale pressure apparatus



Figure 2. 20kg/batch pressure apparatus

Regarding **experimental apparatus**, from laboratory-scale investigations, the optimal conditions selected for the decomposition study at a scale larger than 20 kg/batch in a 60 L autoclave to determine decomposition efficiency were: decomposition temperature of 180°C (4 atm), decomposition time of 2 hours (from the moment the temperature was reached), and an alkali/concentrate mass ratio of 1.2/1. After the experiment concluded, the entire post-reaction mixture was transferred to a phosphate washing tank to remove excess NaOH and Na₃PO₄ from the hydroxides. The hydroxides were then dried naturally and in an oven. The obtained mass was determined, and samples were taken for leaching to determine decomposition efficiency. These optimal decomposition conditions were then applied to decompose a larger quantity of 20 kg/batch of monazite concentrate using the apparatus in Figure 2.

The pressure vessel with a capacity of 20 kg of monazite concentrate was designed and manufactured with the following specifications: Shape: Cylindrical vessel, internal working pressure: $P = 0.8 \text{ MPa}$, inner diameter: $D = 400 \text{ mm} \Rightarrow r_i = 200 \text{ mm}$, shell thickness: $t = 30 \text{ mm} \Rightarrow r_o = 220 \text{ mm}$; Material: Stainless steel (Inox 304).

Typical yield strength: $\sigma_y \approx 215 \text{ MPa}$

Safety factor: $SF = 2$

Stress calculation:

Hoop stress according to the cylindrical vessel formula:

$$\sigma_{hoop} = \frac{P \times (r_o^2 + r_i^2)}{(r_o^2 - r_i^2)} = 8,42 \text{ Mpa}$$

Safety check:

Allowable stress:

$$\sigma_{allow} = \frac{\sigma_y}{SF} = \frac{215}{2} = 107,5 \text{ Mpa}$$

The hoop stress $\sigma_{hoop} = 8,42 \text{ Mpa}$, which is less than $\sigma_{allow} = 107,5 \text{ Mpa}$, *an toàn*, ensuring safety.

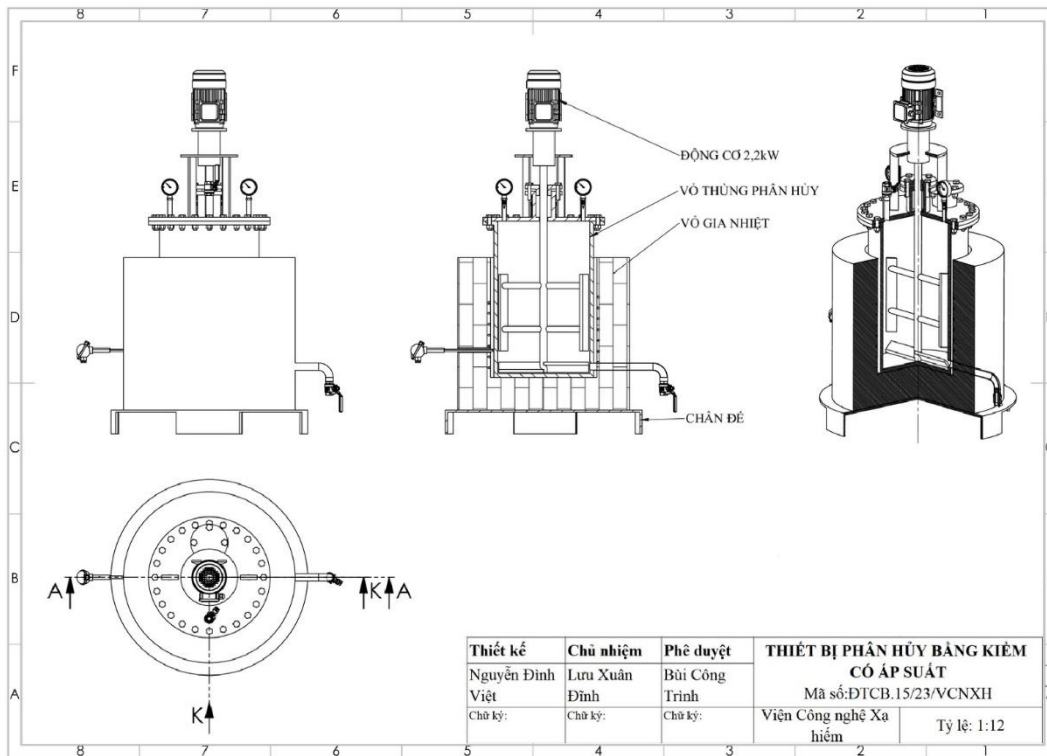


Figure 3. Drawing of the pressure alkali decomposition apparatus.

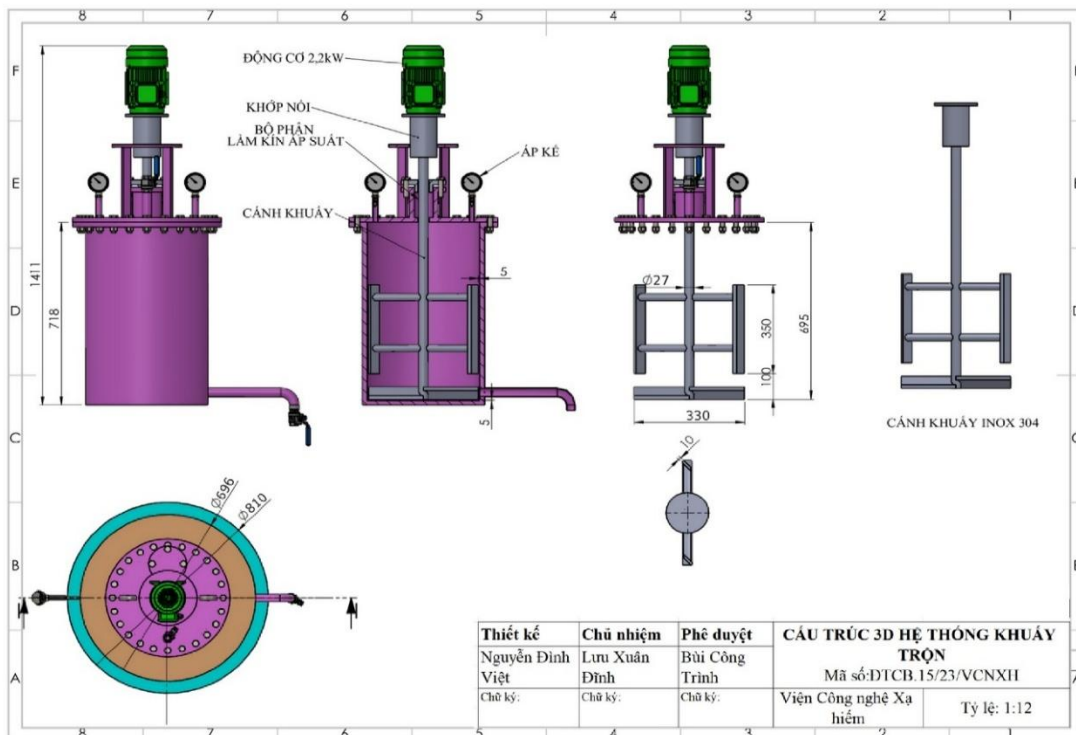


Figure 4. 3D drawing of the pressure alkali decomposition system.

Based on fundamental laboratory-scale research data on the monazite decomposition process (Figure 1), the decomposition process in the larger equipment (Figure 2) was carried out as follows: 20 kg of monazite concentrate with a total rare earth content of 58.8%, supplied by Hung Thinh Company (Binh Thuan), was ground and fed into a 60 L pressure-resistant autoclave for decomposition. This decomposition study was conducted sequentially with different particle size fractions to determine the decomposition efficiency. Initially, 10 kg of RO water was added to the vessel, followed by 24 kg of technical grade NaOH, and the mixture was stirred thoroughly. Then, 20 kg of ground monazite concentrate was gradually added to the reaction vessel. The heating system was activated to reach approximately 180-200°C. After reaching and maintaining the reaction temperature, the heating system was turned off, and the mixture was allowed to cool naturally until the residual pressure dropped to approximately 1-1.5 atm. The bottom valve of the vessel was then opened to transfer the entire reacted mixture to a dilution and washing tank. In this tank, the mixture was stirred, allowed to settle, and the supernatant was siphoned off. This washing step was repeated several times until the residual phosphate content was reduced to less than 1%. The washed mixture was then selectively leached with HCl at pH 4-5 to recover rare earth elements, and radioactive nuclides such as Pb-214, Bi-214, and Ra-226 were subsequently removed using chemical agents such as Na₂S, BaCl₂, and H₂SO₄. The resulting solution was concentrated to obtain the rare earth chloride product. The unreacted residue was retained for further research on the recovery of remaining rare earth elements, Th, and U.

The proposed process for monazite concentrate decomposition by the pressure alkali method is summarized in the flowsheet in Figure 5:

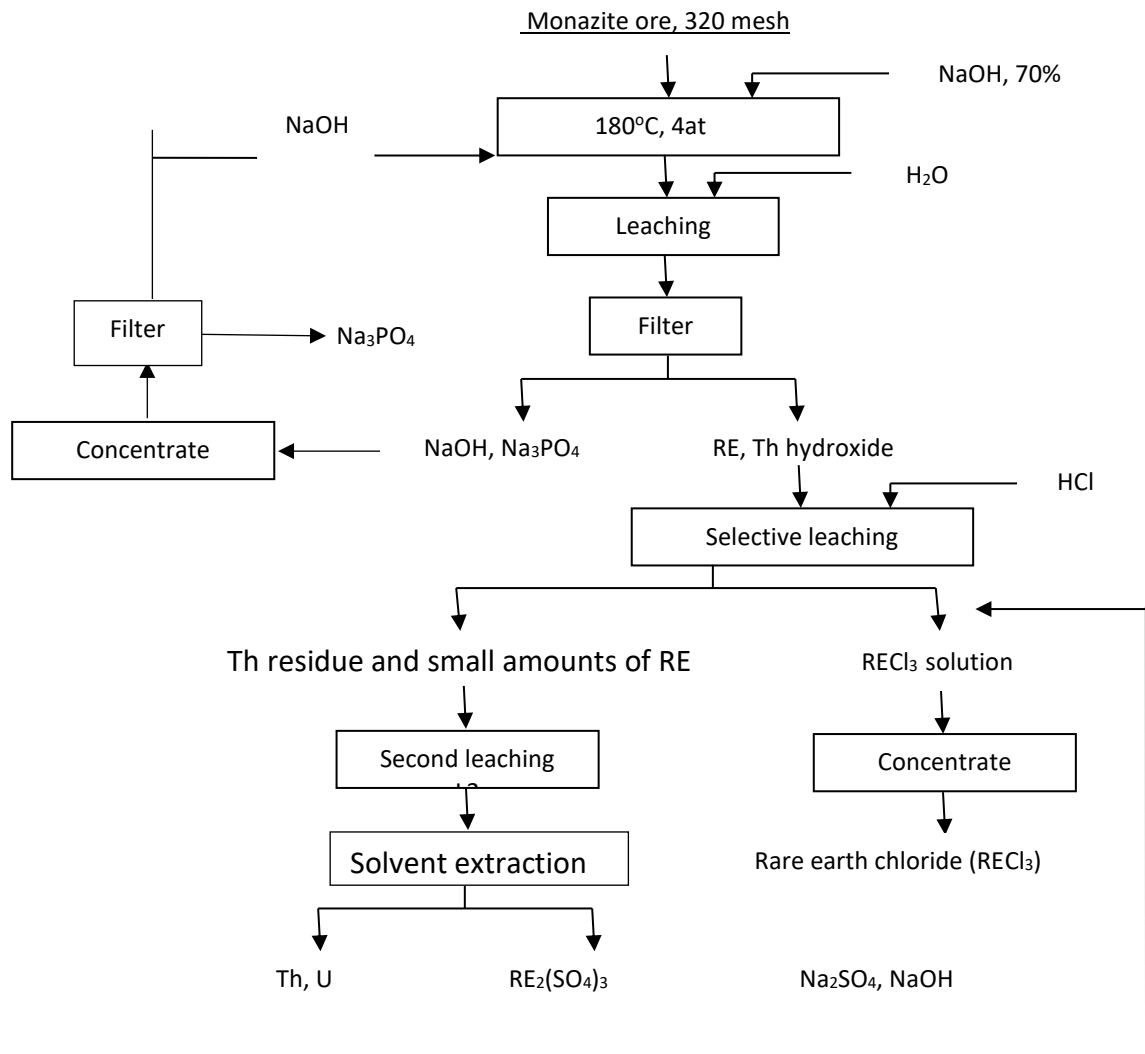


Figure 5. Proposed flowsheet for processing monazite concentrate by pressure alkali method

The residue after HCl leaching is further leached with H_2SO_4 . The resulting solution contains rare earths, thorium, and uranium as sulfates. This solution is then subjected to amine extraction to separate Th and U. The remaining rare earths are converted to hydroxides and combined with the selective leaching feed.

The decomposition efficiency of monazite concentrate according to particle size in the 60L autoclave is shown in Table 1. It can be observed that, in the larger equipment, for the same particle size, the decomposition efficiency of the elements is considerably higher than in the small-scale laboratory equipment. For rare earth elements, the total decomposition efficiency reached ~98% in the large equipment, while this efficiency was >96% for a particle size of $d < 45\mu m$ in the small equipment. Similarly, for a particle size of $d < 63\mu m$, the total rare earth decomposition efficiency was >92% in the large equipment and 88% in the laboratory equipment; for particles $d < 75\mu m$, the decomposition efficiencies in the large and laboratory equipment were >82% and 80%, respectively. For U and Th, there was no

significant difference between the 60L autoclave and the laboratory-scale reactor. This can be explained by the fact that for the small equipment, the agitator blade was small and positioned more than 2cm from the bottom of the reaction vessel, where the ore has a high specific gravity, leading to poor mass transfer. In contrast, for the larger equipment, the agitator was designed to be close to the bottom, possibly enhanced by a mass effect.

Figure 6 shows that the particle size distribution of the 45 μm sample is relatively narrow, from 1 to 40 μm , with a D50 average of 8 μm . However, for the 63 μm sample, the particle size distribution is broader, from 1 to 200 μm , also with a D50 average of 8 μm but with 5% of particles in the 63-200 μm range. For the 75 μm sample, the particle size distribution is wide, from 1 to 260 μm , with a D50 average of 15 μm , and 10% of particles in the 75-260 μm range. Thus, particle size significantly affects the decomposition efficiency of monazite concentrate. For example, for the 63 μm sample with a D50 of 8 μm and 5% of particles in the 63-200 μm range, the efficiency was 92%. If this method is applied industrially, the concentrate needs to be ground and classified to a particle size below 45 μm to ensure decomposition efficiency. Currently, wet ball milling and hydrocyclone classification can achieve particle sizes below 20 μm .

Figures 7 and 8 are the XRD patterns of monazite and hydroxide samples (45 μm) after decomposition. After the decomposition process, a small amount of undecomposed monazite remains, with a characteristic peak at 27° (Figure 7). The rare earth hydroxide product formed shows characteristic peaks at 10.2° and 28°. Since the decomposition efficiency of the 45 μm sample was over 98%, a portion of monazite remained undecomposed.

