

# **ANNUAL REPORT**

# **2022**

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**VIETNAM ATOMIC ENERGY INSTITUTE**

# **The** **ANNUAL REPORT** **for 2022**

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**Hanoi, November 2023**

The VINATOM Annual Report for 2022 has been prepared as an account of works carried out at VINATOM for the period 2022. Many results presented in the report have been obtained in collaboration with scientists from national and overseas universities and research institutions.

### **The ANNUAL REPORT for 2022**

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## Preface

Following the new format of the Annual Report 2021, the Annual Report for 2022 of Vietnam Atomic Energy Institute is modified, completed, and issued. Despite the ongoing COVID-19 pandemic in the first half of the year, this report aims to summarize the significant activities of the Institute during the period 1 January to 31 December 2022.

The first main part of this publication seeks to provide the **status of the Institute and illustrative descriptions of the Institute's activities** within the context of unprecedented difficulties in enduring and coping with severe consequences of the pandemic. Refusing to step back, under the direction of the Board of Management, Vietnam Atomic Energy Institute has flexibly and determinedly made huge efforts to surpass certain obstacles and achieved proud results in terms 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 the Institute's 2022 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.

**The Editorial Board**

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## 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<br>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                                                                                                                    |

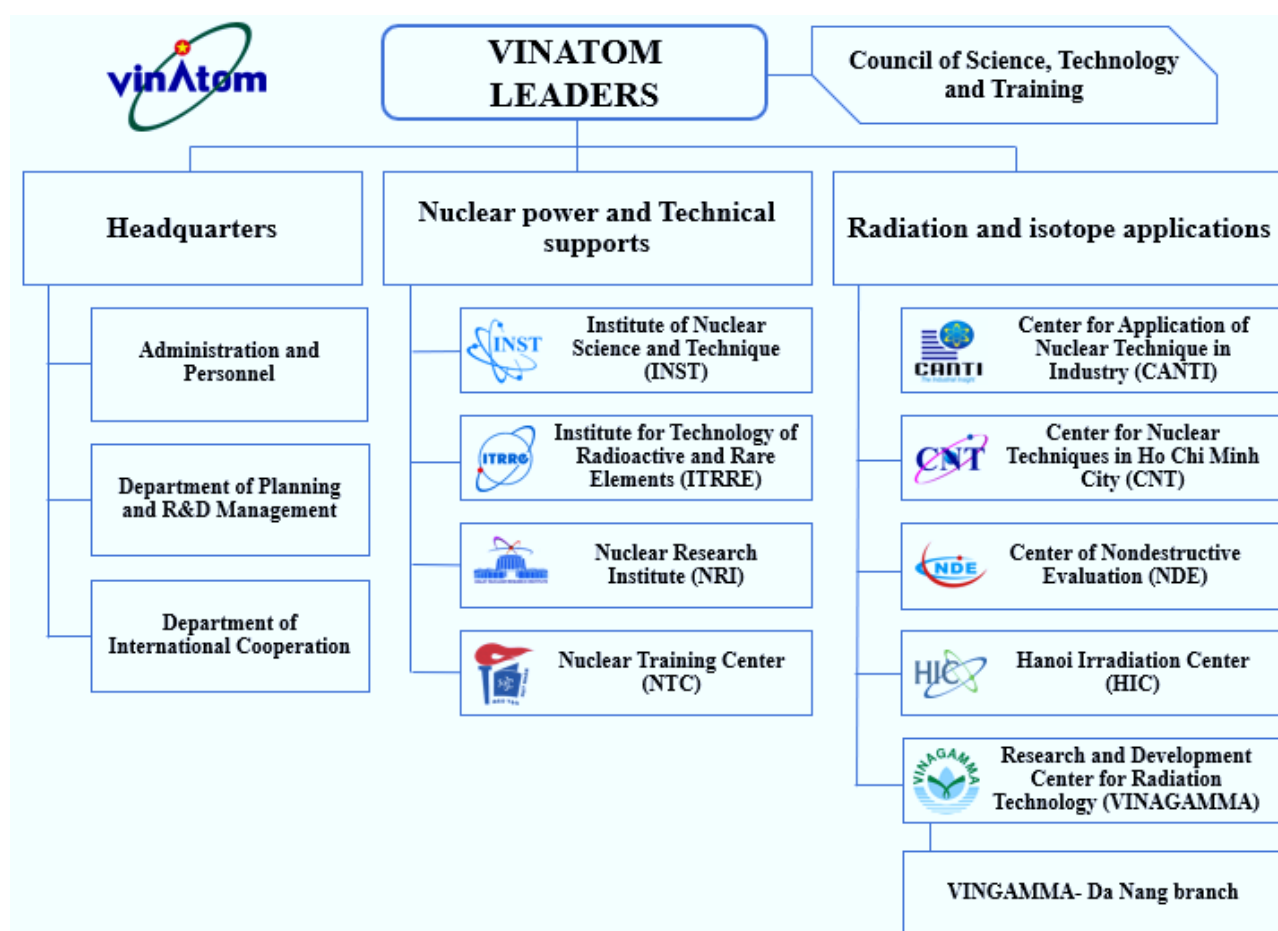
# **1- VINATOM 2022**

## 1.1. VINATOM MEMBERS AND HUMAN RESOURCES

Vietnam Atomic Energy Institute, 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. The current organizational structure of VINATOM is as follows:

COMPOSITION OF VINATOM LEADERS (2021-2022):

- Dr. TRAN Chi Thanh, President
- Dr. TRAN Ngoc Toan, Vice-President
- Dr. PHAM Quang Minh, Vice-President



(\*) 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.

By the end of 2022, VINATOM has **768 officials and contract staff members** (232 of whom are women, which accounts for 30.2 %). According to Decision No. 614/QĐ-BKHCN dated April 26, 2022, VINATOM has been assigned 612 working people.

In terms of professional qualifications, there are 77 doctorates (including 02 professors and 11 associate professors), 217 masters, 381 people with bachelor's degrees and 93 people with intermediate and elementary education degrees. In other words, VINATOM has 14 senior researchers and equivalent, 81 principal researchers and equivalent, 535 researchers, engineers and equivalent, 35 technicians and equivalent, and 103 support staff. In terms of age, there are 135 people under the age of 30 (corresponding to 17.7 %), 360 people in the 30-40 age group (47.2%), 152 people in the 40-50 age group (19.9%), There are 87 people in the age group from 50-60 years old (11.4%) and 34 people over 55 years old (female) and over 60 years old (male) whose working time is extended. This is shown in Figure 2.

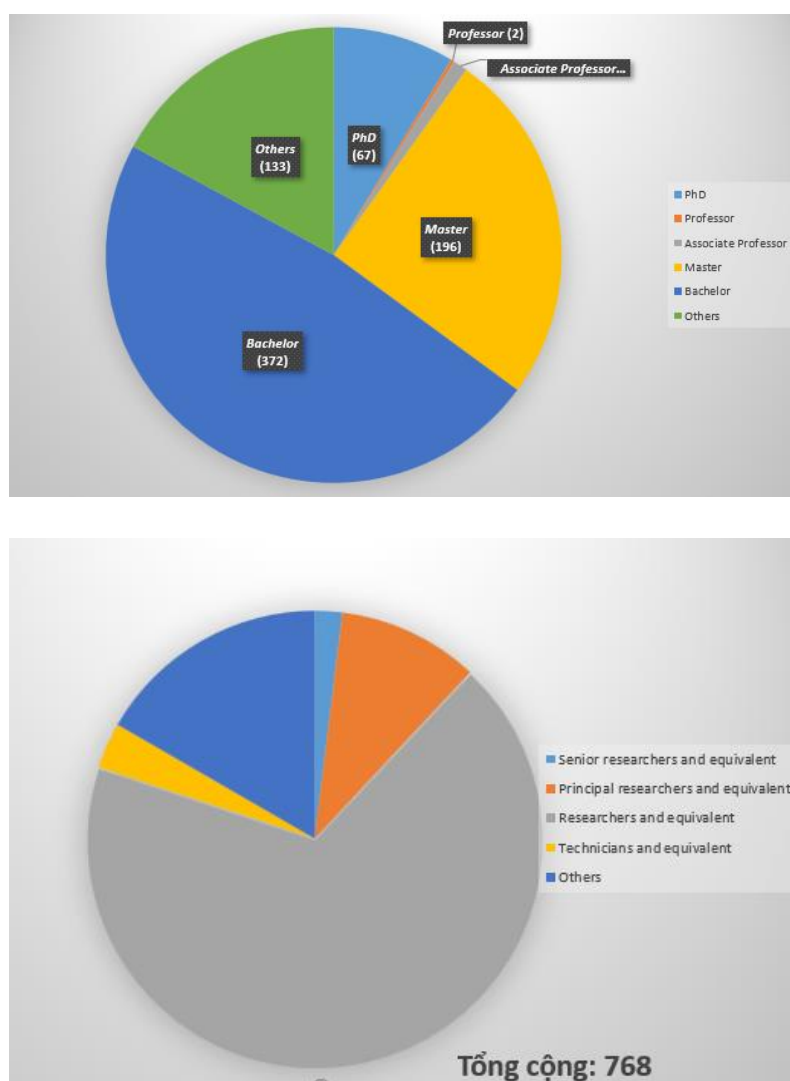


Figure 1 and Figure 2. Academic levels of VINATOM's staff

## 1.2. INVESTMENT RESOURCES

In 2022, the state-funded resources for implementing activities of VINATOM was **more than 120 billion VND.**