Table 1. Decomposition efficiency of monazite concentrate in the 60-liter autoclave equipment

Particle size, d, (μm)	Decomposition Efficiency, %						
	Y	La	Ce	Pr	Nd	U	Th
d < 45 μm	98,37	98,53	97,85	97,62	96,91	50,30	80,49
d < 63 μm	90,71	93,53	92,59	92,01	88,18	46,28	77,47
d < 75 μm	82,82	84,23	85,45	86,08	82,82	40,24	67,41

Table 2. Composition of some rare earth elements in the monazite concentrate and product after decomposition

Sample ID	Content (mg/kg)						
	Y	La	Ce	Pr	Nd	U	Th
H45	13068	139789	260293	29960	114966	2048	39912
H63	12050	132697	246309	28239	104609	1884	38415
H75	11002	119506	227326	26418	98251	1639	33426
Concentrate	10960	117050	219470	25320	97870	3360	40910

Mass of concentrate used: 20kg

Mass of solid product after decomposition (H45, H63, H75): 17 kg

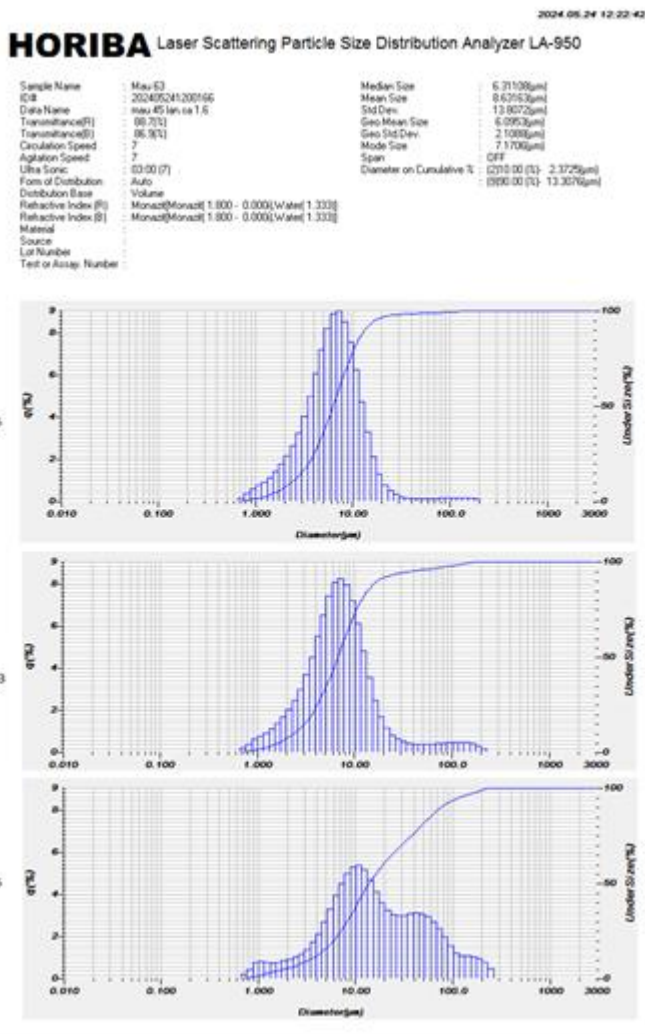


Figure 6. Particle size distribution of 45, 63, and 75µm samples

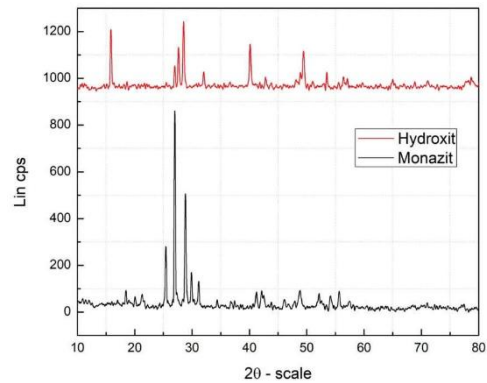


Figure 7. XRD pattern of monazite and hydroxide after decomposition of 45 µm sample

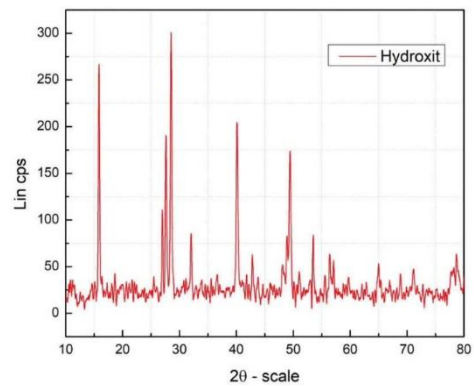


Figure 8. XRD analysis result of hydroxide after decomposition of 45 µm sample

The results of the 20kg/batch monazite decomposition study were compared with previous research conducted at the Institute for Technology of Radioactive and Rare Elements: i) a pilot-scale study in India showed decomposition efficiencies of 80-93% using an open alkali digestion method (reaction conditions: 140°C, 8 hours, mechanical stirring combined with high-pressure steam injection at the bottom of the 7-atm reaction vessel), ii) a ministerial-level project DTCE.09/22/CNXH on monazite decomposition at 1kg/batch scale, under conditions of mechanical stirring and high-power ultrasonication (900W, 20kHz, ON 5s – OFF 5s), achieved efficiencies of 87-98%. Thus, the current results indicate that pressure alkali decomposition can achieve a high efficiency of 98%, with a shorter reaction time (2 hours) and lower alkali consumption compared to previous studies, demonstrating better efficiency in terms of implementation and economics.

Through this research on the process of decomposing monazite concentrate by pressure alkali method with a 20kg batch size, yielding 21kg of $\text{RECl}_3 \cdot 7\text{H}_2\text{O}$ with 99% purity, it is shown that the rare earth recovery capacity can be scaled up to 500kg/day. However, several stages,

such as alkali recovery, sodium phosphate recovery, radiation safety, and management and disposal of radioactive waste at a larger scale, require further investigation.

2.10. COMPUTATION AND OTHER RELATED TOPICS

STUDY ON THE CONDITIONS OF DECOMPOSITION OF LIMONITE ORE BY SULFURIC ACID TO OBTAIN Ni AND Sc

Trinh Nguyen Quynh, Nguyen Trong Hung, Tran Van Son, Bui Ba Duy, Truong Thi Ai, Nguyen Hong Ha, Cao Duy Minh, Do Thi Anh Tuyet

Institute for Technology of Radioactive and Rare Elements, Vietnam Atomic Energy Institute, 48 Lang Ha st., Dong Đa, Ha Noi, Viet Nam

Project information:

- **Project name: Study on the conditions of decomposition of limonite ore by sulfuric acid to obtain Ni and Sc**
- **Code: CS/24/03-02**
- **Managerial Level: Institute**
- **Duration: 12 months (Jan 2024- Dec 2024)**
- **Contact email: tnq2007@gmail.com**
- **Published papers related to the project:**

1. Trinh Nguyen Quynh, Nguyen Trong Hung, Bui Ba Duy, Tran Van Son, Truong Thi Ai, Nguyen Hong Ha, Do Thi Anh Tuyet, Cao Duy Minh, Ngo Quang Huy, Chu Quang Huy, Nguyen Thi Thu Ha, Bui Thi Thuy Uyen "Research on some major factors affecting Ni and Sc extractions in the sulphuric acid stirred leaching of limonite ore". Mining industry journal, No. 5/2024, p. 21-26 (in Vietnamese).

2. Trinh Nguyen Quynh, Nguyen Trong Hung, Bui Ba Duy, Tran Van Son, Truong Thi Ai, Nguyen Hong Ha, Do Thi Anh Tuyet, Cao Duy Minh, Ngo Quang Huy, Chu Quang Huy, Nguyen Thi Thu Ha, Bui Thi Thuy Uyen "Research on some major factors affecting Ni and Sc extractions in the sulphuric acid stirred leaching of limonite ore". Proceeding of the 8th Conference on Nuclear Science and Technology for Young Researchers, Ha Noi, Vietnam, October 2024, 8p (in Vietnamese).

Among the Ni-containing minerals, laterite - nickel ore is accounted for about 70% of the world's total nickel and is considered an important resource of nickel. Laterite ore is divided into two main types of ore including saprolite (10-25% Fe, Ni, 1.5-3%, Sc < 200ppm) with the main mineral composition contains Ni in the form of hydrated nickel silicate - $(\text{Ni,Mg})_6(\text{Si}_4\text{O}_{10})(\text{OH})_8.4\text{H}_2\text{O}$ and limonite (40-50% Fe, Ni < 1.5%, Sc < 300ppm) with the main mineral composition containing nickel in the form of oxide - $(\text{Fe,Ni})\text{O}(\text{OH})$.

Limonite Nickel (Ni) ore often contains a small amount of scandium (Sc) as an accompanying component. Although the Sc content in limonite is low, the presence of Sc in limonite with large limonite reserves poses the problem of studying feasible processing methods to simultaneously recover the valuable Ni and rare earth element Sc

According to the survey data of CAVICO Vietnam Mining & Construction JSC (CAVICO Vietnam Group), the laterite mine in Laos existed in a very large reserve, which distributed mainly on the surface and under the shallow soil layer, so it is easy to exploit. The content of Ni and Sc elements in the ore was as Ni 0.1 - 0.25% and Sc 100 - 200 ppm. These valuable elements needed to be studied and recovered. CAVICO Group provided samples of Laos limonite ore to the Institute for Technology of Radioactive and Rare Elements to conduct the studies to evaluate the ability of recovery and simultaneously extraction of Ni and Sc. From that demand, a project entitled "Study on the conditions of decomposition of limonite ore by sulfuric acid to obtain Ni and Sc" was implemented.

The research object was limonite ore from Laos, which was jointly exploited and supplied by CAVICO Group. A number of factors affecting the yield of Ni and Sc recovery in sulphuric acid stirred leaching process (AL) such as acid concentration, reaction temperature, reaction time, solid/liquid phase ratio and the influence of initial ore particle size were investigated. Leaching tests were conducted under high pressure conditions (HPAL) and the influence of temperature and reaction time on the extraction efficiency was also investigated.

The contents of the studied components in the initial ore sample were determined by the ICP-OES method. The solution sample of each leaching batch was filtered from the ore residue, then analyzed by the ICP-OES method to determine the contents of the investigated components in the obtained leaching solution, thereby calculating their extraction efficiency.

The effects of sulfuric acid concentration on the extraction efficiency of Ni, Sc and iron (Fe) impurities were shown in Figure 1. It can be seen that when increasing the used acid concentration, the extraction efficiency of Ni and Sc increased and reached a maximum at 5-6M H₂SO₄. However, to limit the dissolution of Fe impurities, 4M H₂SO₄ should be suitable.

When the reaction temperature increased, the extraction efficiency of Ni, Sc and Fe increased significantly, especially for Fe. The temperature range of 80 - 90°C gave the highest extraction efficiency for the studied components, however, at a temperature ~ 90°C, it could cause the loss of steam, that would change the S/L phase ratio and change the used acid concentration, and at the same time dissolve the maximum impurity components in the ore. Therefore, the next research direction was conducted at a temperature of 80°C.

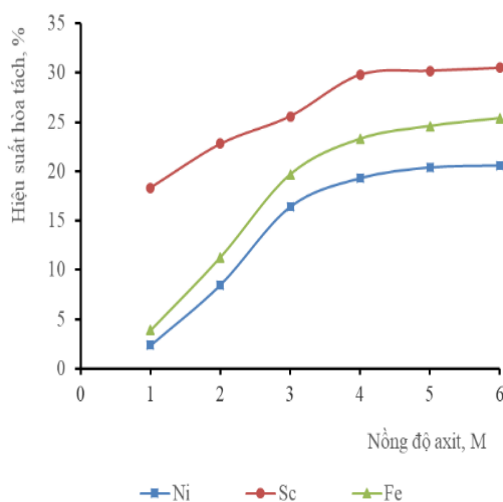


Figure 1. Effect of used acid concentration on extraction efficiency of Ni, Sc and Fe

The time parameters were varied in the range of 2, 3, 4, 5 and 6hrs. The effect of reaction time on the extraction efficiency of Ni, Sc and Fe showed that the extraction of Ni and Sc reached equilibrium within the reaction time of 4hrs, corresponding to ~80% Ni and 94% Sc being extracted from the ore. Meanwhile, the extraction efficiency of Fe reached about 90% at the reaction time of 4hrs and was lower than that of Sc. However, iron was almost completely dissolved into the solution after the reaction time of 5hrs. Therefore, to limit the maximum dissolved iron content, the reaction time of 4hrs was chosen for the following experiments.

The effect of the R/L phase ratio on Ni, Sc and Fe extraction efficiency was given in Table 1, showing that with the R/L ratio = 1/10 (g/mL), the extraction efficiency of the components was the largest.

Table 1. The effect of the R/L phase ratio on the extraction efficiency

S/L ratio (g/mL)	Extraction efficiency (%)		
	Fe	Ni	Sc
1/10	90.0	78.0	93.9
2/10	80.1	65.6	70.7
3/10	60.2	45.5	50.6

The data in Table 2 showed the influence of ore size on the separation efficiency of the studied components. To increase the extraction efficiency of Ni and Sc, the ore particle size P80 = 63 μm was the most suitable.

Table 2. The effect of particle size on extraction efficiency

Particle size	Extraction efficiency, %		
	Fe	Ni	Sc
P80 = 63 μm	90.0	78.0	93.9
P80 = 125 μm	80.2	60.4	70.6
P80 = 215 μm	60.1	50.5	55.5

In order to get more detailed evaluation of the ability to decompose limonite ore by sulfuric acid for obtaining Ni and Sc, and at the same time to build a Data base on the conditions of decomposing limonite ore by sulfuric acid at normal pressure and at high pressure to orient the further study on technology to obtain Ni and rare earth element Sc.

Decomposition test of limonite by high pressure acid leaching method (HPAL) using pressure device (Figure 2). The influence of temperature and reaction time on limonite decomposition efficiency was shown in Table 3. From the obtained data with the parameters such as 4M H_2SO_4 , R/L ratio = 1/10, ore particle size P80 = 63 μm , under HPAL conditions,

the ore could be completely decomposed at a temperature of 150°C within 2hrs reaction time.



Figure 2. HPAL devive

Table 3. Effect of reaction temperature and time on HPAL extraction efficiency of components from limonite ore

Component	Extraction efficiency at different reaction temperatures and times, %								
	100°C			125°C			150°C		
	1hr	2hrs	3hrs	1hr	2hrs	3hrs	1hr	2hrs	3hrs
Fe	60.3	91.5	100	90.0	100	100	100	100	100
Ni	40.6	64.8	73.6	87.6	90.7	95.5	94.4	100	100
Sc	63.4	80.6	84.8	85.4	89.7	92.3	96.6	100	100
Observation	Red residue						White residue		
	Light blue leaching solution						Dark blue leaching solution		

Comparing the results obtained from the two methods, it can be seen that HPAL gave higher efficiency in leaching components than AL. However, the amount of impurities dissolved in the solution was also larger, and the equipment requirements were more complicated, the cost thus was higher. Meanwhile, AL was easy to apply on a large scale and the cost thus was lower.

The results obtained are consistent with research practices in our country and with many previously published international research works on processing laterite nickel ore, including limonite ore. Thereby, it is clearly confirmed that there is a possibility of obtaining valuable elements Ni and Sc from Laos' limonite ore by sulfuric acid leaching method. However, further study is needed, including enrichment of the interested components before

leaching, iron removal to reduce acid costs, and increase the efficiency of Ni and Sc leaching.