## 1.3. VINATOM AND THE COVID-19 PANDEMIC

In the first half of the year 2022, the Covid-19 epidemic situation remained complicated and unpredictable, which significantly affected the recovery of socio-economic development of our country in general as well as on the research and application implementation of our members. In addition, the Russia-Ukraine conflict has caused certain impacts on bilateral cooperation between our country and these two countries. Timely adapting to the challenging circumstances, VINATOM continued carrying out its functions, promoting the spirit of solidarity, and mobilizing all resources to successfully complete key tasks, raising vigilance and preventing the pandemic, protecting people's health and maintaining the stability of employees' lives. With the determination to actualize the Government's annual theme *"Solidarity and discipline, proactive adaptation, safety and efficiency, recovery and development"*, VINATOM focused on instructing and supervising its members to strictly implement the Directives and Resolutions of the Party and the Prime Minister's directions. Additionally, VINATOM detailed the tasks which were assigned in the Action Program following Resolution No. 01/NQ-CP dated January 8, 2022 and Resolution No. 02/NQ-CP dated January 1, 2022 of the Government issued enclosed with Decision No. 60/QD-BKHCH dated January 24, 2022 on assigning tasks to MOST's units. For VINATOM, the tasks of scientific and technological research and innovation were essential to closely associate with those of socio-economic development of the country, thereby giving top priority to the directions of research and development of application of atomic energy, nuclear and radiation safety for peaceful purposes.

VINATOM's members were required to closely follow the research contents, accelerate the progress in implementing the scientific and technological research projects at all levels and environmental tasks assigned by MOST's leaders in the work plan of 2022, issued together with Decision No. 413/QD-BKHCH dated March 24, 2022. Accordingly, the quality of research products was paid attention from the first months of the year. VINATOM kept working with localities to apply scientific research to socio-economic development and giving priority to applied research and deployment in industry, agriculture and health, application of nuclear techniques and radiation technology in many fields of the country, research and development of new and high-tech technologies in the field of atomic energy. The application for registration of the pharmaceutical circulation was completed. Da Lat nuclear reactor was safely operated and efficiently exploited. The nuclear techniques were applied for socio-economic development such as production and supply of radioisotopes, and services of sample analysis, personal dosimetry and equipment calibration services, environmental impact assessment and monitoring, production and supply of agricultural products, product

certification, VietGAP, etc. VINATOM's scientific research results have also been shown by the scientific publications published in 2022 in prestigious international and domestic journals.

Under the close guidance of VINATOM, its members properly performed the role of an independent national institute of technical assistance in inspection, assessment and quality assurance, nuclear safety and security and environmental protection to support for socio-economic development programs. International cooperation and joint ventures with domestic and foreign organizations and individuals were strengthened in scientific research, technology application as well as training to improve the capacity of scientific research. Accordingly, the management of doctoral training was completed; the cooperation in postgraduate training in the field of atomic energy was bolstered; the professional training in atomic energy was carried out in accordance with the provisions of law. On the other hand, proposals and plans were progressed while the payment for investment projects was surmounted. Also, experimental equipment was safely and effectively operated and maintained. Furthermore, information and propaganda activities were boosted with standardized portals, publications and information materials on atomic energy in line with the laws.

Throughout the year, VINATOM strived to successfully complete the tasks of scientific research and technology deployment as planned.

## **1.4. RESULTS OF RESEARCH, DEVELOPMENT AND APPLICATIONS**

### **1.4.1. HIGHLIGHT OF RESEARCH ACTIVITIES AND SERVICE IMPLEMENTATION**

With the goal of improving the national capacity of nuclear science and technology, approaching the advanced research orientations in the field of atomic energy application in the world, promoting the application and development of radiation technology and radioisotopes in economic and technical branches, VINATOM's members actively strengthened the application and implementation in production and achieved the outstanding results as follows:

- NRI: Safe operation and efficient exploitation of Da Lat Reactor (LPU) with total operating time at rated capacity reaching 4,530 hours (surpassing the target by 51%). Having overcome difficulties and challenges, NRI made many technical improvements to increase the production of radiopharmaceuticals to meet the hospitals' needs under the circumstance of drug shortage due to supply shortage and instability of imports. The output of radiopharmaceuticals supplied in 2022 is 1,166 Ci, which surpassed the target by ~ 16%).

- NRI: Frequent improvement of the management system to support the promotion of atomic energy's applications for socio-economic development such as making a good practice in radioactive drug production (WHO GMP); ISO 9001:2015, ISO/IEC 17025:2017; VIMCERTS and being qualified for VietGAP certification.

- HIC: Attainment of the certificate of ISO 9001: 2015 Quality Management System for irradiation and training services in the field of atomic energy.

- INST: Regular operation of the environmental radiation monitoring and warning network, including 11 stations for monitoring radioactivity in the gaseous environment located in localities and 01 control center. The database of radioactive background in key areas that may be affected early from transboundary nuclear radiation incidents was kept up to date.

- With the growth by 9.2% compared to the same period of 2021, the revenue reached VND 372.51 billion. The production of zinc products at the Technology Implementation Center (under ITRRE) was still at the top with the revenue of VND 185 billion.

- The international cooperation in 2022 of VINATOM is one bright spot after two beleaguered years seriously affected by the Covid-19 epidemic. As the current holder of RCA National Coordinators' rotating presidency, VINATOM successfully held the 44th RCA National Coordinator Conference virtually in April 2022 and the RCA Ministerial Conference on September 26, 2022 in Vienna, Austria. NRI was honored to receive the RCA award for human resource development on the 50th RCA anniversary. The relevant research projects and contracts have been effectively operating and making a significant contribution by numerous means.

#### **1.4.2. SCIENTIFIC RESEARCH**

In 2022, 34 scientific research and technological development projects which belonged to Ministerial-level Program of Science and Technology for the period of 2021-2025 "*Application of nuclear and radiation technology in economic and technical sectors*" and the group of other ministerial R&D projects were assigned to VINATOM (18 ongoing ministerial projects and 16 new ministerial projects). In addition, there were 06 projects of environmental protection and 18 projects of science and technology at institutional level. In general, the scientific research projects were more closely linked to the socio-economy of the country. Moreover, it is noteworthy that VINATOM was getting more and more excited by scientific research thanks to the soaring number of young researchers involved in these activities.

##### **1.4.2.1. Basic research**

##### **Nuclear Physics Research**

The research team from NRI implemented 01 basic research project funded by National Foundation for Science and Technology Development (Nafosted), with the aim of measuring nuclear data and level structure of some unstable heavy nuclei ( $^{153}\text{Sm}$ ,  $^{162}\text{Dy}$  and  $^{172}\text{Yb}$ ).

Another research team who followed this research orientation was from the Center for Nuclear Physics, INST. They focused on the study of nuclear structure and nuclear interaction through microscopic description of nuclear reactions, study on the physics of

nuclei far from the stability line, expanded both theoretical and experimental studies of low-energy nuclear reactions which is associated with nuclear astrophysics, and conducted their researches on domestic accelerators. In 2022, one ministerial-level project *“Study on the structure of the neutron-rich isotopes neighboring  $^{49}\text{Ar}$  and  $^{78}\text{Ni}$  nuclei through the experiments of direct nuclear reaction at medium energy region”* was completed by INST. The other ministerial-level project *“Study on nuclear reactions of natural boron isotope on a low-energy proton beam from the 5SDH-2 Pelletron accelerator”* is still in progress by INST and HIC.

Regarding to this research orientation, 20 ISI publications, 04 domestic articles and 14 reports at international and domestic scientific conferences were published.

### **Research on Reactor Physics, Technology and Safety**

The research team from NRI implemented 02 ministerial-level projects with the following objectives: (i) Updating the preliminary plan for all clean-up of radioactivity and progressive dismantling of Da Lat reactor after its retirement from operation; (ii) Developing the requirements and criteria for periodic safety assessment for Da Lat reactor; (iii) Assessing Da Lat reactor’s capability of continuing well in the next 10 to 15 years; (iv) Preparing the application for re-grant of Da Lat reactor’s operating license.

Apart from doing research on power reactors, INST strengthened the studies on physics and technology of research reactors, small modular reactors, floating nuclear power stations (Center for Energy - Institute of Nuclear Science and Technology). Since 2022, the two-year project at ministerial level *“Study on physical and hydrothermal design and safety analysis of small modular nuclear reactors for floating nuclear power plants”* has been carried out. The research team of the Center for Nuclear Energy, INST has been doing research to propose the concepts and fundamental design of the core and the hydrothermal and safety systems for SMR-VN1 reactor.

Meanwhile, one ministerial-level project *“Research and development of a research reactor core simulation program based on reactor physics and fluid dynamics”* was conducted by CNT, Ho Chi Minh City.

Regarding to this research orientation, 6 ISI publications, 11 reports at international scientific conferences, 3 domestic conferences were published.

### **1.4.2.2. Handling and processing of radioactive ores, nuclear fuel and materials, and radioactive waste**

The research and development of rare earth ore processing technology and research into application of rare earth elements continued to be strengthened at ITRRE. Some scientific and technological projects were being carried out, including: Application and development of technological process for extraction and division of rare earths from total rare earths Ben Den; Research on disease resistance and growth effects of rare earth organic products on pangasius; Synthesis of some rare earth complexes to produce rare earth fertilizer and test their effectiveness on medicinal plants. In 2022,

positive results were obtained by the research team on rare earth applications in agriculture. The research group has produced and applied for a number of rare earth trace preparations on the combined use of nanotechnology and radiation which were experimented in livestock such as pigs, chickens and in aquaculture such as white-legged shrimp, sturgeon, pangasius.

In terms of cultivation, organic fertilizers containing rare earth elements and nanosilica have been tested on rice plants in Can Tho province over 3 rice crops with 10 hectares, helping to increase rice yield and reduce the use of inorganic fertilizers. These fertilizers have also used for tea plants in Thai Nguyen in the past few crops for good yield and high quality. Currently, ITRRE is coordinating with several companies in producing animal feed and fertilizers to conduct a larger scale pilot for further aim of licensing the production and business.

Another area which was in progress at ITRRE in 2022 was the research and development of beach sands processing technologies in sustainable and environmentally friendly manners. The ministerial project of improving the efficiency of the decomposition of monazite concentrates by alkaline method with the soundwave technology was implemented at ITRRE was implemented by ITRRE. In addition, the cooperation with Hung Thinh Company and Ukraine Titanium Institute in researching technology to produce titanium from Ilmenite was actively bolstered.

Regarding the research direction on nuclear fuel and (radioactive) waste treatment by the implementation of ministerial projects. 01 project conducted by ITRRE was the research on technology for the preparation of high-density  $U_3O_8$  to support the process of manufacturing low-enriched nuclear fuel for research reactors and improving the efficiency of Vinacomin's wastewater treatment process with activated lime milk. Meanwhile, another ministerial project was carried out by NRI with the objective of fabrication of a measurement system to determine the activity and activity distribution of gamma-emitting isotopes in radioactive waste bins of NRI by TGS (Tomography Gamma Scanning) technique. The research results of the project "The process of treating industrial wastewater containing iron and manganese with activated lime milk" have been submitted to the Department of Intellectual Property, Vietnam to apply for utility solution patent.

#### **1.4.2.3. Application of nuclear and radiation technology**

##### **Research on preparation/production of radioisotopes**

The research on the application of nuclear and radiation technology in the production of radioisotopes continued to be promoted and expanded at NRI and HIC.

NRI conducted 2 ministerial projects with the following objectives: (i) Synthesis of composite based on high purity activated carbon and metal ferrite with high adsorption capacity for the production of  $^{99}Mo/^{99m}Tc$  generators on Da Lat reactor; (ii) Preparation of  $Fe_3O_4@lapatinib-^{153}Sm$  radioactive nanoparticles; (iii) Assessment of acute toxicity and

biodistribution of  $\text{Fe}_3\text{O}_4@\text{lapatinib-}^{153}\text{Sm}$  in experimental animals causing breast cancer.. Regarding to these two projects, 03 ISI articles, 07 national journal articles and 02 domestic conference reports were published.

HIC collaborated with Faculty of Nuclear Medicine, Accelerator Center, 108 Central Military Hospital and Department of Pharmaceutical Chemistry, Hanoi University of Pharmacy to develop a state-level science and technology project on radiopharmaceutical  $^{18}\text{F}$ -PSMA 1007 used to diagnose prostate cancer with the following objectives: i) Development of radiopharmaceuticals with potential applications in diagnosis and treatment; ii) Development of techniques for testing, analyzing and evaluating radiopharmaceuticals quality; iii) Applications of radiochemistry in other fields.

### **Research and application of nuclear and radioisotope techniques**

INST built and developed the capacity to research and apply physical methods, nuclear techniques, and applied isotope techniques in several fields such as water resource assessment, plastic waste pollution, quality authentication and traceability of agricultural products by conducting these following projects: 01 ministerial project “Study on isotope technique application for hydraulic relationship between the Red River flow and unconfined aquifers from Son Tay to Hung Yen”, 01 international cooperation project named IAEA RAS5081 “Enhancement of food safety and assistance on the inspection of food items in the region using nuclear techniques”. The research teams had 03 international publications (two of which on the ISI list), 03 domestic papers and 02 domestic scientific conference reports.

CNT carried out 01 ministerial project “Research on determination of the age, origin and level of aquifers in the Southwest region” and 01 institutional project “Monitoring isotope composition in rainwater and river water for the study of water resources in the Southern region by isotope hydrology techniques”.

CANTI promoted the applications in the oil and gas field; accordingly, 02 ministerial projects were conducted: “Research on the method, design and manufacture of leak detection equipment in gas-lift wells using chemical tracking techniques” and “Research on the tracking characteristics of some Perfluorocarbon compounds (PFCs) applied to gas injection survey in oil fields. Additionally, the institutional project “Study on the application of the 2D gamma tomography technique to survey the differential of liquid phases on trays in refinery plants” created the main tools for performing 2-D gamma scanning, thereby making an important contribution to improving the gamma column scanning technique. Another institutional project “Calculation of partition coefficients of some Perfluorocarbons (PFCs) gas tracer in two condensate-gas phases at reservoir conditions” was completed. The calculation method of the project can also be extended as part of the algorithm for simulating the movement of the PFC gas tracers using the E300 software to explain the tracer results and improve the simulation model of oil companies. On the other hand, in 2022, CANTI’s proposal for 01 National Science and Technology Project (under Program 562) on “Research on building a dataset of isotopic

composition in rainwater, surface water and underground water to determine the source and replenishment for groundwater in the Dong Nai river basin in the Southeast" was approved. MSc. Bui Quang Tri, Director of CANTI was appointed to be the project's leader according to Decision No. 2570/QĐ-BKHCHN dated December 20, 2022 of MOST.

### **Research on ionizing radiation measurement standards and radiation safety**

This research area of VINATOM is of great importance to support regulatory agencies in radiation safety and contribute to promoting the applications of atomic energy and make great contribution to socioeconomic development. In 2022, the implemented tasks include:

INST conducted 01 ministerial project (2022-2024) "*Research on establishing the database for machine learning application in PET/CT image processing to support lung cancer diagnosis*" and 01 institutional project "*Establishment of photon dose standard fields using multi-source gamma system and X-ray generator system*". The research teams had 02 international publications, including 01 article in the ISI list, 02 domestic articles and 01 domestic scientific conference report.