STUDY AND DEVELOPMENT OF THE MOMENT METHOD FOR DETERMINING RESIDUAL OIL SATURATION IN THE NEAR-WELLBORE REGION INCLUDING DISPERSION AND HYDROLYSIS EFFECTS IN SINGLE WELL TRACER TECHNIQUE

Tran Trong Hieu, Nguyen Thanh Hai, Huynh Thi Thu Huong, Nguyen Huu Quang, Le Van Son, Nguyen Thi Kim Anh

*Centre for Applications of Nuclear Technique in Industry (CANTI),
01 DT 723, ward 12, Dalat city, Lamdong province*

Project information:

- **Project name:** Study and development of the moment method for determining residual oil saturation in the near-wellbore region including dispersion and hydrolysis effects in single well tracer technique.
- **Code:** CS/24/06-03
- **Managerial Level:** Institute
- **Implementation time:** 12 months (Jan 2024- Dec 2024)
- **Contact email:** hieutt@canti.vn
- **Published papers related to the project:**

1. Tran Trong Hieu et al., Research and development of moment method to determine residual oil saturation including dispersion and hydrolysis effects in single well tracer technique, Nuclear Science and Technology conference for young scientists, Ha Noi, Vietnam, 2024 (in Vietnamese).

The single-well tracer technique (SWTT) has been widely applied in field-scale over the years to determine the residual oil saturation (S_{or}) in the near-wellbore region, aiming to evaluate the efficiency before and after applying enhanced oil recovery techniques. S_{or} can be determined using the retardation factor (R) of two tracers, ester (e) and alcohol (a), along with the distribution coefficient (K_d) of the ester. The value of R is obtained through the moment analysis of the concentration curves of tracers over time, while K_d can be measured in laboratory experiments. Traditional formula for determining R do not account for the effects of hydrolysis and dispersion of the tracers. Hence, this research proposes a new formula for determining the retardation factor (R) to estimate the residual oil saturation in single-well tracer tests, taking into account both the dispersion coefficient and the hydrolysis coefficient in the tracer transport equation. The proposed formula has been validated using datasets from numerical simulations, laboratory experiments and field data from published papers. For a tracer concentration distribution, the first-order moment represents the mean of the distribution, corresponding to the mean residence time (\bar{t}) of the tracer in the investigation region. The second-order moment is the variance of the distribution (σ^2), reflecting the tracer dispersion during transport. S_{or} and the retardation factor R are determined using equations (1) and (2):

$$S_{or} = \frac{R-1}{R-1+K_d} \quad (1)$$

$$R = \bar{t}_e \left[\frac{1}{\bar{t}_a} + \frac{1}{2} \left(\frac{\sigma_a^2}{\bar{t}_a^3} - \frac{\sigma_e^2}{\bar{t}_e^3} \right) + \lambda \left(\frac{M_a}{M_e} \frac{\int_0^\infty t C_e dt}{\int_0^\infty t C_a dt} + 1 \right) \right] \quad (2)$$

Where:

C_e and C_a are the concentrations of ester and alcohol over time, respectively (M/V3),

λ is the hydrolysis rate of ester in the aqueous phase (1/T),

M_e and M_a are the molecular mass of ester and alcohol, respectively (M/mol).

The reservoir simulation software UTCHEM was utilized to simulate the single-well tracer test. S_{or} was estimated using the proposed formula and compared with traditional ones. A reservoir model with dimensions of $X = 35$ ft, $Y = 1$ ft and $Z = 5$ ft was built. The radius of the injection well (also serving as the production well) was 0,25 ft. The investigation radius was 30 ft. The reservoir's porosity and permeability were set at 0,25 and 2000 mD, respectively. The residual oil saturation of the model was 0,25. Ethyl acetate (EA) was utilized as the tracer in this simulation. The tracer injection and production durations in this simulation were both set to 1 day. The distribution coefficient, hydrolysis rate, soaking time, and dispersion coefficient were varied in the simulation cases to evaluate their impact on the accuracy of residual oil saturation determination. The results show that most of the estimates from our proposed formula method are within a 10% tolerance ($\pm 0,025 S_{or}$), while only a few predictions from other methods achieve this level of accuracy. The influence of these parameters on the residual oil saturation determination was also analyzed. Specifically, as the hydrolysis rate or dispersion coefficient increases, the deviation between the estimated residual oil saturation and the actual value tends to increase. In contrast, an increase in the soaking time or distribution coefficient reduces the error between the estimated and actual values.

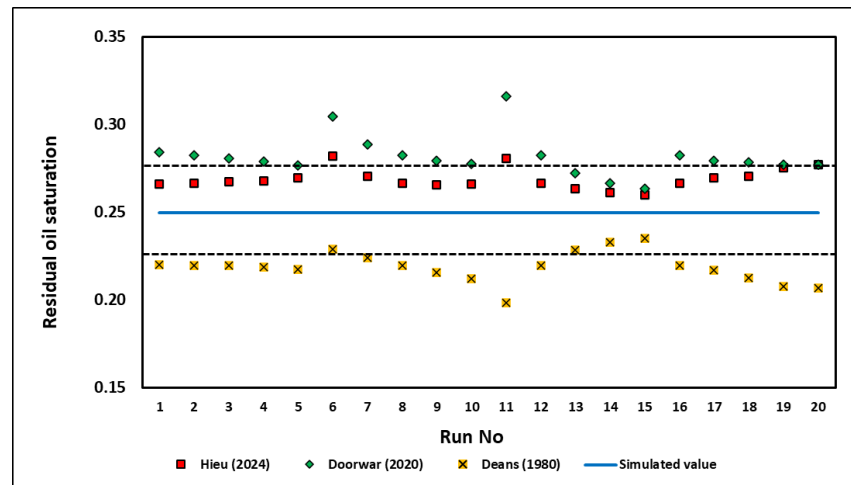


Figure 1. The estimated residual oil saturation results using different formula under varying survey parameters.

A laboratory packed column experiment was set up and the residual oil saturation in the column was determined using different formula to evaluate the error of each method. Through this, the effectiveness of the proposed method was assessed. The column was established with a residual oil saturation of 0,39. The residual oil saturation was estimated based on the concentration distribution curves of the two tracers, the hydrolysis rate and the K_d coefficient of EA. The results indicated that the proposed method estimates a residual oil saturation value of 0,351. This estimate is the closest to the actual value with an error of 10,02%, whereas other methods give errors exceeding 13%.

The field data sets were also used to estimate S_{or} using various methods. The results showed that most of the S_{or} estimates from the proposed formula in this study are closest to the actual value. Meanwhile, Deans' method mostly provides an estimation of S_{or} that were lower than the actual value, as demonstrated in both the simulation and laboratory experiment results.

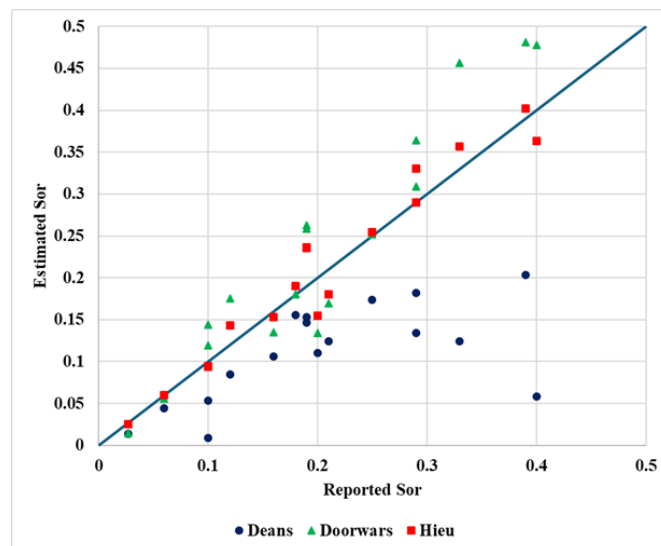


Figure 2. The estimated S_{or} values from different methods are compared with the field values.

Thus, the moment method that accounts for dispersion and hydrolysis effects to determine residual oil saturation was validated. This method gives a result with lower error compared to traditional methods. The results of this study serve the need to determine residual oil saturation during the enhanced oil recovery for oil companies in Vietnam. The further study will focus on evaluating the factors influencing the tracer curve during field implementation, such as reservoir heterogeneity (permeability, porosity, layering, etc.), fluid drift effects and variation of hydrolysis rate due to pH effects during ester hydrolysis.

A SIMULATION STUDY ON EDDY CURRENT SIGNALS OF TYPICAL ARTIFICIAL DISCONTINUITIES ON NON-FERROMAGNETIC TUBES TO ASSESS THE CURRENT CONDITION OF THE HEAT EXCHANGE SYSTEM

Pham Thi Lan Anh, Đau Tuyet Nhung, Nguyen Nhat Quang, Vu Huy Bach

*Center for Nuclear Technologies (CNT) Ho Chi Minh city; No. 217 Nguyen Trai Street,
Nguyen Cu Trinh Ward, District 1, HCMC*

Project information:

- Project name: A simulation study on eddy current signals of typical artificial discontinuities on non-ferromagnetic tubes to assess the current condition of the heat exchange system.

- Code: CS/24/02-01

- Managerial Level: Institute

- Implementation time: 12 months (Jan 2024 - Dec 2024)

- Contact email: phamlananh678@gmail.com

- Published papers related to the project:

1. Pham Thi Lan Anh et al., A simulation study of eddy current signals for typical artificial discontinuities on non-ferromagnetic tubes of heat exchanger system, Presentation at the 8th Nuclear Science and Technology Conference for Young Researchers in Ha Noi.

The heat exchange system is a critical component in many major industrial plants such as aviation, machinery manufacturing, oil and gas, transportation, and energy. Therefore, effective inspection methods, early fault detection, and accurate system condition assessment are vital and regular tasks. Eddy Current Testing (ECT) is quite popular and widely implemented worldwide, including in Vietnam. However, the simulation of ECT signals has not been extensively researched domestically, prompting the development of this project to enhance local capabilities and applications in this field.

The principle of the ECT method is based on electromagnetic induction. When an alternating current flows through a coil, it generates a fluctuating primary magnetic field around it. When the coil is brought near a conductive material, the magnetic field induces eddy currents within the conductor. These eddy currents, in turn, generate a secondary fluctuating magnetic field that opposes the primary field of the coil. Thus, when the coil is placed close to the conductor, the coil's magnetic field intensity is affected, leading to changes in the system's impedance.

COMSOL software was used to analyze Maxwell's equations in both axisymmetric two-dimensional and three-dimensional spaces and to simulate the ECT inspection process. The simulation model describes a bobbin coil moving inside a reference tube designed to ASME standards, containing typical defects, including circumferential and localized defects. Circumferential defects consist of external wall corrosion with depths of 20% (J), 40% (C),

and 60% (B), and an internal corrosion defect of 10% (K), representing material degradation on the tube surface. Localized defects include 100% through-wall holes (D) and flat-bottom holes with depths of 20% (E), 40% (F), 60% (G), and 80% (H) of the tube wall thickness, typically caused by corrosion, abrasion, or mechanical impact.

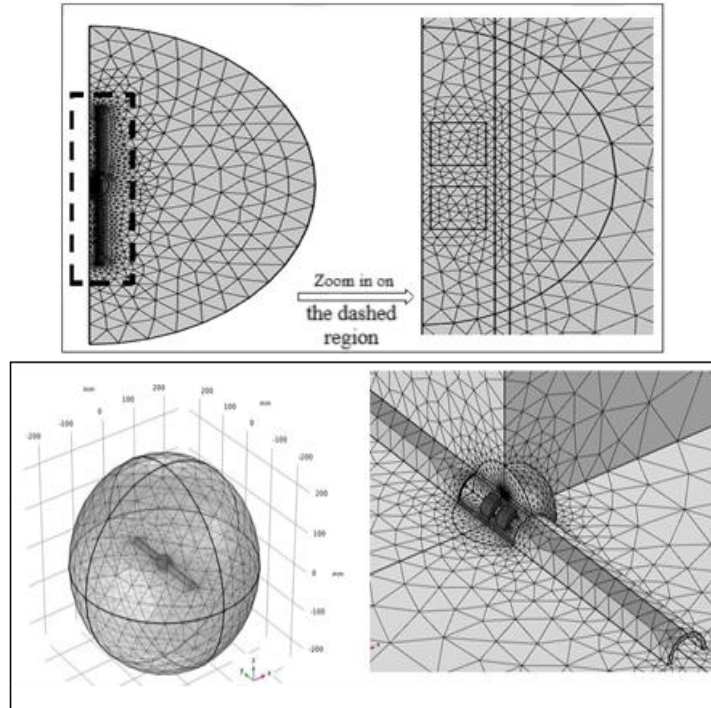


Figure 1. COMSOL mesh for 2D-axial symmetry (left) and 3D (right)

The impedance diagram indicates a correlation between defect depth and both the amplitude and phase of the defect response signal. The real R and imaginary Z_L (inductive reactance) components of impedance tend to increase or decrease depending on the testing frequency. After calibration according to ASME standards, the size and shape of the signal trajectories change with the defect depth percentage. These results confirm the feasibility of detecting and quantifying discontinuities through simulation.

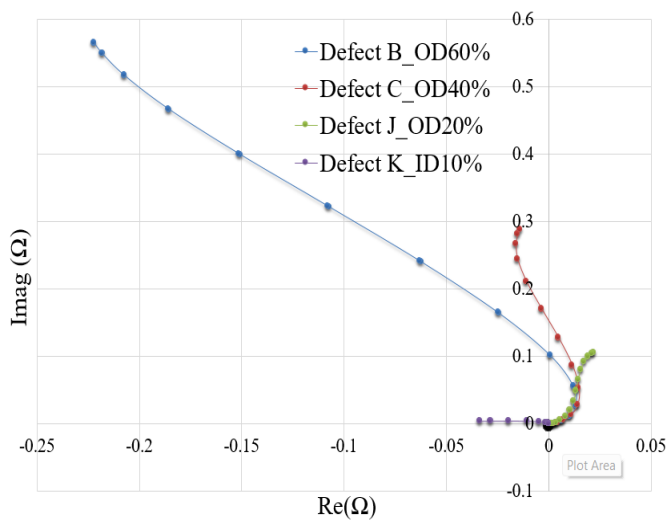


Figure 2. Signal trajectories of circumferential defects

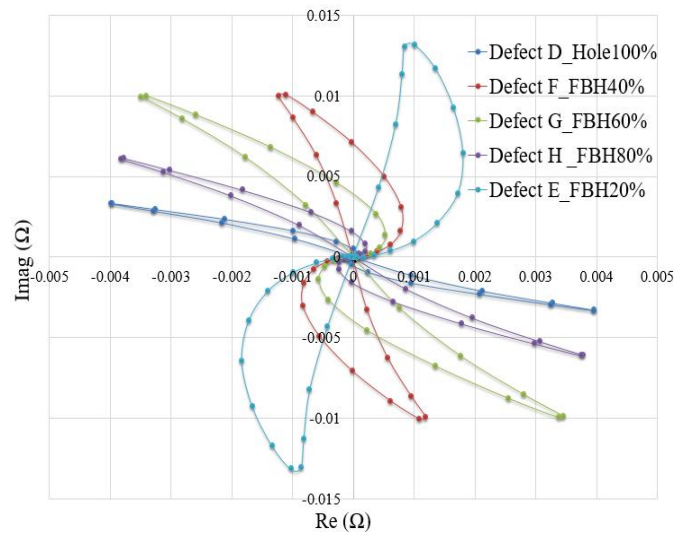


Figure 3. Signal trajectories of localized defects

Future research should focus on practical experiments that need to be conducted to collect comparative data, allowing for the refinement and updating of the simulation model to ensure high accuracy and reliability in the final results. Additionally, strengthening research capabilities and developing specialized ECT probes, integrating automation technology and artificial intelligence should be promoted in ECT inspection, to enhance local capacities and reduce dependence on foreign technical services, contributing to the long-term development in the field of Non-Destructive Testing (NDT).