NRI carried out 02 ministerial projects with the following objectives: : (i) Finalizing the manufacturing process of  $K_2GdF_5:Tb$  materials and determining the radiation sensitive characteristics of photon and neutron for  $K_2GdF_5:Tb$  materials; (ii) Developing a level II dose standards of radioactivity for radiopharmaceuticals to serve medical examination and treatment and develop a process for a standard sample preparation of I-131 radiopharmaceutical. The research team had 01 publication in ESCI international journal and 01 domestic conference report.

#### **Nuclear electronics, reactor measurement and control**

NRI carried out 02 ministerial projects with the following objectives: Designing and manufacturing several functional modules (reactivity measurement, power maintenance control, control of technological parameters) of the Da Lat reactor's control system by DSP technique using FPGA technology. The research teams had 01 national journal publication and 01 domestic conference report.

INST collaborated with HIC to carry out 01 ministerial project (2021-2022) "*Study on design and construction of cosmic-ray neutron detector using multi-layered scintillators for soil moisture measurement*". The system for measuring cosmic-ray neutrons in the environment to determine soil moisture was manufactured withing the framework of the project. The relevant details can be found in Part 2 – Research Reports of this Annual Report.

HIC carried out 02 ministerial projects with the objectives as such: (i) Mastering the technology, upgrading the water target transfer system and building a particle beam current measurement system on the target to ensure safe operation of the KONTRON-13 cyclotron accelerator; (ii) Designing and manufacturing of multi-channel spectrometers with integrated alpha, beta, and neutron detectors using PIN photodiode for the purpose

of measurement and radiation control. In addition, the project "Experimental Production of a multi-band radiometer with integrated surface contamination measurement function for military purposes" was implemented by HIC in cooperation with the Military Institute of Environmental Chemistry under Chemical Army, Ministry of Defense to design and manufacture 05 radiometric devices. With the research project's results in the year 2022, 01 international journal article, 01 national journal article, 01 international conference report (co-author), 02 reports at Conference of nuclear science and technology for young researchers were published.

VINAGAMMA was responsible for the Institutional project "Research, design and manufacture of the Bridgman furnace applicated in scintillation crystals growth use in radiation measurement". Accordingly, the research team successfully fabricated a Bridgman-type crystal furnace capable of growing KDP crystals ( $\text{KH}_2\text{PO}_4$ ), NaI crystals and CsI crystals. KDP crystals are used as electro-optical modulators, optical switches (Q-Switches) and laser frequency modulators through quadratic and third-order nonlinear effects. NaI crystals are widely used in nuclear medicine, logging, environmental monitoring, high-energy physics, and in many other applications. CsI crystals are useful in applications such as specialized applications in high-energy, nuclear, space and medical physics.

CANTI is in charge of an ongoing ministerial project (2022-2024) "Research, design and manufacture of mobile devices for gamma radiation detection using plastic scintillator detector".

NDE is currently implementing a ministerial project (2022-2023) "Research, design and manufacture of the magnetic particle testing system to meet the required standards of the American Society for Testing and Materials (ASTM). A number of the system's components have been done.

### **Research on applications of radiation technology and biotechnology**

NRI took full responsibility for conducting 01 ministerial project as well as 01 research contract with IAEA, with the following objectives: (i) Preparation of nanoliposomes encapsulating natural radioprotectants for supporting radiotherapy in cancer treatment; (ii) Expanding the application of biological dose method, in particular, the potential of using indicators in biological dose to personalize radiation, standardize cell genetics in biological dose for response to emergency radiation situations, promoting the laboratory network. Regarding this project, 02 ISI articles, 03 ESCI articles, 01 Scopus article, 01 international specialized book chapter, 05 national publications, 01 international conference report and 06 domestic conference reports were published.

The prioritized research team at HIC implemented 02 ministerial topics with the aim of promoting the application of irradiation: (i) Potential microbiological mutations used in biology and agriculture; (ii) Create substances with biological activity, functional materials; (iii) Producing preparations and products applied in sustainable agricultural

production. In 2022, with reference to this research direction, 01 international article ISI, 02 domestic articles and 02 national conference reports were published.

Concerning this research orientation, VINAGAMMA worked on 02 ministerial projects, including “Study on the procedures for phytosanitary irradiation longan fruit, mango, dragon fruit on Electron beam accelerator UELR-10-15S2” (01 international article and 01 domestic article) and “Study on decontamination of azo dye residues from textile wastewater by electron beam irradiation in action with biological treatment. In addition, 02 Institutional projects were performed: “Study on the formation of Maillard reaction products of chitosan and glucosamine induced by gamma irradiation method for application of pork fillet preservation” and “Synthesis of Cu/TiO<sub>2</sub> nanocomposite material by electron beam irradiation for photo-degradation of organic substances in leachate”.

CNT was accountable for 01 ministerial project “Study on enhancing the activity of ZSM-5 zeolite in cracking reaction by electron irradiation”.

### **Research and develop technical support capacity in terms of safety, security and environmental protection**

The National network of environmental radiation monitoring and warning continued to be developed with the aim of timely detecting any abnormal developments in radiation throughout the territory of Vietnam, supporting the proactive response to radiation incidents, nuclear incidents and providing the national database on environmental radiation to serve the state management of atomic energy and nuclear safety. Simultaneously, VINATOM has paid much attention to grouping the research teams who can perform nuclear safety tasks, calculate, simulate, and evaluate the possibility of radiation dispersion from possible transboundary nuclear incidents in the future, forecast incident scenarios to support incident response (if any) by the implementation of projects at NRI, INST and CNT. The details are presented as follows.

- 01 ministerial project (2020-2022): “Research on the use of nuclear and isotope techniques to identify the origin and history of pollution in the coastal ecosystem of the Red River estuary”.

- 01 ministerial project (2021-2023): “Study on the characteristics and origin of fine aerosol pollution in Hanoi”.

- 01 ministerial project (2021-2023): “Investigation to determine the locations of installation of radiation monitoring stations within the EC-ASEANTOM project phase I”.

- Regular environmental monitoring project: “Monitoring and analyzing environmental radiation in Hanoi, Lang Son, Quang Ninh, Lao Cai and monitoring and analyzing the radioactivity of upstream water of the Red and Ky Cung rivers.”

- Environmental protection project (2020-2023), namely “Monitoring and warning of environmental radiation in the period of 2020-2022”, performs synchronous monitoring of environmental radiation situation in major environmental components such as air, sediment, soil, water, ... at monitoring locations in order to determine the current state of

environmental radiation, to ensure timely detection of radiation abnormalities and assistance to radiation and nuclear incident response. Regarding this project, the database on environmental radiation was established to support the State management of atomic energy, radiation and nuclear safety.

- Environmental protection project (2020-2023), namely “Investigation, evaluation and establishment of a data set of environmental radiation background in the area which is likely to be affected early by a nuclear incident from the northern border, supporting for incident response”. Its main objective is to set up the database, the management software, and the digital map of environmental radiation in 14 northern provinces/cities.

- 01 institutional project (2022): “Developing a review on environmental radiation monitoring data of INST from 2000 to 2022”.

In terms of this research direction, 06 international journal articles (04 of which are in the ISI list), 02 domestic articles and 01 domestic scientific conference report were published.

#### 1.4.2.4. Scientific publications

In 2022, scientific research activities were boosted, thereby achieving remarkable results. Compared to the previous year, the number of publications this year increased in both quantity and quality, as shown in Table 2 and Figure 3 below.