A STUDY ON THE APPLICATION OF ARTIFICIAL INTELLIGENCE (AI) FOR THE IDENTIFICATION AND QUANTIFICATION OF RADIONUCLIDE ACTIVITY FROM GAMMA ENERGY SPECTRA USING AN N-TYPE HPGE DETECTOR IN ENVIRONMENTAL RADIOACTIVITY STUDIES (SOIL SAMPLES).

Nguyen Thi Thu Ha¹, Duong Duc Thang¹, Nguyen Hao Quang¹, Le Dinh Cuong¹, Nguyen Huyen Trang², Pham Kim Long², Nguyen An Trung², Nguyen Chi Thanh³, Phung Nhu Hai³, Phan Tuan Anh⁴

(1) Institute for Nuclear Science and Technology, 179 Hoang Quoc Viet, Nghia Do, Cau Giay, Hanoi

(2) Vietnam Atomic Energy Institute, 59 Ly Thuong Kiet, Hoan Kiem, Hanoi

(3) Institute of Information Technology, Academy of Military Science and Technology, 17 Hoang Sam, Nghia Do, Cau Giay, Hanoi

(4) Research and Development Center for Radiation Technology - Da Nang, Dai La, Hoa Vang, Da Nang

Project information:

- **Project name:** A study on the application of artificial intelligence (AI) for the identification and quantification of radionuclide activity from gamma energy spectra using an n-type HPGe detector in environmental radioactivity studies (soil samples).

- **Code:** ĐTCB.03/23VKHKTHN

- **Managerial Level:** Ministry

- **Implementation time:** 30 months (Jan 2023- Jun 2025)

- **Contact email:** thuhaus@gmail.com

Published papers related to the project:

1. Nguyen Hao Quang, Nguyen An Trung, Nguyen Thi Thu Hà, Dương Đức Thang, Simulation of gamma spectra from soil samples by using MCNP: A case study, the 15th Vietnam Conference on Nuclear Science and Technology (VINANST 15), Nha Trang, Vietnam, 2023.

2. Nguyen, A. T., Nguyen, H. Q., Nguyen, T. T. H., & Duong, D. T. (2024). Simulation of gamma spectra from soil samples by using MCNP: A case study. *Nuclear Science and Technology*, 13(3), 27-37. <https://doi.org/10.53747/nst.v13i3.416>

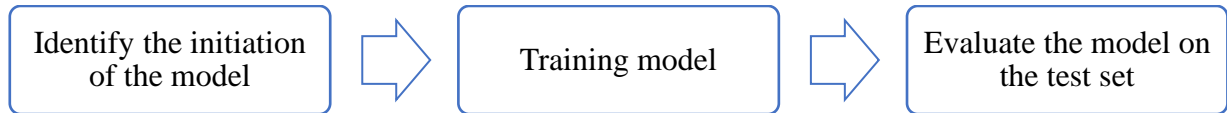
3. Quantification of Ra-226 and U-235 in Soil Using HPGe Gamma Spectra and Linear Regression. The paper is under revision after peer review.

4. MCNP-Simulated HPGe Soil Spectra: A Public Dataset and Machine Learning Benchmark for Multi-Isotope Quantification. The paper is under revision after peer review.

Over the past decade, machine learning has become a powerful tool in many fields of science and engineering, including the identification and determination of radionuclide activity from the gamma energy spectrum. Machine learning models are capable of processing and analyzing large amounts of complex data, thereby optimizing the identification of radionuclides quickly and accurately. In particular, gamma energy spectroscopy provides important information about the types of radionuclides present in the sample, which in turn allows to determine their activity. The main objectives of this study are as follows: (i) To develop a simulated dataset of gamma spectra (with an n-type HPGe detector and 2π L measurement geometry) for environmental soil samples using MCNP to support machine learning; (ii) To develop and master a number of machine learning models to automatically identify and determine the radionuclide activity from the gamma spectrum of environmental soil samples measured by an n-type HPGe detector under 2π L measurement geometry; (iii) To train human resources and promote the application of artificial intelligence in the field of atomic energy in Vietnam.

The gamma spectroscopy system at the Center for Radiation Monitoring and Environmental Impact Assessment consists of an HPGe GMX40P4-76 detector (FWHM:2.0 keV at 1.33 MeV), combined with an ORTEC digiDART 8192-channel amplitude analyzer. The measuring sample box is cylindrical with a diameter of 10.3 cm, placed close to the detector face. Figure 1 shows the components of the detector including: (1) Ge crystal, (2) Vacuum layer outside the Ge crystal, (4) Polystyrene protection layer for Be window, (5) Sample holder base, (6) Sample container, (8) Air layer outside the detector inside the polystyrene base, (9) Aluminum shielding layer, (10) Ge Crystal Inner Vacuum Column, (14) Weak-Field Vacuum, (17) Be-Window Support Aluminum Sheet, (18) Dead Layer Outside Vacuum Column, (19) Copper Base beneath the Ge crystal. We used the MCNP 6 program to simulate the gamma radiation spectrum obtained from the measurement system. The verification results on the RGU-1 and RGTh-1 standard samples show that there is a good match between the measurement spectrum and the simulated spectrum. To simulate the gamma radiation spectrum of soil samples, we hypothesize that there are 41 radionuclides including those in the three decay chains ^{238}U , ^{235}U , ^{232}Th and ^{40}K , ^{137}Cs and ^7Be in the measured sample. To generate 3000 simulated spectra, we generated 3000 input files for the MCNP program with the activity of radionuclides in the series ^{238}U , ^{235}U , ^{232}Th respectively varied 0-1000 Bq, 0-45 Bq, 0-700Bq and the activity of radioactive nuclei ^{40}K , ^{137}Cs , ^7Be varied 0-321Bq, 0-80Bq, 0-100Bq respectively. The results of processing the output files of the MCNP simulation program have given the data of the gamma radiation simulation spectrum. Each gamma radiation simulation spectrum consists of 8192 channels corresponding to an energy range of 0 keV to 2950 keV. The data in each channel represents the pulse count rate (pulses per second) with an amplitude corresponding to the ordinal number of that channel. The gamma spectral dataset (SpecDensity) has dimensions of (8986, 8192). The activity data of the 41 radionuclides corresponding to the gamma radiation simulation spectra stored in the S41 array with dimensions (8986, 41). The gamma spectral dataset is a dataset of the features of the gamma radiation spectrum, and the S41 dataset is a dataset of labels of 41 radionuclide activity.

The models studied include: Linear regression, Lasso, Ridge, K-Nearest Neighbors (KNN), decision trees, SVM (Support Vector Machine), XGBoost, ANN (Artificial Neural Network), and CNN (Convolutional Neural Network). Evaluate the performance of the models based on MAE (Mean Absolute Error), MSE (Mean Squared Error), R^2 , MAPE (Mean Absolute Percentage Error). Each model has its own applications and limitations, and the choice depends on the nature of the data and the requirements of the problem. The machine learning model training process is as follows:



The results of the 41 radionuclide activity prediction of 4 models are given in Table 1. In which, $P_{<15}$ is the probability of predicting radionuclide activity with an error of less than 15%.

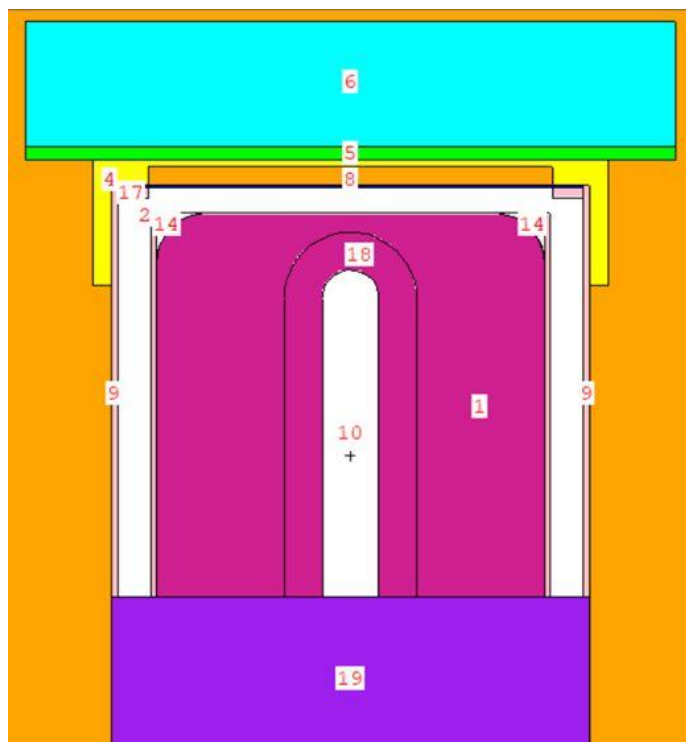


Figure 1. Components of detector and sample box

Table 1. Results of evaluating the performance of the models on 41 radionuclides

Model	$P_{<15}$	MAPE	MAE	MSE
Ridge	0.971	0.105	3.490	68.747
XGBoost	0.950	0.246	5.289	112.868
ANN	0.843	607.7	5.780	117.127
CNN	0.832	997.4	4.569	77.597

A software tool was developed to automatically identify and quantify the activity of radioactive isotopes including ^{137}Cs , ^{40}K , ^{228}Th , ^{232}Th , ^{226}Ra , ^{235}U , ^{210}Pb , ^{212}Pb , ^{214}Pb , ^{214}Bi , ^{212}Bi , ^{208}Tl , and ^{228}Ac based on gamma spectra acquired from the measurement system.

Regarding future research direction of this study, the simulated gamma spectrum dataset of soil samples with a $2\pi\text{L}$ measuring configuration from the HPGe gamma spectrometer system can be used to further research machine learning models for radionuclide identification and activity quantification with higher performance. The research method can be applied to other measurement configurations, measurement sample objects, and types of HPGe detector of the Center for Radiation Monitoring and Environmental Impact Assessment.

3- PHOTO ALBUM

**A Wrap-up of VINATOM significant events
in 2024**

3.1. HEADQUARTERS



The Deputy Director General of the International Atomic Energy Agency visited and worked at the Vietnam Atomic Energy Institute.



Mr. Hua Liu took a commemorative photo with the leadership of the Vietnam Atomic Energy Institute.



The awarding ceremony of “For Contributions to the Advancement of Science and Technology” commemorative medal to Ms. Jane Gerardo-Abaya, former Director of the Technical Cooperation Division for the Asia-Pacific region at the International Atomic Energy Agency (IAEA).



Ms. Jane Gerardo-Abaya delivered a speech at the commemorative medal awarding ceremony.



The 3rd Congress of Delegates for the 2024–2029 term of the Vietnam Atomic Energy Association.



Minister of Science and Technology Huỳnh Thành Đạt delivered a speech at the Congress of the Vietnam Atomic Energy Association.



Mr. Phan Xuân Dũng, Chairman of the Vietnam Union of Science and Technology Associations, delivered a speech at the Congress of the Vietnam Atomic Energy Association.



Group photo at the Congress of the Vietnam Atomic Energy Association.



Dr. Trần Chí Thành shared on the topic “Nuclear Energy and Wind Energy” at the workshop “Viettel – Aspiring to Conquer the Pinnacle of Technology.”



The Vietnam Ministry of Science and Technology and Rosatom discussed the cooperation plan for the 2025–2030 period.



Rosatom Director General Alexey Likhachiov presented the “For Merit in the Nuclear Industry” medal to Mr. Trần Chí Thành, President of Vietnam Atomic Energy Institute.



The 8th Conference on Nuclear Science and Technology for Young Staff in the Atomic Energy Sector



Dr. Trần Chí Thành, President of the Vietnam Atomic Energy Institute, delivered the keynote address at the conference.



The Vietnam Atomic Energy Institute worked with the expert delegation from the Joint Institute for Nuclear Research (Dubna).



The delegation of experts from the RCARO Regional Cooperation Office and relevant research institutes of Korea attended the Strategic Meeting on Nuclear Cooperation at the Vietnam Atomic Energy Institute.



The Vietnam Atomic Energy Institute (VINATOM) and RCARO signed the Minutes of the Meeting on December 13, 2024.



The 2024 Year-End Review Conference and 2025 Orientation and Task Plan of the Vietnam Atomic Energy Institute.



Minister of Science and Technology Huỳnh Thành Đạt delivered a speech at the 2024 Year-End Review Conference

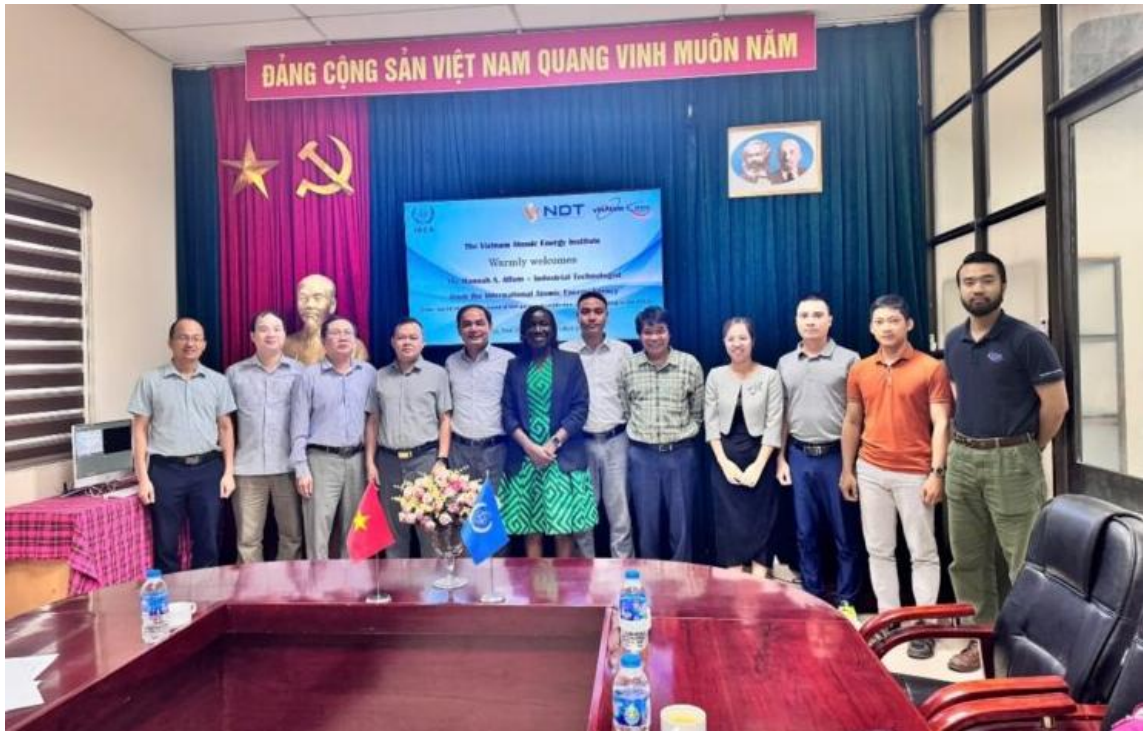
3.2. NON-DESTRUCTIVE EVALUATION CENTER



The signing ceremony of the MOU on cooperation between NDE and DOSM in Laos



Fellowship training for DOSM, Laos



IAEA Expert working at the NDE within the framework of TC project VIE1012



IAEA Expert working at the NDE within the framework of TC project VIE1012



ASNT India assesses NDE for Authorized Training Centre (ATC)



Promote material analysis and evaluation activities



Certificate of Accreditation ISO/IEC 17024:2012 and ISO/IEC 17025:2017



Workshop "Introduction to Non-Destructive Testing methods" in Da Nang



The trainees of the training course on Non-Destructive Testing methods



Training course on Radiation Safety



Deployment maintenance of thermal power plant in Nghi Son 2



Deployment Non-Destructive Testing (NDT) service

3.3. CENTER FOR APPLICATION OF NUCLEAR TECHNIQUES IN INDUSTRY



Application of the leak control method for gas-lift wells using the chemical tracer technique



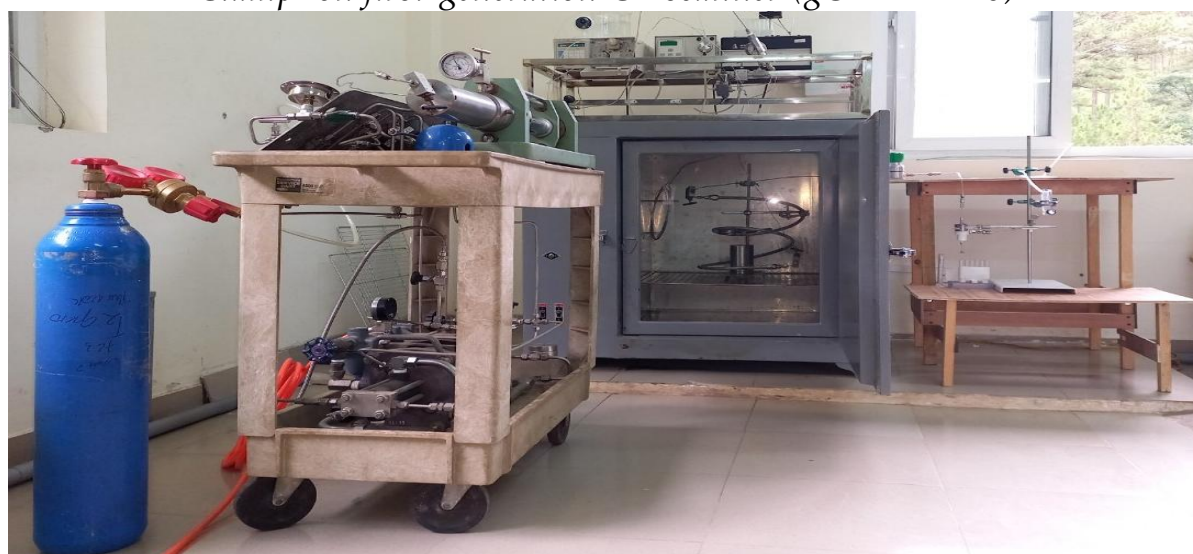
Installation of Well Head Sampler for produced water extraction



Workshop on the Introduction and Promotion of Technologies at the Russia-Vietnam, Joint Venture- Vietsovpetro



Clamp- on first-generation CT scanner (gORBIT-140)



The slim-tube system at Tracer Laboratory of Centre for Applications of Nuclear Technique in Industry

3.4. INSTITUTE OF NUCLEAR SCIENCE AND TECHNOLOGY

3.4.1. Center for Environmental Radiation Monitoring and Impact Assessment



FTC on Nuclear and Radiological Emergency Preparedness



Sampling and pretreatment of seawater at Truong Sa Island



Sampling and pretreatment of seawater at Truong Sa Island

3.3.2. Center for Nuclear Energy



*Instructor Training Course 2024 on Reactor Engineering,
4 September - 10 October 2024, Japan*



*IAEA/INPRO Advisory Service Workshop on MESSAGE-NES,
18-22 November 2024, Hanoi, Vietnam*

3.3.3. Center for Nuclear Physics



Seminar on “Nuclear Reactions at Low Energy and Applications to Nuclear Astronomy” at the INST



Researchers from the Nuclear Physics Center of the INST visited the JINR Flerov Laboratory of Nuclear Reactions, Dubna, Russia



MSc. Do Thi Khanh Linh received the B Prize at the 8th Conference on Nuclear Science and Technology for Young Researchers in Atomic Energy



The internship guidance for students in the Nuclear Physics Center, INST

3.3.4. Center for Nuclear Techniques Application



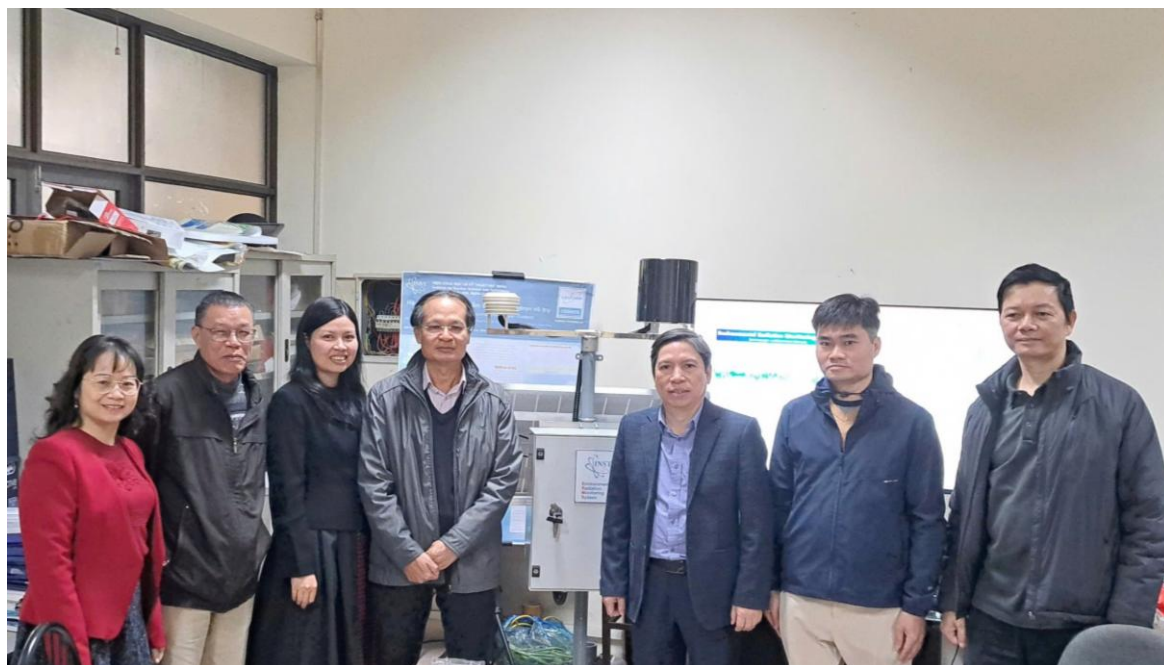
RAS7038 Project: TC Expert Mission on Evaluation and Optimization of Marine Sediment Dating Techniques using Po-210, INST, Hanoi, Vietnam



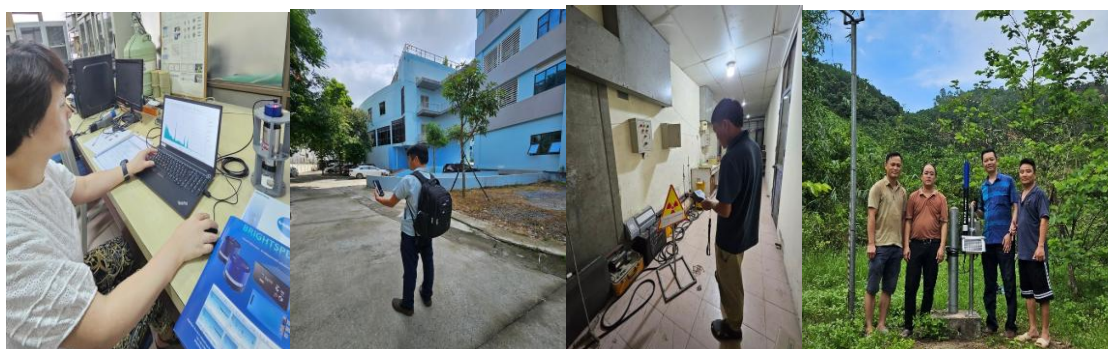
IAEA's TC project participants



Doctoral Degree Conferment Ceremony



Environmental radiation monitoring system – Ministry level project 2023-2024



Deploying equipments received from the RAS1026 project

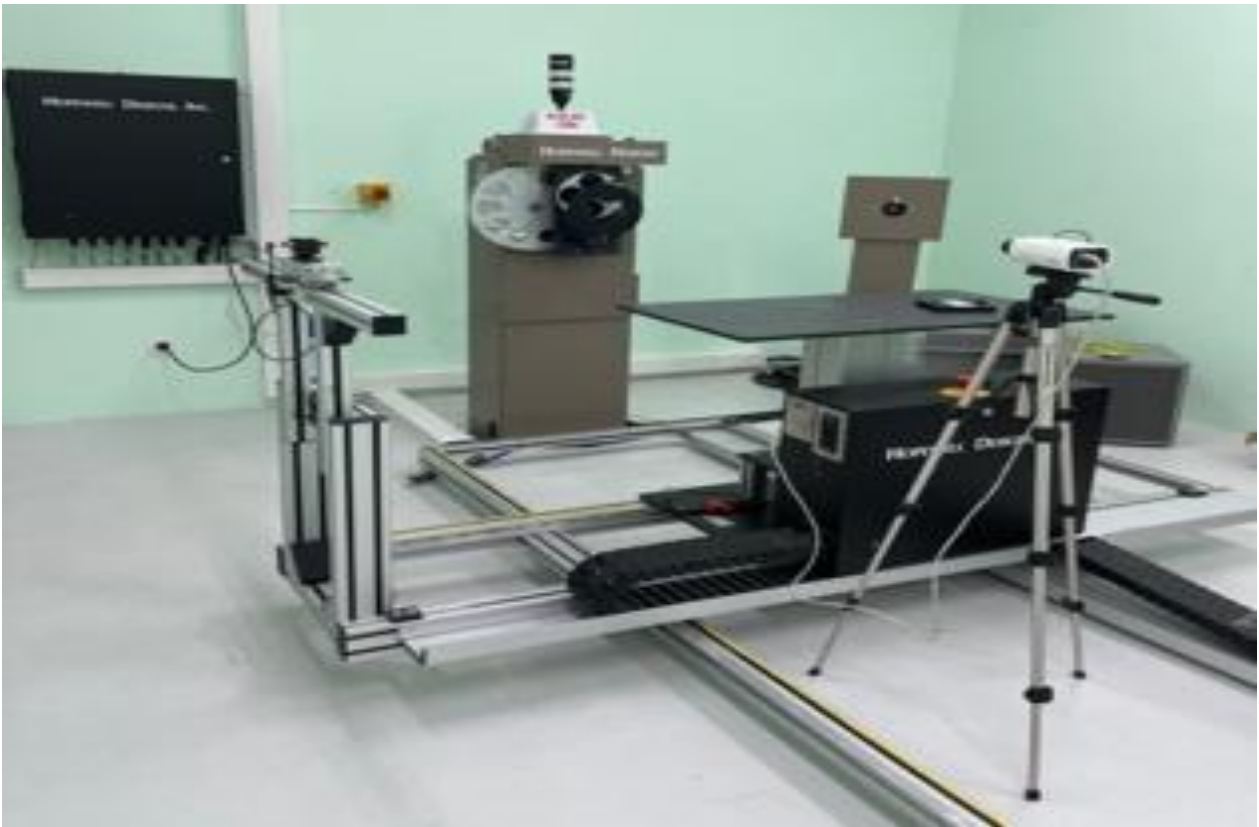
3.3.5. Center for Radiation Protection



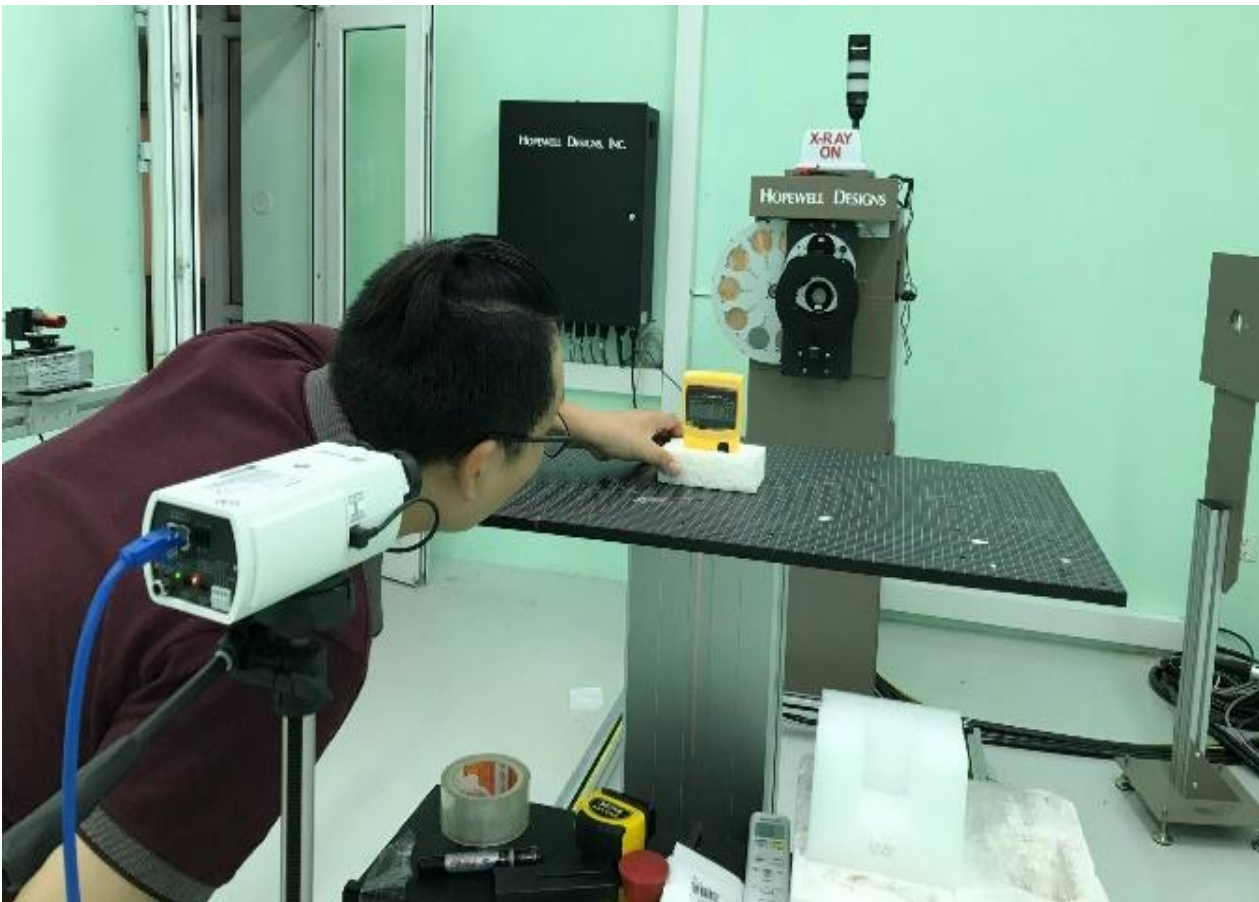
Scientific visit of Wollongong University, Australia



Gamma Standard Dosimetry Laboratory



X-Ray Standard Dosimetry Laboratory



Calibration of radiation measurement equipments



Radiation protection training

3.5. NUCLEAR TRAINING CENTER



President of VINATOM has awarded the PhD Degree to students



Building the Nuclear Safety Laboratory with the support and cooperation of Japanese partners (Science Tokyo) and funding from the IAEA



Research Cooperation on Hydrothermal Safety with Science Tokyo



The 10th Follow-up Training Course on Reactor Engineering in cooperation with JAEA, Japan to be held at NTC



Research cooperation in the field of water analysis with BOKU University (Austria) under NĐT/AT/22/27



The VINATOM's Committee for criteria evaluation of Professor Candidate in 2024



PhD candidates, Do Duc Chi and Nguyen Duy Khoi have successfully defended their Dissertation



PhD candidate, Ha Lan Anh, has successfully defended her Dissertation



PhD candidate, Tran Thi Nhan has successfully defended her Dissertation



The 14th Vietnam-Japan Research & HRD Forum on Nuclear Technology

3.6. NUCLEAR RESEARCH INSTITUTE



Workshop on Site Security Plan Development organized by the Office of Radiological Security, NNSA, USA



Coordinate with JAEA for a Follow-up Training Course on Environmental Radioactivity Monitoring at DNRI



Delegates attend the 40th Anniversary of the Inauguration of the Dalat Nuclear Reactor Reconstruction and Expansion Project



IAEA Deputy Director General, Mr. Hua Liu, congratulates the DNR for 40 years of safe and effective operation



Workshop on Radioisotope Applications in Medicine, organized on the occasion of the 40th Anniversary of the Inauguration of the Dalat Nuclear Reactor Reconstruction and Expansion Project



The DNRI was honored with the "Vietnamese Pharmaceutical Star" award for its capsules and Sodium Iodide (Na ¹³¹I) solution in 2024.