**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       | 26                 | 03                                      | 10                | 11                        | 08                   |                            | -                         | <b>58</b> |
| NRI        | 24                 | 06                                      | 21                | 13                        | 19                   | 01                         | -                         | <b>84</b> |
| ITRRE      | 05                 | 05                                      | 11                | -                         | 09                   | -                          | 01                        | <b>31</b> |
| CNT        | 09                 | 02                                      | 05                | 04                        | 10                   | -                          | -                         | <b>30</b> |
| VINAGAMMA  | 03                 | -                                       | 02                | 14                        | 05                   | 02                         | -                         | <b>26</b> |
| CANTI      | -                  | 01                                      | 02                | -                         | 05                   | -                          | -                         | <b>08</b> |
| HIC        | 03                 | 02                                      | 04                | 02                        | 05                   | -                          | -                         | <b>16</b> |
| NDE Center | 03                 | -                                       | 01                | -                         | 03                   |                            |                           | <b>07</b> |
| NTC        | 02                 | 02                                      | 01                | 02                        | 02                   | -                          | -                         | <b>09</b> |

| Units         | ISI journals (ISI) | SCOPUS and other international journals | National journals | International conferences | National conferences | International publications | Patents /utility solution | Total      |
|---------------|--------------------|-----------------------------------------|-------------------|---------------------------|----------------------|----------------------------|---------------------------|------------|
| Head Quarters | 02                 | 01                                      | -                 | -                         | -                    | -                          | -                         | <b>03</b>  |
| <b>Total</b>  | <b>77</b>          | <b>22</b>                               | <b>57</b>         | <b>46</b>                 | <b>66</b>            | <b>03</b>                  | <b>01</b>                 | <b>272</b> |

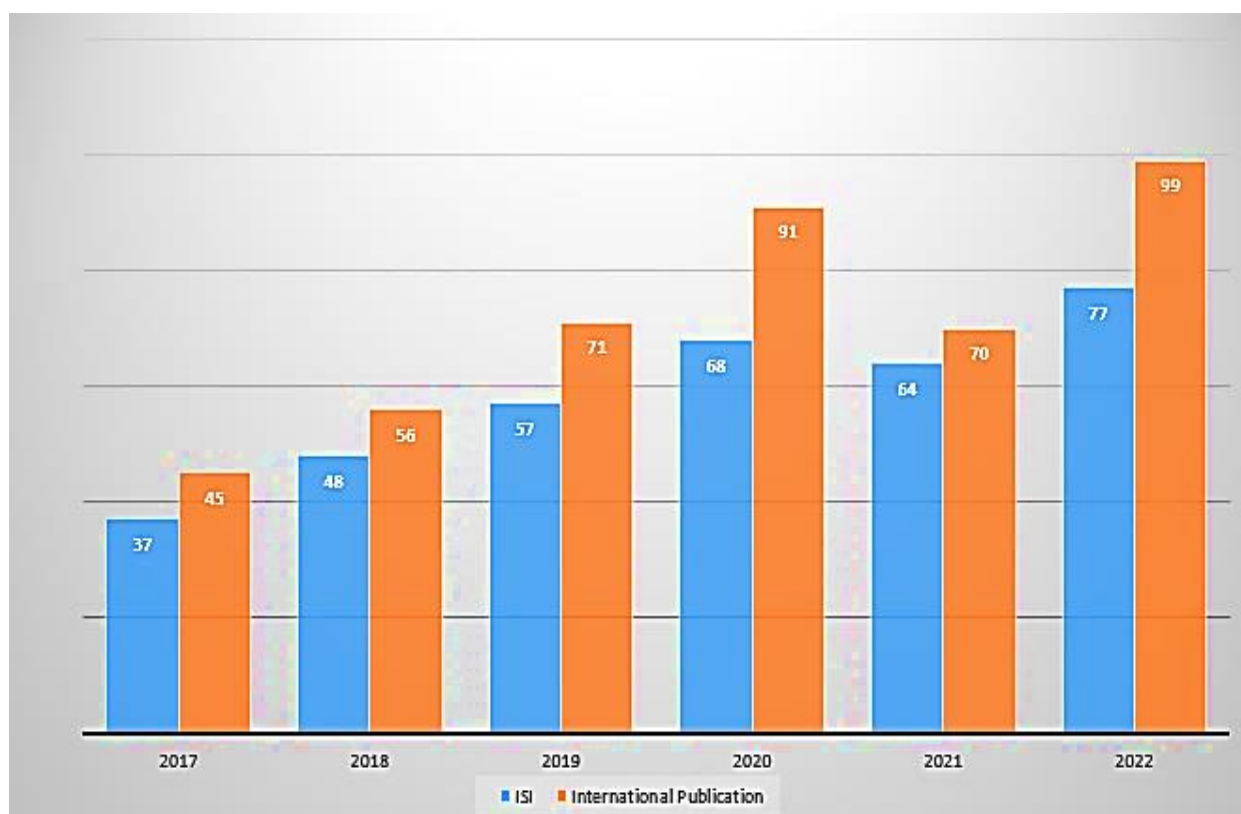


*Figure 3: Overview of international publications and ISI articles between 2017 and 2022*

### 1.4.3. RESULTS OF APPLICATIONS AND SERVICES

In the first half of 2022, VINATOM's members made great efforts to overcome difficulties caused by the Covid-19 pandemic and continued the application and service activities to serve the socio-economic development of the country. In general, all areas of the Institute made significant contributions to the overall results. Some outstanding results of the members are detailed as follows:

There was a growth (~10%) of VINATOM's total revenue of production and services from various types of application and service deployment over the year 2022 (Figure 4) in comparison with the same period of 2021.

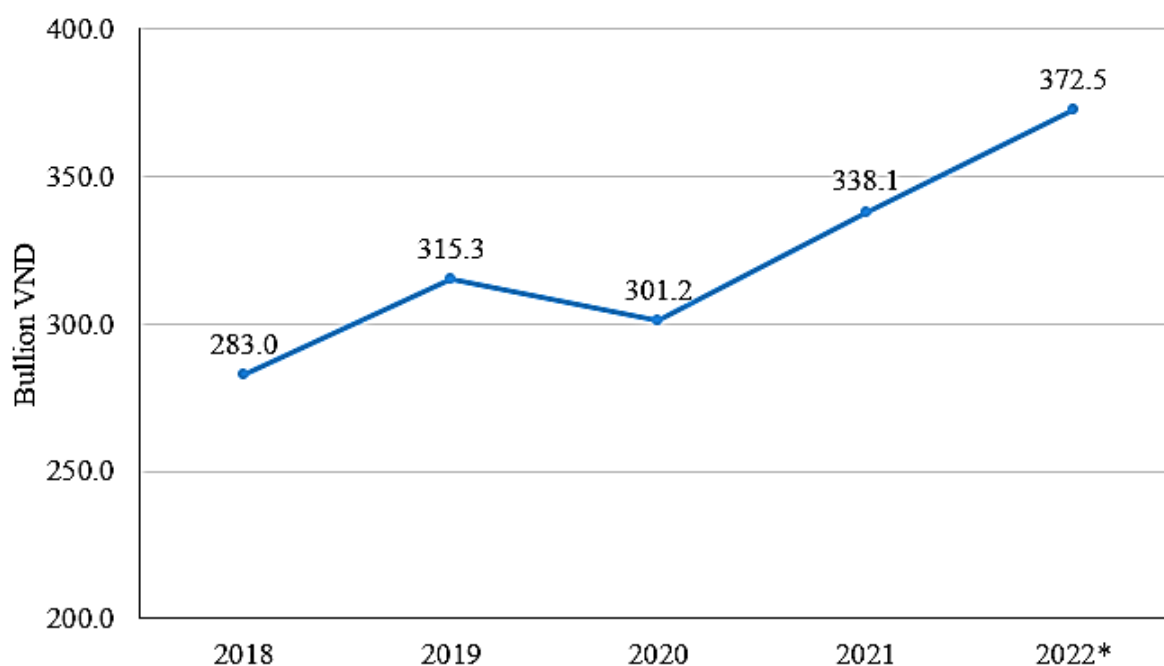


Figure 4: Total revenue from all types of services of VINATOM

#### Nuclear Research Institute

By the end of 2022, the total revenue was VND 57.9 billion (around 52 billion VND in 2021). The revenue of each service is specified below.

+ Preparing and supplying radiopharmaceuticals and marker kits to 23 domestic hospitals with a frequency of once a week: By December 6, 2021, a total of about 1,166 Ci radioisotopes of all kinds and 2520 kit vials, 80% of which was produced by Da Lat nuclear reactor. The revenue reached about 43.5 billion VND (38.8 billion VND in 2021). Since July 2022, the export of radioactive drugs to Cambodia has been resumed after nearly a one-year hiatus. In the last 6 months of the year 2022, 7.8 Ci of radiopharmaceuticals was exported to Cambodia.

+ Personal dosimetry, calibration and testing of equipment for radiation facilities: The total revenue reached about VND 6.66 billion (VND 5.72 billion in 2021).

+ The service of analysis for exporting agricultural products and ensuring domestic food hygiene and safety, VietGAP assessment and certification, environmental radiation monitoring, radioactive testing in food, exported food, environmental impact assessment of investment projects, etc.: The revenue was VND 6.45 billion (*5.48 billion VND in 2021*).