3.7. RESEARCH AND DEVELOPMENT CENTER FOR RADIATION TECHNOLOGY

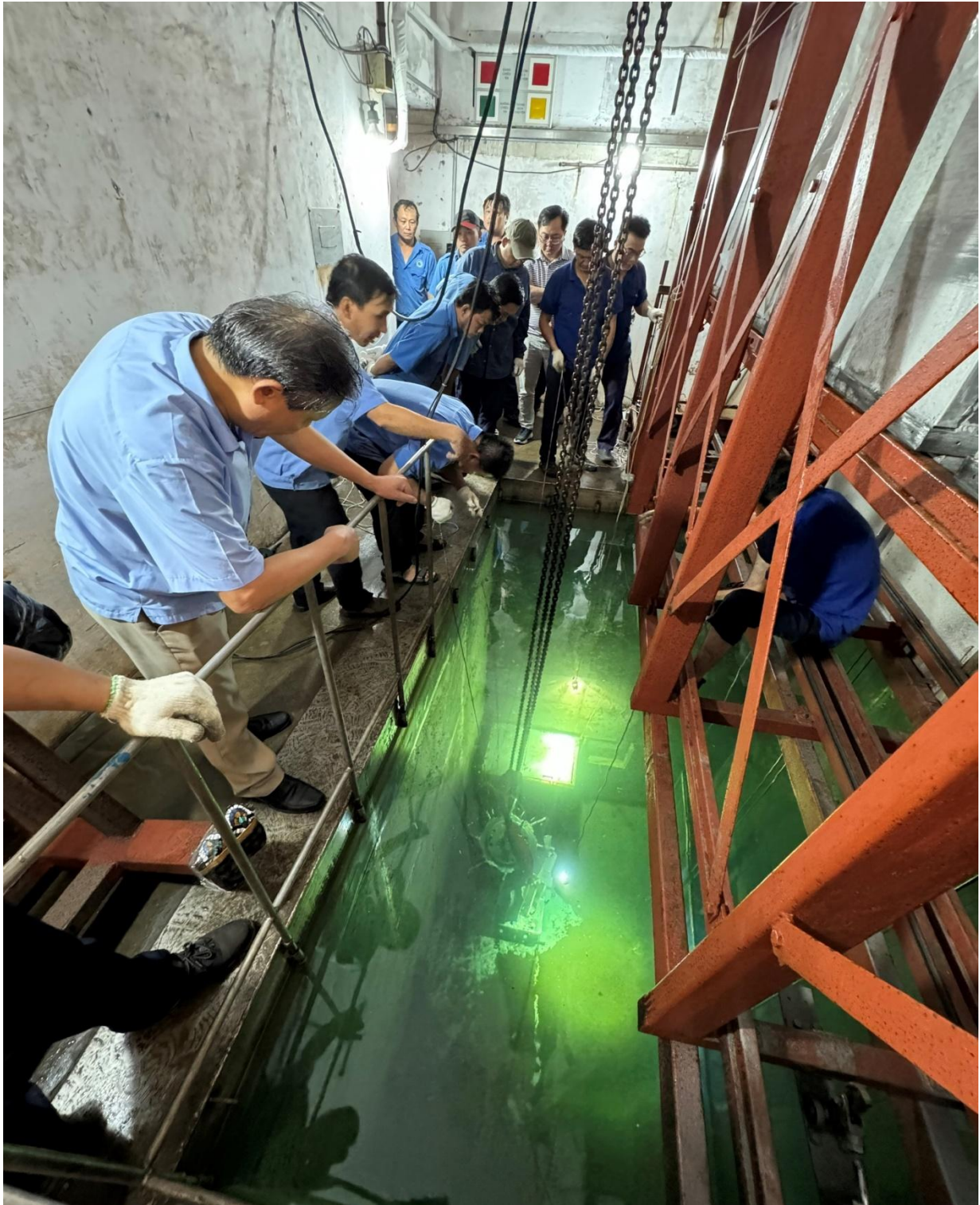


Signing a Memorandum of Understanding on research collaboration with the Institute of Biotechnology, Hue University.

Regional Coordination Meeting on Quality Management Practices in Radiation Processing Facilities



Participating the Regional Coordination Meeting on “Quality Management Practices in Radiation Processing Facilities”



Supplementing the Cobalt-60 radioactive source for the SVST-Co60/B irradiator



Participating the Regional Training Course on Quality Assurance and Quality Control for Gamma Dosimetry Applications



Coorganizing the Regional Training Course on Quality Assurance and Control of Dosimetry Systems on Electron Beam Accelerators



Coorganizing the Hands-on Regional Workshop on eBeam Applications



Coorganizing the Radiation and Nuclear Incident Response Drill in Da Nang city



Back-to-the-Roots Activities for all staff and employees.



Participating the Regional Training Course on Technical and economic feasibility studies for radiation-assisted recycling of polymer waste

3.8. INSTITUTE FOR TECHNOLOGY OF RADIOACTIVE AND RARE ELEMENTS



Signing Ceremony of the Memorandum of Understanding (MOU) between the Institute for Rare Radiation Technology (CNXH) and the Korea Institute of Ceramic Engineering and Technology (KICET).



Carrying out the task of repairing the radioactive waste storage facility



Doing scientific experiments





Doing scientific experiments



Warehouse of Technology Deployment Center (ITRRE)



Radioactive waste storage

3.9. CENTER FOR NUCLEAR TECHNOLOGIES



Workshop to Celebrate the Vietnam Science and Technology Day



Dr. Do Duy Khiem presented a report at the workshop.

3.10. HANOI IRRADIATION CENTER



Within the framework of the trade promotion program for exporting irradiated, quarantine-treated fruits from the Hanoi Irradiation Center to the U.S. market, on July 30, 2024, a delegation of experts from the U.S. Department of Agriculture visited and worked with the Hanoi Irradiation Center to assess technical conditions and facilities in order to ensure compliance with requirements for irradiation-based quarantine treatment of exported fruits.



Regarding the previous recommendations from the U.S. Department of Agriculture on quarantine irradiation equipment, on behalf of the Center, Mr. Trần Minh Quỳnh provided a brief report on the actions the Center has taken since 2022 to meet APHIS requirements.



The expert delegation inspected the irradiation facility and its infrastructure.



The Hanoi Irradiation Center worked with the expert delegation from the Joint Institute for Nuclear Research (Dubna).



The JINR expert delegation visited the control room of the accelerator system.

4- APPENDICES

4.1. LIST OF VINATOM'S INTERNATIONAL SCIENTIFIC PUBLICATIONS IN 2024

(Data updated based on the website <https://vinatom.gov.vn/cong-trinh-cong-bo-quoc-te-nam-2024/>)

No	Name of publications	Authors	Journals
1	Optical model potentials for deuteron scattering off ^{24}Mg , ^{28}Si , ^{58}Ni , ^{90}Zr , ^{116}Sn , and ^{208}Pb at ~ 100 MeV/nucleon	Đỗ Công Cường, Đào Tiến Khoa và cộng sự	Physical Review C Online ISSN: 2469-9993 Print ISSN: 2469-9985
2	Pauli nonlocality and the nucleon effective mass	Đào Tiến Khoa, Nguyễn Hoàng Phúc, Doãn Thị Loan	Physical Review C Online ISSN: 2469-9993 Print ISSN: 2469-9985
3	Nuclear rainbow of the symmetric nucleus-nucleus system: Interchange of the nearside and farside scattering	Đào Tiến Khoa, Nguyễn Hoàng Phúc, Nguyễn Trí Toàn Phúc	Physical Review C Online ISSN: 2469-9993 Print ISSN: 2469-9985
4	Systematics of supernumerary nuclear rainbow in inelastic $^{16}\text{O}+^{12}\text{C}$ scattering	Đỗ Công Cường, Nguyễn Hoàng Phúc, Nguyễn Trí Toàn Phúc	Physical Review C Online ISSN: 2469-9993 Print ISSN: 2469-9985
5	Spectroscopy of deeply bound orbitals in neutron-rich Ca isotopes	Lê Xuân Chung, Bùi Duy Linh và cộng sự	Physics Letters B Online ISSN: 1873-2445 Linking ISSN: 0370-2693
6	Onset of collectivity for argon isotopes close to $N=32$	Lê Xuân Chung, Bùi Duy Linh và cộng sự	Physical Review C Online ISSN: 2469-9993 Print ISSN: 2469-9985
7	Spectroscopy of ^{52}K	Lê Xuân Chung, Bùi Duy Linh và cộng sự	Physical Review C Online ISSN: 2469-9993 Print ISSN: 2469-9985
8	Checking the 8Be Anomaly with a Two-Arm Electron Positron Pair Spectrometer	Đỗ Thị Khánh Linh, Lê Xuân Chung và cộng sự	Universe 2024 EISSN: 2218-1997
9	Benchmarking Geant4 photonuclear process model for the photo-induced reaction of deformed nuclei in the GDR region	Phạm Đức Khuê, Lê Xuân Chung, Đỗ Thị Khánh Linh, Lê Tuấn Anh và cộng sự	Nuclear Instruments and Methods in Physics Research A Online ISSN: 1872-9576 Print ISSN: 0168-9002
10	Angular differential cross section measurement for $^{11}\text{B}(p, \alpha_0)^8\text{Be}$ reaction with proton energy of 2.5 MeV	Đỗ Thị Khánh Linh, Lê Xuân Chung, Lê Tuấn Anh, Phạm Đức Khuê, Mai Văn Diện và cộng sự	Nuclear Physics A Print ISSN: 0375-9474 Online ISSN: 1873-1554

11	Gamma-ray spectroscopy of ^{55}Sc	Lê Xuân Chung , Bùi Duy Linh và cộng sự	Physica Scripta 99 Online ISSN: 1402-4896 Print ISSN: 0031-8949
12	Impact of nonlocality effects in proton optical potential from folding model on $p+^{16}\text{O}$ elastic scattering at low energies	Đỗ Công Cường , Nguyễn Hoàng Phúc, Nguyễn Trí Toàn Phúc	Brazilian Journal of Physics Electronic ISSN: 1678-4448 Print ISSN: 0103-9733
13	Evaluation of fluence-to-dose response function of neutron survey meter using singular value decomposition method	Lê Ngọc Thiêm, Nguyễn Ngọc Quỳnh, Phạm Đức Khuê và cộng sự	Radiation Measurements Print ISSN: 1350-4487 Online ISSN: 1879-0925
14	^{239}Pu -Be neutron reference field: Physical and dosimetric parameters	Nguyễn Ngọc Quỳnh, Lê Ngọc Thiêm và cộng sự	Radiation Physics and Chemistry Print ISSN: 0969-806X Online ISSN: 1879-0895
15	Intercomparison of neutron personal dose equivalent measured by thermoluminescence dosimeters	Lê Ngọc Thiêm, Bùi Đức Kỳ, Nguyễn Ngọc Quỳnh và cộng sự	Applied Radiation and Isotopes Print ISSN: 0969-8043 Online ISSN: 1872-9800
16	Parameter of Neutron Calibration Field in Viet Nam	Lê Ngọc Thiêm	RadioProtection ISSN: 0033-8451 eISSN: 1769-700X
17	Calibration of Ionization Chamber in Megavoltage X-ray Field of Medical Linear Accelerator	Lê Ngọc Thiêm, Lê Tuấn Anh, Nguyễn Hữu Quyết, Nguyễn Ngọc Quỳnh và cộng sự	Nuclear Technology & Radiation Protection ISSN: 1451-3994
18	Impact of the East Asia monsoon on PM _{2.5} acidity in Hanoi	Vương Thu Bắc, Hà Lan Anh, Vương Trần Quang và cộng sự	Atmospheric Pollution Research Online ISSN: 1309-1042
19	Characteristics of natural radionuclides and ^{137}Cs in surface soil in Phonsavan, Xiengkhouang, Laos	Dương Đức Thắng, Lê Ngọc Thiêm và cộng sự	Nuclear Technology and Radiation Protection ISSN: 1451-3994 eISSN: 1452-8185
20	Transfer of natural radionuclides from soil to water spinach (<i>Ipomoea aquatica</i> Forssk) under flooded and unflooded conditions in Hanoi, Vietnam	Dương Đức Thắng, Lê Ngọc Thiêm và cộng sự	Journal of Environmental Radioactivity Online ISSN: 1879-1700 Print ISSN: 0265-931X

11	Gamma-ray spectroscopy of ^{55}Sc	Lê Xuân Chung , Bùi Duy Linh và cộng sự	Physica Scripta 99 Online ISSN: 1402-4896 Print ISSN: 0031-8949
12	Impact of nonlocality effects in proton optical potential from folding model on $p+^{16}\text{O}$ elastic scattering at low energies	Đỗ Công Cường , Nguyễn Hoàng Phúc, Nguyễn Trí Toàn Phúc	Brazilian Journal of Physics Electronic ISSN: 1678-4448 Print ISSN: 0103-9733
13	Evaluation of fluence-to-dose response function of neutron survey meter using singular value decomposition method	Lê Ngọc Thiêm, Nguyễn Ngọc Quỳnh, Phạm Đức Khuê và cộng sự	Radiation Measurements Print ISSN: 1350-4487 Online ISSN: 1879-0925
14	^{239}Pu -Be neutron reference field: Physical and dosimetric parameters	Nguyễn Ngọc Quỳnh, Lê Ngọc Thiêm và cộng sự	Radiation Physics and Chemistry Print ISSN: 0969-806X Online ISSN: 1879-0895
15	Intercomparison of neutron personal dose equivalent measured by thermoluminescence dosimeters	Lê Ngọc Thiêm, Bùi Đức Kỳ, Nguyễn Ngọc Quỳnh và cộng sự	Applied Radiation and Isotopes Print ISSN: 0969-8043 Online ISSN: 1872-9800
16	Parameter of Neutron Calibration Field in Viet Nam	Lê Ngọc Thiêm	RadioProtection ISSN: 0033-8451 eISSN: 1769-700X
17	Calibration of Ionization Chamber in Megavoltage X-ray Field of Medical Linear Accelerator	Lê Ngọc Thiêm, Lê Tuấn Anh, Nguyễn Hữu Quyết, Nguyễn Ngọc Quỳnh và cộng sự	Nuclear Technology & Radiation Protection ISSN: 1451-3994
18	Impact of the East Asia monsoon on PM _{2.5} acidity in Hanoi	Vương Thu Bắc, Hà Lan Anh, Vương Trần Quang và cộng sự	Atmospheric Pollution Research Online ISSN: 1309-1042
19	Characteristics of natural radionuclides and ^{137}Cs in surface soil in Phonsavan, Xiengkhouang, Laos	Dương Đức Thắng, Lê Ngọc Thiêm và cộng sự	Nuclear Technology and Radiation Protection ISSN: 1451-3994 eISSN: 1452-8185
20	Transfer of natural radionuclides from soil to water spinach (<i>Ipomoea aquatica</i> Forssk) under flooded and unflooded conditions in Hanoi, Vietnam	Dương Đức Thắng, Lê Ngọc Thiêm và cộng sự	Journal of Environmental Radioactivity Online ISSN: 1879-1700 Print ISSN: 0265-931X

21	Radiological risk assessment and characteristics of gross alpha and beta activities in vegetables, tubers, and fruits in Hanoi, Vietnam	Lê Đình Cường, Dương Đức Thắng, Nguyễn Huyền Trang, Phạm Đức Khuê và cộng sự	International Journal of Environmental Analytical Chemistry ISSN: 0306-7319 eISSN: 1029-0397
22	International intercomparison and quality assessment of passive and active ²²² Rn measuring devices in the Asia-Pacific region	Lê Đình Cường và cộng sự	Radiation Measurements 178 (2024) Print ISSN: 1350-4487 Online ISSN: 1879-0925
23	Residual, sequential extraction, and ecological risk assessment of some metals in ash from municipal solid waste incineration, Vietnam	Dương Văn Thắng và cộng sự	Green Processing and Synthesis 2024 ISSN: 2191-9550
24	Modeling of the Arsenic Uptake by Brassica perviridis (L. H. Bailey) (Spinach Mustard) Growing on Different Soils Collected in Northern Vietnam	Nguyễn Thị Bảo Mỹ, Hà Lan Anh, Nguyễn Thị Thu Hà và cộng sự	Water, Air, & Soil Pollution, Volume 235 Electronic ISSN: 1573-2932 Print ISSN: 0049-6979
25	Evaluation of soil contamination and health risks associated with consumption of Brassica perviridis grown on various soils collected in Northern Vietnam	Nguyễn Thị Bảo Mỹ, Hà Lan Anh, Nguyễn Thị Thu Hà và cộng sự	Journal of Radioanalytical and Nuclear Chemistry Electronic ISSN: 1588-2780 Print ISSN: 0236-5731
26	Calculation and Uncertainty Analysis of Core Parameters of Advanced Lead-Cooled Modular Nuclear Reactor Using New Nuclear Data Libraries	Phạm Như Việt Hà và cộng sự	ASME J of Nuclear Rad Sci. Jul 2024 Online ISSN: 2332-8975 Print ISSN: 2332-8983
27	Enhancement of Reflood Test Prediction by Integrating Machine Learning and Data Assimilation Technique	Nguyễn Hữu Tiệp và cộng sự	International Journal of Energy Research Online ISSN: 1099-114X
28	Machine learning applications and uncertainty quantification analysis for reflood tests	Nguyễn Hữu Tiệp và cộng sự	Applied Sciences ISSN: 2076-3417
29	Comments on "Evaluation of neutron radiation damage in the VVER-1200 reactor pressure vessel" by Louis et al. [Radiat. Phys. Chem. 221 (2024): 111738]pressure vessel"	Nguyễn Hữu Tiệp và cộng sự	Radiation Physics and Chemistry Print ISSN: 0969-806X Online ISSN: 1879-0895
30	Uranyl ammonium carbonate precipitation and conversion into triuranium octaoxide	Nguyen Trong Hung et al.	Heliyon 10 (2024) e25930 Online ISSN: 2405-8440

31	Adsorption Studies of Ternary Metal Ions (Cs ⁺ , Sr ²⁺ , and Co ²⁺) from Water Using Zeolite@Magnetic Nanoparticles (Z@Fe ₃ O ₄ NPs)	Tung Van Nguyen, Lien Thi Nguyen, Ha Thi Thu Nguyen and et al.	Inorganics 2024, 12, 276 ISSN: 2304-6740
32	Application of ultrasound for leaching of Vietnamese monazite concentrate with NaOH solutions to obtain chlorides of rare earth elements	Hoàng Xuân Thi và cộng sự	Bulletin of the Tomsk Polytechnic University, Geo Assets Engineering ISSN:2500-1019 E-ISSN:2413-1830
33	Study on the adsorption of 2,4-dichlorophenoxyacetic acid on silver doped carbon nanotube using tight-binding quantum chemical method	Bui Cong Trinh and et al.	Computational and Theoretical Chemistry ISSN: 2210271X
34	Comprehensive Study on the Adsorption and Degradation of Dichlorodiphenyltrichloroethane on Bifunctional Adsorption–Photocatalysis Material TiO ₂ /MCM-41 Using Quantum Chemical Methods	Bui Cong Trinh and et al.	ACS Omega, Vol 9/Issue 7 7976–7985, 2024. ISSN/ eISSN: 2470-1343
35	¹⁵³ Sm-labeled Fe ₃ O ₄ @lapatinib nanoparticles as a potential therapeutic agent for breast cancer: synthesis, quality control, and in vivo evaluation	Thanh Minh Pham* , Dong Vu Cao , Ho Hong Quang Dang , Phuoc Minh Thanh Mai , Thanh Binh Nguyen , Ngoc Bao Nam Dinh , Thi Khanh Giang Nguyen , et al.	Journal of Materials Chemistry B ISSN/ eISSN: 2050-750X/ 2050-7518
36	Electrochemical determination of theophylline using a nickel ferrite/activated carbon-modified electrode	Nguyen Mau Thanh, Nguyen Giang Nam, Nguyen Nho Dung, Van Thanh Son Le, Phan Thi Kim Thu*, Nguyen Quang Man, Le Thi Hong Phong, Nguyen Thanh Binh* , et al.	Mater.Res.Express11 (2024) ISSN/ eISSN: 2053-1591
37	Photon Energy Estimation in Diagnostic Radiology using OSL Dosimeters: Experimental Validation and Monte Carlo Simulations	Bui Ngoc Huy* , Pham Van Dung , Huynh Thi Tinh , Nguyen Thi Ha , Nguyen Minh Duc	Radiation Measurements ISSN/ eISSN: 1350-4487/ 1879-0925
38	A Kriging-Based Uncertainty Quantification for Fracture Assessment	Tran C.H. Nguyen and et al.	International Journal of Computational Methods ISSN/ eISSN: 0219-8762/ 1793-6969
39	Count Loss Evaluation for Accuracy Enhancement of Gamma Spectroscopy Based on FPGA	Hoai-Phuong Pham , Viet-Huy Le , The-Dat Trang , and Nhi-Dien Nguyen*	Science and Technology of Nuclear Installations ISSN/ eISSN: 1687-6075/ 1687-6083
40	Thermoluminescence properties of K ₂ GdF ₅ :Tb material irradiated in neutron-gamma fields of ²⁴¹ Am-Be source	Van-Toan Phan , Van-Hung Nguyen* , Hung-Thai Pham , Van-Dung Pham , Dinh-Khoa Tran , Hoai-Nam Tran*	Nuclear Technology & Radiation Protection ISSN/ eISSN: 1451-3994/ 1452-8185

41	Predicting element concentrations by machine learning models in neutron activation analysis	Nguyen Huu Nghia*, Tran Quang Thien*, Tran Tuan Anh, Phan Quang Trung, Nguyen Minh Dao, Tuong Thi Thu Huong, Chau Thi Nhu Quynh	Journal of Radioanalytical and Nuclear Chemistry ISSN/ eISSN: 0236-5731/ 1588-2780
42	4D-printed microneedles from dual-sensitive chitosan for non-transdermal drug delivery	Quang Tuan Che, Jeong WoThông tin chính xác Seo, Korakot haroensri, Minh Hiep Nguyen, Hyun Jin Park*, Hojae Bae*	International Journal of Biological Macromolecules ISSN/ eISSN: 0141-8130/ 1879-0003
43	3D printed multicolor Prussian blue-viologen hybrid electrochromic devices: Toward high contrast ratio and fast switching electrochromic devices	Le Huy Thai, Le Thi Thanh Nhi, Truong Chau Giang, Nguyen Minh Hiep , Truong Quang Trung, Tran Quang Hung, Le Hoang Sinh*	Applied Materials Today ISSN/ eISSN: 2352-9407
44	Enhanced optical bistability of energy saving viologen-based electrochromic display with a commercial phenol-based epoxy resin	Le Huy Thai, Le Thi Thanh Nhi, Truong Chau Giang, Le Van Quyet, Nguyen Minh Hiep , Tran Quang Hung, Le Hoang Sinh*	Solar Energy Materials and Solar Cells
45	All-in-one electrochromic device from viologen-based Cu-MOF and photocurable eutectogel	Le Huy Thai, Le Thi Thanh Nhi, Nguyen Minh Hiep , Dinh Thanh Khan, Trinh Ngoc Dat, Le Vu Truong Son, Truong Quang Trung, Le Hoang Sinh*	Solar Energy Materials and Solar Cells ISSN/ eISSN: 0927-0248/ 1879-3398
46	Bioconcentration and translocation of elements from soil to vegetables and associated health risk	Vu Ngoc Ba*, Bui Ngoc Thien, Huynh Truc Phuong, Truong Thi Hong Loan, Tran Tuan Anh	Journal of Food Composition and Analysis ISSN/ eISSN: 0889-1575/ 1096-0481
47	Systematic investigation on semi-empirical thermodynamic quantities of excited nuclei using canonical ensemble	Vu Dong Tran, Nhut Huan Phan, Quang Hung Nguyen, Xuan Hai Nguyen , Thi Quynh Huong Le and Ngoc Anh Nguyen*	Journal of Physics G: Nuclear and Particle Physics 51 (2024) 065105
48	Observation of a positive-parity wave in the low-energy spectrum of ^7He	A. M. Quynh and et al.	Physical Review C
49	Decay study of ^{11}Be with an optical time-projection chamber	A. M. Quynh and et al.	Physical Review C, 110, 034328, 2024
50	Sensitivity and uncertainty analysis of the first core of the DNRR using MCNP6 and new nuclear data libraries	Duc-Tu Dau, Kien Cuong Nguyen, Nhi Dien Nguyen and et al.	Nuclear Engineering and Design

51	Effects of Gold Nanoparticles on <i>Mentha spicata</i> L., Soil Microbiota, and Human Health Risks: Impact of Exposure Routes	Alexandra Peshkova, Inga Zinicovscaia*, Liliana Cepoi, Ludmila Rudi, Tatiana Chiriac, Nikita Yushin, Tran Tuan Anh , Ho Manh Dung, Serghei Corcimaru	Nanomaterials
52	Radioactivity Concentration and Risk Indices in Intertidal Sediments of the Red River Delta, Vietnam	Phan Son Hai, Le Nhu Sieu , et al.	Environmental Earth Sciences, Volume 83, article number 74, (2024).
53	Pure CaF ₂ crystal for fast neutron detection	Nguyen Duy Quang*, Phan Bao Quoc Hieu , Hongjoo Kim.	Radiation Physics and Chemistry 221, 111756, 2024
54	A gel-based electrochromic device towards fast response and high coloration efficiency for low-power consumption smart window applications	Le Huy Thai, Le Thi-Thanh-Nhi, Truong Chau Giang, Tran Quang Hung, Truong Quang Trung, Nguyen Van Huy, Nguyen Minh Hiep , Le Hoang Sinh*	Organic Electronics, 128, 107040 (2024) ISSN/ eISSN: 1566-1199/ 1878-5530
55	Electron-beam irradiation of ZSM-5 catalyst with a designed sample holder: Simulation and experiment	Phan Trong Phuc, Nguyen Thi Ngoc Hue, Pham Thi Hue, Tran Dong Xuan, Pham Ngoc Son, Ngo Dang Trung, Le Van Toan , et al.	Nuclear Engineering and Technology ISSN: 1738-5733, 2234-358X
56	An antimicrobial acrylic polyurethane coating with TiO ₂ -Ag hybrid nanoparticles	Thien Vuong Nguyen*, Truc Vy Do, Thu Ha Hoang, Tuan Anh Nguyen, Le Trong Lu, Thi Mat Le, Thanh Minh Pham , Raa Khimi Shuib and Dai Lam Tran	Pure and Applied Chemistry ISSN: 0033-4545, 1365-3075
57	Transfer of natural radionuclides from soil to water spinach (<i>Ipomoea aquatica</i> Forssk) under flooded and unflooded conditions in Hanoi, Vietnam	Thi-Hong Bui, Van-Loat Bui*, Van-Hao Duong*, Duc-Thang Duong, Ngoc-Thiem Le, Dinh-Khoa Tran , et al.	Journal of Environmental Radioactivity ISSN: 0265-931X, 1879-1700
58	A Geant4 procedure for precise simulation of PGNAA prompt γ -ray spectrum in a wide energy range up to 8 MeV	Chau Thanh Tai*, Pham Ngoc Son , Tran Thien Thanh, Vo Cong Phat, and Chau Van Tao	Journal of Radioanalytical and Nuclear Chemistry ISSN: 0236-5731, 1588-2780
59	Examining Beam Matching in the Commissioning of a Halcyon Accelerator	Duong Thanh Tai, Hoang Duc Tuan, Nguyen Xuan Hai , et al.	Nuclear Science and Engineering ISSN: 0029-5639, 1943-748X
60	Assessment of the level and risk of radioactive hazards in coastal sediments in northern Vietnam	Dang Hoai Nhon*, Le Nhu Sieu, Phan Son Hai , et al.	Isotopes in Environmental and Health Studies, Volume 60, 2024 - Issue 4