+ Regarding radiation technology and biotechnology, a lot of efforts were made in reaching customers and promoting products. Some products are currently used by customers, such as OLICIDE to stimulate growth, orchids using tissue culture methods, chromosomal aberrations for teaching and learning. The total revenue reached VND 0.25 billion (*1.4 billion VND in 2021*).

+ Training and fostering knowledge of radiation safety for radiation staff: 13 training courses were organized with revenue of VND 1.04 billion (*0.60 billion VND in 2021*).

### **Institute for Nuclear Science & Technology**

The total revenue from application and technical services of INST by the end of November 2022 reached VND 14,561 billion, which shows a slight increase over the same period in 2021, VND 14,140 billion. The total revenue includes:

- + Radiation safety service: VND 10.565 billion (*In 2021: VND 11.276 billion*)
- + Analysis services: VND 1.695 billion (*In 2021: VND 1.809 billion*)
- + Training services: VND 2.180 billion (*In 2021: VND 1.056 billion*)
- + Other services: VND 0.120 billion

### **Institute for Technology of Radioactive Waste and Rare Elements**

The total revenue from production and service of ITRRE reached VND 189,930 billion (*about VND 154.723 billion in 2021*). The revenue of each service is specified below.

- + Production of zinc products: VND 185.00 billion (*In 2021: VND 154.723 billion*)
- + ZOC factory waste treatment service: VND 4.419 billion (*In 2021: VND 4.728 billion*)
- + Analysis service: VND 0.261 billion (*In 2021: VND 0.167 billion*)
- + Production of heat stabilizers: VND 0.250 billion (*In 2021: VND 0.252 billion*)
- + Other activities: VND 0.0 (*In 2021: VND 0.562 billion*)

### **Research and Development Center for Radiation Technology**

In 2022, VINAGAMMA kept its main irradiation activities going well and achieved proud results, successfully completed the assigned tasks. The total revenue by the end of December 2022 reached VND 66.164 billion (*VND 66.47 billion in 2021*). The revenue of each service is specified below.

- + Irradiation service: VND 61.967 billion (*In 2021: VND 62.724 billion*)

+ Service of manufacturing silver nano preparations, chitosan preparations, antibacterial fabric, and other activities: VND 4.197 billion (*In 2021: VND 3.746 billion*)

### **Hanoi Irradiation Center**

The total irradiated goods reached about 6,451 m<sup>3</sup>, equivalent to a volume of irradiated goods of 1,344 tons with an irradiation time of about 3,750 hours. At the reported time, the total revenue from these activities was expected to reach VND 12.733 billion (*VND 13.433 billion in 2021*). The revenue of irradiation and quarantine of fresh fruits for export showed a sharp decline of 65% compared with 2021. Meanwhile, there was a slight fall (~ 2%) in the turnover from the service of radiation safety, radiation and nuclear incident response. Also, the earnings from other services dropped by 11%. The revenue of each service is specified below.

+ Irradiation of traditional medicines and fruit quarantine: VND 9.528 billion (VND 10.131 billion in 2021)

+ Support for implementation of radiation safety and incident response: VND 2.4 billion (VND 2.442 billion in 2021)

+ Irradiation for research, medicine, and other activities: VND 0.805 billion (VND 0.861 billion in 2021)

Additionally, HIC's radiopharmaceutical FDG18 produced by a 13 MeV accelerator was licensed; thus, the preparation for its production and supply to Hanoi area hospitals for cancer diagnosis is actively made.

### **Center for Application of Nuclear Techniques in Industry**

CANTI takes responsibilities for performing scientific and technical services of radiation safety, analytical services, nuclear engineering applications in the environment. The revenue from service implementation in 2022 reached 6.5 billion VND (*a drop by nearly 50% compared to 2021, 13.8 billion VND*). Here are the details.

+ Analysis service: VND 1.3 billion (VND 1.5 billion in 2021)

+ Applications of nuclear techniques in industry: VND 5.2 billion (VND 12.3 billion in 2021)

### **Center for Nuclear Technique, Ho Chi Minh City**

The revenue by December 15<sup>th</sup> 2022 reached VND 6.231 billion (a ~ 25% rise compared to the same period in 2021). The revenue of each service is specified below.

+ Radiation safety and dosimetry: VND 2.287 billion (VND 1.930 billion in 2021)

+ Analysis service: VND 1.012 billion (VND 1.930 billion in 2021)

+ NDT service: VND 0.423 billion (VND 0.204 billion in 2021)

+ Training service: VND 1.113 billion (VND 0.705 billion in 2021)

+ Other activities: VND 1.375 billion (VND 0.837 billion in 2021)

### NDE Center, Ha Noi

The total revenue from service deployment by December 15<sup>th</sup> 2022 reached about VND 17.950 billion (*VND 13.952 billion in 2021*). The revenue of each service is specified below.

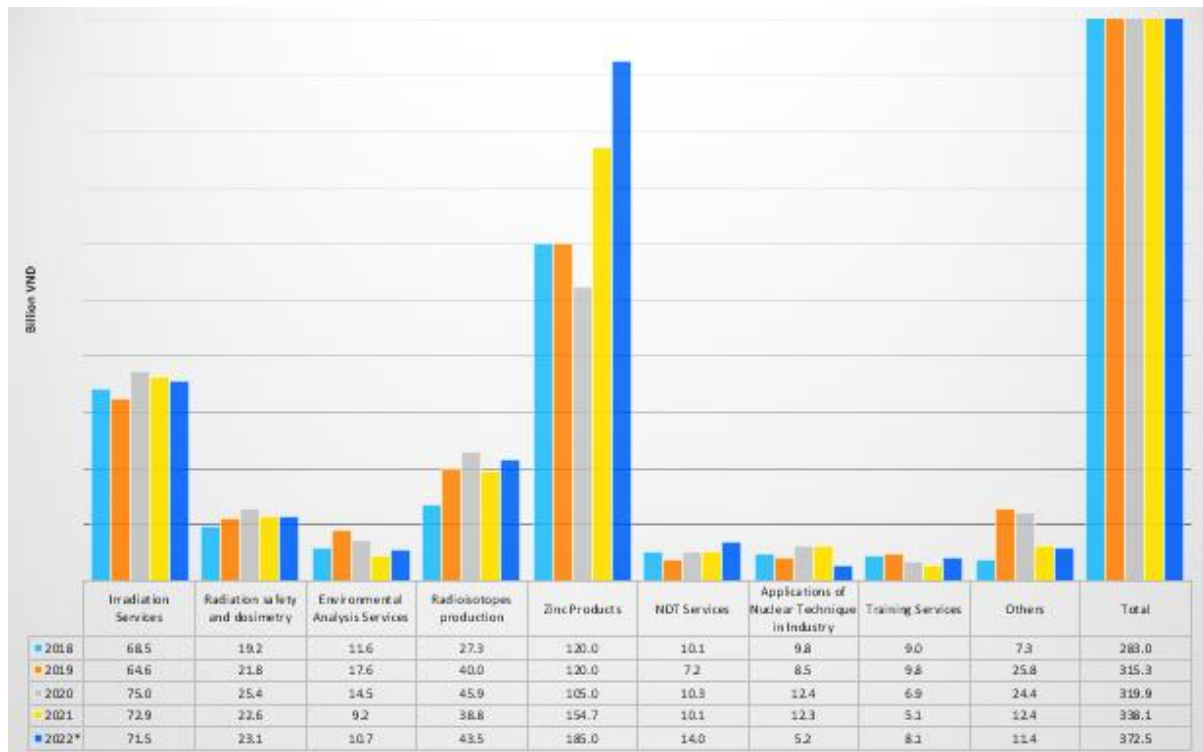
+ Radiation safety service: VND 1.2 billion (VND 1.277 billion in 2021)

+ NDT service: VND 13.55 billion (VND 9.937 billion in 2021)

+ Training services: VND 3.2 billion (VND 2.738 billion in 2021)

**Table 3. VINTOM's services and corresponding revenues in 2021 and 2022**

| No           | Services                                      | Revenue (billion VND) |                |
|--------------|-----------------------------------------------|-----------------------|----------------|
|              |                                               | Year 2021             | Year 2022      |
| 1            | Irradiation                                   | 72.855                | 71.495         |
| 2            | Radiation safety, dosimetry                   | 22.644                | 23.113         |
| 3            | Analysis services, environment                | 9.188                 | 10.718         |
| 4            | Radioisotope production                       | 38.800                | 43.500         |
| 5            | Producing zinc products                       | 154.723               | 185.000        |
| 6            | NDT                                           | 10.140                | 13.993         |
| 7            | Application of nuclear techniques in industry | 12.300                | 5.200          |
| 8            | Training                                      | 5.099                 | 8.075          |
| 9            | Others                                        | 12.386                | 11.416         |
| <b>Total</b> |                                               | <b>338.135</b>        | <b>372.510</b> |



\* Estimated revenue in December 2022

Figure 4: VINTOM's services and corresponding revenues in the period 2018-2022

#### 1.4.4. TRAINING AND DEVELOPMENT OF HUMAN RESOURCES

##### 1.4.4.1. Doctoral Training

In 2022, VINATOM delivered 4 Doctor of Philosophy (PhD) programs including: Atomic and nuclear physics; Theoretical and computational physics; Analytical chemistry; Inorganic chemistry.