61	Characteristics of natural radionuclides and ^{137}Cs in surface soil in Phonsavan, Xiengkhouang, Laos	Thi-Hong BUI , Van-Loat BUI*, Somsavath LEUANGTAKOUN, Lemthong LATHDAVONG , Sonexay XAYHUANGSY , Duc-Thang DUONG, Dinh-Khoa TRAN , et al.	Nuclear Technology & Radiation Protection ISSN/ eISSN: 1451-3994/ 1452-8185
62	Enhanced capability of model fitting to nuclear level density and heat capacity: testing on $^{93-98}\text{Mo}$ nuclei	Nguyen Ngoc Anh*, Phan Nhut Huan, Nguyen Quang Hung and Nguyen Xuan Hai	Physica Scripta ISSN: 0031-8949
63	Assessment of radioactivity and radiological risk indices in the sediments of the Tam Giang-Cau Hai, Thi Nai, and Nai lagoons in the Center of Vietnam	Dang Hoai Nhon*, Nguyen Van Quan, Phan Son Hai , et al.	Radiochimica Acta ISSN/ eISSN: 0033-8230/ 2193-3405
64	Properties of the ^7He ground state studied by the $^6\text{He}(d, p)^7\text{He}$ reaction	A.M. Quynh , et al.	International Journal of Modern Physics E ISSN/ eISSN: 0218-3013/ 1793-6608
65	An efficient and simple method for enriching metaphase cells for dicentric chromosome assay	Ryo Nakayama, Thanh Mai Tran , et al.	Radiation Protection Dosimetry ISSN/ eISSN: 0144-8420/ 1742-3406
66	Study of proton and deuteron pickup reactions $^2\text{H}(^{10}\text{Be}, ^3\text{He})^9\text{Li}$ and $^2\text{H}(^{10}\text{Be}, ^4\text{He})^8\text{He}$ with 44 AMeV ^{10}Be radioactive beam at Acculinn-2 fragment separator	A. M. Quynh , et al.	Physics of Atomic Nuclei ISSN: 1063-7788, 1562-692X
67	Simulation dataset of thermal and epithermal neutron self-shielding correction factors for $^{186}\text{W}(n, \gamma)^{187}\text{W}$ reaction rate experiments using tungsten foil targets	Trinh T. Tu Anh, Pham Ngoc Son* , Chau T. Tai, Truong Phuong Dung , Trinh Van Cuong , Phan Bao Quoc Hieu , Cao Dong Vu	Data in Brief ISSN/ eISSN: 2352-3409
68	Preparation and characterization of ZnO composite nanomaterials in chitosan oligosaccharide iodine solution	Bui Duy Du, Le Nghiem Anh Tuan, Tran Phuoc Tho, Doan Thi Bich Ngoc, Nguyen Trong Hoanh Phong*	Vietnam J. Chem. ISSN/ eISSN: 2352-3409
69	Assessment of the Performance of the Dose Calibrator Used in Radioactivity Measurement	Dinh Xuan Hoang* , Truong Dinh Vu , Do Van Dan , Nguyen Thanh Nhan	Indian Journal of Nuclear Medicine ISSN/ eISSN: 0972-3919/ 0974-0244
70	Preparation and in vitro antibacterial activity against <i>Pantoea stewartii</i> causing jacking disease of nano ZnO/oligochitosan-iodine complex	Bui Duy Du, Nguyen Trong Hoanh Phong* , Le Nghiem Anh Tuan*, Tran Phuoc Tho, Nguyen Quoc Hien	Vietnam Journal of Science and Technology ISSN: 2525-2518, 2815-5874

71	Theraopeutiec potential of electron beam and gamma irradiation synthesized selenium nanoparticles for health care	Vo Anh Kiet, Truong Thi Bich Ngoc, Tran Thi Thanh Ngoc, Nguyen Ngoc Duy, Dang Thi Phuong Thao, Tran Linh Thuoc, Phan Dinh Tuan and Vu Le Van Khanh	Materials Research Express ISSN: 2053-1591
72	Recognized Ionic Structures in Large Dimension of Graft-type Polymer Electrolyte Membranes Using Pair Distribution Function Expanded for Small Angle X-Ray Scattering	Nguyen Manh Tuan, Nguyen Huynh My Tue, Vo Thi Kim Yen, Nguyen Nhat Kim Ngan, Huynh Truc Phuong, Vinh Nguyen Thanh Pham, Le Quang Luan, Pham Thi Thu Hong, Tran Van Man, and Tran Duy Tap	Macromolecula Chemisty and Physics ISSN: 1022-1352/ 1521-3935
73	Fast and simplified fabrication of Cu/Cu ₂ O nanocomposites for antioxidant and antibacterial activities	Hanh Thi Truong, Thu Hong Thi Pham and Luan Quang Le	Materials Technology ISSN: 1066-7857/ 1753-5557
74	ZnO/TiO ₂ photocatalytic nanocomposite for dye and bacteria removal in wastewater	Hanh Thi Truong, Hai Bang Truong and Thuan Chi Nguyen	Materials Research Express ISSN: 2053-1591
75	Analysis of structural defects and their influence on red-emitting γ -Al ₂ O ₃ :Mn ⁴⁺ ,Mg ²⁺ nanowires using positron annihilation spectroscopy	Pham Thi Hue, Nguyen Thi Ngoc Hue, Phan Trong Phuc, La Ly Nguyen, Lo Thai Son, Luu Anh Tuyen and et al.	Luminescence ISSN: 1522-7243
76	Unraveling Precise Locations of Indium Atoms in g-C ₃ N ₄ for Ameliorating Hydrogen Peroxide Piezo-Photogeneration	Tuyen Anh Luu, Pham Thi Hue, Nguyen Thi Ngoc Hue, et al.	Solar Rapid Research Letter ISSN: 2367-198X
77	Insights into Molten Salts Induced Structural Defects in Graphitic Carbon Nitrides for Piezo-Photocatalysis with Multiple H ₂ O ₂ Production Channels	Tuyen Anh Luu, Pham Thi Hue, Nguyen Thi Ngoc Hue, et al.	Advanced Sustainable Systems ISSN: 2366-7486

4.2. LISTS OF INTERNATIONAL PROJECTS 2024

4.2.1 - LIST OF VIE PROJECTS 2024

(Implemented by VINATOM)

Code	Project Title	Start Year	Finish Year	Budget (Euro)	Field code	Project Counterpart
VIE1011	Enhancing National Capacity for Design and Safety Analysis for a New High Power and Multipurpose Research Reactor.	2024	2025	196.373	08	Tran Chi Thanh VINATOM
VIE1012	Establishment of NDT Personnel Certification Scheme According to ISO 9712	2024	2025	138.895	18	Nguyen An Trung VINATOM

4.2.2. LIST OF INT AND NON-RCA PROJECT 2024

(Implemented by VINATOM)

Code	Project Title	Start Year	Finish year	Budget (Euro)	Field code	Project Counterpart
INT2022	Supporting Capacity Building in Member States for Uranium Production and Safety of Naturally Occurring Radioactive Material Residue Management	2020	2024	517,367.37	7	Tran The Dinh Institute for Technology of Radioactive and Rare Elements, VINATOM
INT9186	Sustaining Cradle-to-Grave Control of Radioactive Sources - Phase II	2020	2024	3,978,603.21	19	Hoang Nhuan Institute for Technology of Radioactive and Rare Elements, VINATOM
INT7022	Strengthening Ocean Health for Sustainable Development: A Global Approach Using Nuclear and Isotopic Techniques	2024-	2025	5.170.154		Tran Tuan Anh Nuclear Research Institute, VINATOM

INT7021	'Contributing to the global monitoring of marine plastic pollution under the IAEA NUTEC Plastic initiative"	2024	2027	999.900		Ha Lan Anh Institute for Nuclear Science and Technology, VINATOM
INT9187	Sustaining Cradle-to-Grave Control of Radioactive Sources – Phase III	2024	2027	1.100.137,50	19	
RAS1033	Strengthening Regional Capabilities and Infrastructure to Support Research Reactor Safe Operation, Utilization and Scientific Research for Prosperous Development.	2024	2027	2.117.700	08	Tran Quoc Duong Nuclear Research Institute, VINATOM
RAS1031	Reutilizing and Recycling Polymeric Waste through Radiation Modification for the Production of Industrial Goods – Phase II	2024	2027	1.536.853,55	18	Nguyen Ngoc Duy Center for Nuclear Technologies, VINATOM
RAS1027	Improving the Utilization of Nuclear Techniques for Cultural Heritage Characterization, Consolidation, and Preservation	2022	2025	270.900,00	18	Tran Quang Thien Nuclear Research Institute, VINATOM
RAS1030	Using Radioisotope Techniques and Computational Fluid Dynamics Simulation for Troubleshooting and Optimizing of Industrial Processes	2020	2025	419.250,00	18	Dang Nguyen The Duy Centre For Applications of Nuclear Technique in Industry, VINATOM
RAS5096	Strengthening Multi-Stakeholder Food Safety Monitoring Programmes for Chemical Contaminants and Residues in Plant and Animal Products Using Nuclear/Isotopic Techniques	2022	2025	1.283.755	24	Nguyễn Tiến Đạt Nuclear Research Institute, VINATOM
RAS7038	Monitoring the Marine	2022	2025	892.800,00	17	Hà Lan Anh

	Environment for Enhanced Understanding of the Abundance and Impact of Marine Plastic Pollution						Institute for Nuclear Science and Technology, VINATOM
RAS9093	Strengthening Technical Services in Occupational Radiation Protection in Compliance with the International Basic Safety Standards	2022	2025	858.690,00	12		Phan Văn Toàn Nuclear Research Institute, VINATOM
RAS9094	Enhancing Nuclear Emergency Preparedness and Response in the Member States of the Association of Southeast Asian Nations	2022	2025	1.286.670	16		Phạm Quang Huy Nuclear Research Institute, VINATOM
INT2022	Supporting Capacity Building in Member States for Uranium Production and Safety of Naturally Occurring Radioactive Material Residue Management	2020	2024	517,367.37	7		Tran The Dinh Institute for Technology of Radioactive and Rare Elements, VINATOM
INT9186	Sustaining Cradle-to-Grave Control of Radioactive Sources - Phase II	2020	2024	3,978,603.21	19		Hoang Nhuan Institute for Technology of Radioactive and Rare Elements, VINATOM

4.2.3 - LIST OF FNCA PROJECTS 2024

(Participated by VINATOM and other Vietnam organizations)

Field	Project Title	Project Coordinator
Research Reactor Utilization Development	Research Reactor Utilization	Dr. Pham Thanh Minh Director, Center for Research and Production of Radioisotope, Nuclear Research Institute (NRI) Vietnam Atomic Energy Institute (VINATOM)
		Dr. Tran Tuan Anh Head, Department of Nuclear Technique and Isotope Applications Research Nuclear Research Institute (NRI) Vietnam Atomic Energy Institute (VINATOM)
Radiation Utilization Development (Agricultural/ Healthcare /Industrial/ Environmental Utilization)	Mutation Breeding	Dr. Le Duc Thao Deputy General Director Agricultural Genetics Institute (AGI) Ministry of Agriculture and Rural Development (MARD)
	Radiation Oncology	Dr. Nguyen Cong Hoang Head of General Radiation Oncology Department National Cancer Hospital (K Hospital)
	Radiation Processing and Polymer Modification for Agricultural, Environmental and Medical Applications Project	Dr. Nguyen Ngoc Duy Head of Research and Development Department, Research and Development Center for Radiation Technology (VINAGAMMA), Vietnam Atomic Energy Institute (VINATOM)
	Radiocarbon-based approach to evaluating the CO ₂ emission from forest soils in Asia	Mr. Phan Quang Trung Deputy Head, Department of Nuclear Technique and Isotope Applications Research Nuclear Research Institute (NRI) Vietnam Atomic Energy Institute (VINATOM)
	Combating Food Fraud using Nuclear Technology	Dr. Nguyen Thi Hong Thinh Head of the Department of Planning and International Cooperation Institute for Nuclear Science and Technology (INST) Vietnam Atomic Energy Institute (VINATOM)

Nuclear Safety Strengthening	Radiation Safety and Radioactive Waste Management	Mr. Nguyen Thanh Thuy Deputy Head Radioactive Waste Management Center Institute for Technology of Radioactive and Rare Elements (ITRRE) Vietnam Atomic Energy Institute (VINATOM)
Nuclear Infrastructure Strengthening	Nuclear Security and Safeguard	Ms. Bui Thi Thuy Anh Director, International Cooperation Division Vietnam Agency for Radiation and Nuclear Safety (VARANS)

4.2.4 - LIST OF RAS PROJECTS 2024

(Participated by VINATOM and other Vietnam organizations)

Code	Title	Year of approval	Budget (EUR)	Project Type	Project Coordinators
RAS1028	Improving the Quality Management Practices in Radiation Processing Facilities for Better Performance and Applications	2022	641.150,00	RCA	Mr. Tran Minh Quynh Hanoi Irradiation Center, VINATOM
RAS1029	Enhancing Regional Capabilities in Advanced Non-Destructive Testing Techniques for Improved Safety and Inspection Performance in Industries	2022	660.625,00	RCA	Mr. Nguyen The Man Non-Destructive Evaluation Center, VINATOM
RAS5088	Enhancing Crop Productivity and Quality through Mutation by Speed Breeding	2020	425.250,00	RCA	Mr. Le Duc Thao Agricultural Genetics Institute
RAS5091	Assessing and Mitigating Agro-Contaminants to Improve Water Quality and Soil Productivity in Catchments Using Integrated Isotopic Approaches	2022	541.800,00	RCA	Ms. Nguyen Thi Huong Lan Nuclear Research Institute, VINATOM
RAS5101	Using Mutational Biofortification for Improving the Nutritional Quality of Food Crops	2024	790.650,00	RCA	Mr. Le Duc Thao Agricultural Genetics Institute
RAS6098	Improving the Quality and Safety of Radiation Medicine through Medical	2022	637.400,00	RCA	Mr. Nguyen Cong Hoang National Cancer

	Physicist Education and Training				Hospital
RAS6100	Strengthening Clinical Application of Hypofractionated Radiotherapy	2022	490.000,00	RCA	Mr. Bui Quang Bieu Central Military Hospital 108
RAS6101	Improving the Quality and Safety of Radiation Medicine through Medical Physicist Education and Training	2022	617.000,00	RCA	Mr. Tran Ngoc Toan Institute for Nuclear Science and Technology, VINATOM
RAS6105	Improving Cancer Management through Theranostics by Using Radioisotope Based Diagnostic and Therapeutic Techniques	2024	689.850,00	RCA	Mr. Mai Trong Khoa Bach Mai Hospital
RAS6108	Strengthening Cancer Care by Training Radiation Oncology Health Professionals in Consistent and Accurate Data Collection through Oncology Information Systems	2024	397.500,00	RCA	Mr. Bui Quang Bieu Central Military Hospital 108
RAS6109	Improving the Quality and Safety of Diagnostic and Interventional Radiology Services to Benefit Health Care by Enhancing the Status, Knowledge and Skills of Medical Physicists	2024	804.825,00	RCA	Mr. Ho Quang Tuan Institute for Nuclear Science and Technology, VINATOM
RAS6110	Improving the Radiotherapy Capacity of Newcomer Government Parties	2024	413.175,00	RCA	Mr. Le Van Tinh Vietnam National Cancer Hospital
RAS7040	Improving Water Resources Management Practices by Enhancing the Regional Collaboration in Environmental Isotope Analysis and Applications	2022	630.775,00	RCA	Mr. Dang Duc Nhan Institute for Nuclear Science and Technology, VINATOM
RAS7043	Evaluating the Efficacy of Artificial Recharge to Groundwater in Water Scarce Regions using Isotope Techniques	2024	870.90,00	RCA	Ms. Vo Thi Anh Institute for Nuclear Science and Technology, VINATOM
RAS9092	Strengthening the Capacity	2020	324.450,00	RCA	Mr. Pham Hung

to Respond to Radiological
Emergencies of Category II
and III Facilities

Thai
Nuclear Research
Institute,
VINATOM

The ANNUAL REPORT for 2024

Edited by
Vietnam Atomic Energy Institute
59 Ly Thuong Kiet, Ha Noi, Vietnam
President: Dr. TRAN Chi Thanh
Tel: +84-24-39423434

This report is available from:
Department of Planning and R&D Management
Vietnam Atomic Energy Institute
59 Ly Thuong Kiet, Ha Noi, Vietnam
Tel: +84-24-39423591
Cell: +84-976-681529
E-mail: phamtrangvinatom@gmail.com

DRAFT