The total number of PhD candidates at NTC by 2022 was 37, 22 of whom followed Atomic and Nuclear Physics, 5 of whom followed Theoretical and computational physics, 3 of whom followed Analytical chemistry and the rest followed Inorganic chemistry.

##### 1.4.4.2. Human Resources Development

Besides, VINATOM organized the courses to improve skills and foster knowledge for the officials, coordinated and supported the internship programs, research skills to improve the personnel quality. The courses are specified below:

- + 01 training course on analysis of stable isotope ratio C-O in environmental research and climate change for 23 students including VINATOM's staff and students of the University of Natural Sciences, Ho Chi Minh City. 20 out of 23 trainees received certificates of training completion.

+ 01 training course on using Ansys 3-dimensional finite element (FEM) software to simulate thermomechanical problems, evaluate the safety of material structures. 15 out of 16 trainees received certificates of training completion.

+ 05 internship periods for 111 undergraduate students in the field of atomic energy at VINATOM's facilities and members.

+ Training and granting certificates of radiation safety to thousands of radiation officials and employees of the Departments of Science and Technology (Hanoi, Ninh Binh, Thai Nguyen...) and radiation facilities nationwide. In 2022, INST itself held the training courses and issued certificates for 1,400 radiation safety officials and 115 inspectors.

#### **1.4.5. INTERNATIONAL COOPERATION**

##### **1.4.5.1. Multilateral cooperation activities**

Despite many difficulties due to complicated developments of the Covid-19 pandemic, VINATOM made efforts in maintaining specialized cooperation and integration activities with foreign partners under bilateral and multilateral mechanisms as the focal point of the government.

As the National Coordinating Body of RCA, VINATOM took responsibility of coordinating 15 IAEA/RCA (RAS) on-going projects in the areas of Health, Agriculture and Food, Industry, Environment, Radiation safety and RCA program management, 11 of which have been implemented by VINATOM.

As the president of RCA in 2022, Vietnam successfully hosted the 44th RCA National Coordinator Conference in Hanoi. At the event, the results achieved by the RCA program for the Asia-Pacific region in terms of mutant breeding, non-destructive testing and radiotherapy techniques were highly appreciated. The participants reached a consensus on five projects whose designs and implementation phases in 2024-2025 will be continued. One of those five projects is fully funded by Australia. The RCA scholarship program proposed by the RCA Scholarship Program Committee was also discussed on this occasion.

As the national focal point of FNCA, VINATOM supervised 7 FNCA projects, 4 of which were implemented by VINATOM. They focused on radiation technology applications, research reactor applications, radiation safety, radioactive waste management and climate change. Due to the impact of the Covid-19 epidemic, the FNCA Symposium 2022 on "Building public trust in nuclear science and technology" and FNCA National Coordinator Meeting were virtually held on March 9<sup>th</sup> and June 19<sup>th</sup>, 2022, respectively. FNCA Ministerial Meeting took place on October 31<sup>st</sup>, 2022 in Mongolia.

Regarding the cooperation with the IAEA, VINATOM kept implementing the Project VIE1010 "Promoting the program of reactor safety development" to strengthen the

national capacity for safety analysis and risk assessment, and to support Vietnam in the project implementation of Research Center of Nuclear Science and Technology in Vietnam (CNST); Additionally, the VIE7006 project "Using isotopes as a tool for general assessment of flow conditions and biogeochemistry of the downstream area of the Red River system of Vietnam" was implemented. The total cost of the two projects is 360,885 Euro. The activities within the framework of the project (such as exchanging experiences with experts, sending staff on scientific visits, short-term professional training abroad, and providing some research equipment) have contributed to improving Vietnam's research capacity in the field of reactor safety and application of radioisotope techniques.

Furthermore, VINATOM has also been participating in 11 Non-RCA projects and 04 inter-regional INT projects. Through these projects, Vietnamese officials have been able to attend IAEA Workshops and training courses. The IAEA has also provided Vietnam with 02 sets of equipment and 02 sets of tools for training in nuclear electronics applications which are ready to be delivered to Vietnam through the RAS1026 project, but the procedure for receiving the equipment is still being handled due to the lack of a project approval decision. On the other hand, VINATOM plays the role of one of the two national focal points of the IAEA's Asian Nuclear Safety Network (ANSN) for capacity building training in the field of atomic energy.

Within the framework of the Tripartite Cooperation Agreement between Vietnam - IAEA - Cambodia/Laos, the experts from VINATOM joined the delegation to work at Cambodia's Ministry of Mines and Energy (MME) and other relevant agencies and organizations from March 21-25, 2022 in order to identify, make plans and outline strategic orientations for activities supporting the host country in the development of atomic energy applications to ensure safety and security. On July 14-23, 2022, VINATOM also welcomed and worked with the delegation of Cambodia's MME in Vietnam. During this time, several Cambodian technical staff also got the training by VINATOM experts.

Upon the invitation of the IAEA, the experts from VINATOM joined the Mission to work at the Ministry of Education and Sports (MOES) and relevant agencies and organizations of the Lao People's Democratic Republic from June 27-July 1, 2022 to identify, make plans and outline strategic orientations for activities supporting Laos in the development of atomic energy applications for socio-economic development.

VINATOM remains the focal point in Vietnam in cooperation with Japanese atomic energy organizations, most notably with the Japan Atomic Energy Agency (JAEA). In accordance with the schedule and announcement of JAEA, VINATOM's officials were nominated to participate in the courses organized by JAEA such as ITC, AITC, MEXT and the training courses on nuclear technology. The 12th Vietnam-Japan Forum "Nuclear Power Development after the COP26 Climate Change Summit" was virtually organized. This forum is a regular activity within the framework of cooperation between VINATOM and JINED on nuclear technology human resource development.

In May 2022, a cooperation plan in improving the capacity of Vietnamese officials in research on small modular reactors (SMR) was developed by VINATOM and the Korea Atomic Energy Research Institute (KAERI).

VINATOM was assigned by MOST to be the focal point and in collaboration with the US Department of State, to implement the Cooperation Program on Capacity Building on SMR Technology (FIRST). Within the framework of this Program, 02 international seminars (01 online and 01 in person) on the topic of SMR and floating nuclear power plants (FNPP) were organized by VINATOM.

In 2022, VINATOM developed the cooperation with the India Rare Earth Company in the field of mineral mining and rare earth processing, organized online training courses to share experiences and improve in-depth knowledge for Vietnamese staff on mineral and rare earth mining technology as well as safety and environmental protection aspects. The VINATOM's delegations paid a visit to exchange the cooperation in this field in India and Binh Thuan. India continues being Vietnam's Cobalt-60 supplier through VINAGAMMA.

In terms of the CNST project implemented together with the partner State Atomic Energy Corporation of the Russian Federation (ROSATOM), online working sessions between VINATOM and ROSATOM were organized in 2021, which brought out positive results. The Terms of Reference for the project's feasibility study report (FS) bidding package and the contract draft were developed. Request for proposals for consulting service contract of bidding package "Development of feasibility study report and dossier for site approval" was prepared and finalized.

In addition to cooperation in CNST project, numerous activities between VINATOM and Russian partner were conducted such as: study on technology for processing Ilmenite ore by the fluorine method (*in cooperation with TOMSK*); study on technology and techniques of high-power accelerators (*Cooperation with the Institute of Nuclear Physics of the Academy of Science and Technology of the Russian Federation*); study on small modular reactors (*in cooperation with ROSATOM*); sharing experiences in radioactive waste management (*cooperation with TVEL, ROSATOM*); cooperation in the MBIR multi-purpose fast neutron reactor project (*Vietnam sent MSc. Nguyen Kien Cuong to virtually attend the first meeting of the Advisory Board of the Center for International Studies*).

VINATOM also implemented the activities of the ASEAN Network of Atomic Energy Regulatory Authorities (ASEANTOM). The coordination between VINATOM and Ministry of Foreign Affairs and relevant ministries and sectors was established to develop national and regional legal frameworks so that they meet international nuclear safety standards. Plus, VINATOM participated in the establishment of the ASEAN regional network on early warning of radiation incidents and incident response.

On June 7<sup>th</sup>, 2022, VINATOM, Hanoi University of Science and Technology and the International Company for Nuclear Energy Development (JINED), Japan reached a

tripartite agreement on training cooperation for school year 2022-2023. On the other hand, the Memorandum of Understanding on cooperation between the Regional Cooperation Agreement Office on research, development and training related to nuclear science and technology in the Asia-Pacific region (RCARO) and VINATOM was signed on the occasion of the meeting of the RCA Ministerial Conference in Vienna, Austria at the end of September 2022.

#### 1.4.6. INFORMATION & COMMUNICATION, SCIENTIFIC CONFERENCES

The following publications were completed by VINATOM in 2022:

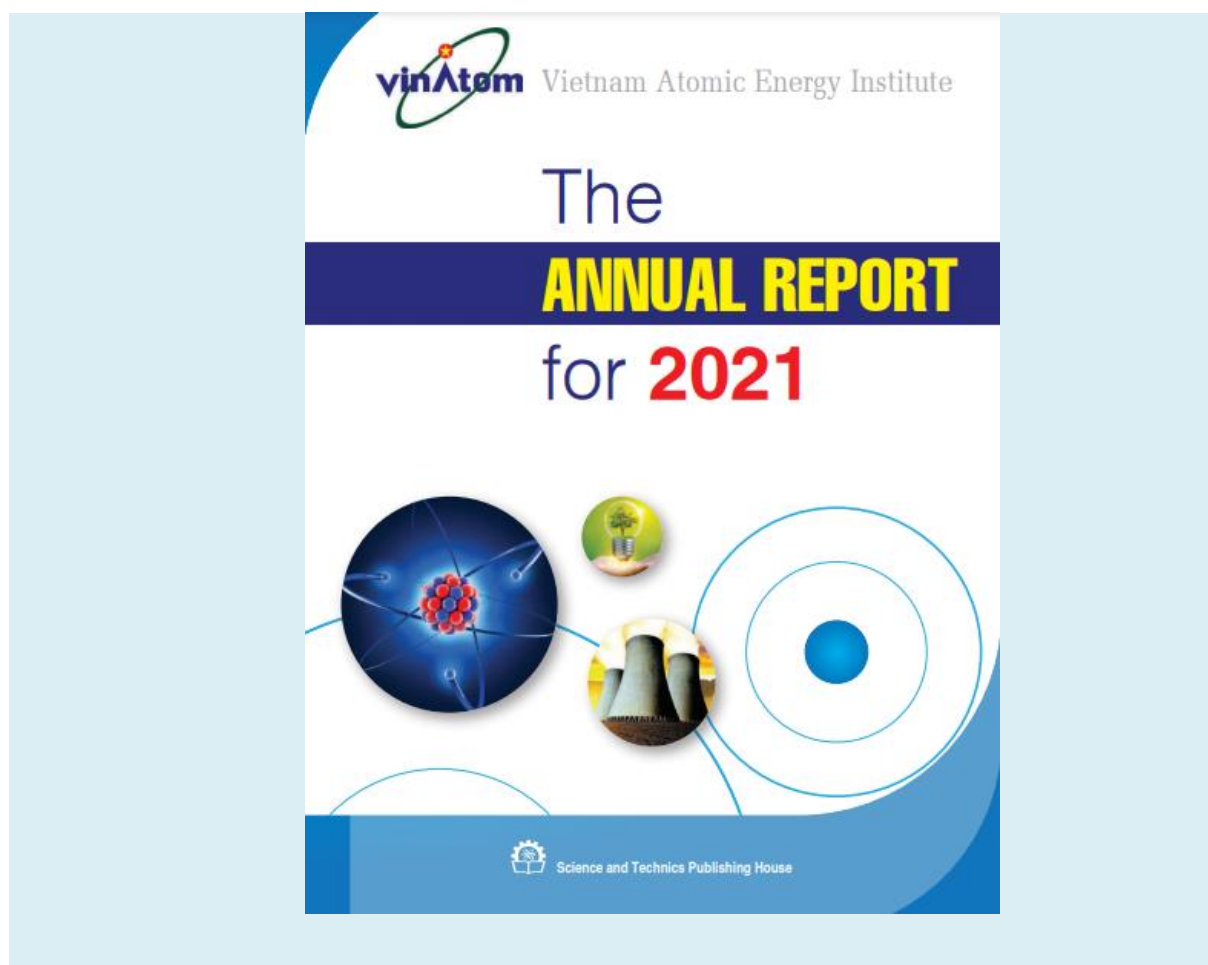
+4 issues of Journal of Nuclear Science and Technology (printed and online versions. Available from <https://vinatom.gov.vn/an-pham-tai-lieu/>). The online publishing system (jnst.vn) and the DOI digital identification system for the Journal were put into operation, which strongly support the online submission and review of articles and tightly connect with domestic and international scientific database systems.

+4 issues of Nuclear Science and Technology Information (online versions. Available from <https://vinatom.gov.vn/an-pham-tai-lieu/>)





+ Annual reports for 2021 (printed and electronic versions providing an insight in VINATOM's activities and scientific research projects in 2021)



To build and develop a database for the Institute's electronic library, important printed science and technology documents were converted into computer files and transferred into the e-library, a platform for search, research, and training activities.

The Institute's 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.

The 7th Nuclear Science and Technology Conference for Young Researchers was successfully organized in October 2022 in Hanoi.

The high-performance computing system (VINATOM-HPC) was efficiently deployed for scientific research.

#### **1.4.7. SERVING STATE MANAGEMENT IN THE FIELD OF ATOMIC ENERGY**

##### **1.4.7.1. Drafting the Plan for development and application of atomic energy in the period of 2021-2030, with a vision to 2050**

VINATOM closely coordinated with Vietnam Atomic Energy Agency (VAEA) in developing the plan for the development and application of atomic energy for the period 2021-2030, with a vision to 2050. VINATOM completed in drafting the content of formulating the planning component of the development of nuclear science and technology potential, human resource development, and ensuring safety and security, which is one of the 5 planning components of the Master Plan.

##### **1.4.7.2. Technical support for radiation and nuclear safety**

VINATOM paid close attention to supervising the activity of ensuring radiation and nuclear safety at its units using radioactive sources, radiation, and nuclear equipment. At VINATOM's members, particularly INST and NRI, the plans to collect radioactive sources posing a risk to the safety and security were developed. In general, the affiliated units made efforts in complying with the law on radiation and nuclear safety, nuclear security, radioactive source security and nuclear inspection. In particular, the storage, transportation and use of radioactive sources and radiation equipment was frequently reported; radiation work permits were renewed; the training on radiation safety knowledge and medical examinations for radiation workers were provided; occupational radiation dose was monitored; radiation measuring devices and radiation equipment were calibrated and verified; radioactive sources were examined and counted. The results of occupational radiation dose monitoring showed that no radiation worker was overexposed. Moreover, there was no loss of radioactive sources or radiation equipment. However, the radiation safety inspection at the units showed that there were still shortcomings and limitations that required them to overcome and continuously improve the radiation and nuclear safety according to regulations.

Also, VINATOM cooperated with VARANS and relevant units in doing research and developing drafts/regulatory documents on radiation safety and nuclear safety for the new research reactor.

#### **1.4.7.3. Support for regulatory agencies to finalize legal documents in the field of atomic energy**

VINATOM cooperated with VARANS and related units in researching and developing regulatory drafts/documents on radiation safety and nuclear safety for the new research reactor.

Plus, VINATOM coordinated with VARANS in developing the report assessing several contents related to VINATOM's management scope to serve the preliminary assessment of the 5-year period implementing Resolution No. 31/2016/QH14 of the National Assembly on halting Ninh Thuan nuclear power project.

Coordinate with functional units of Ministry of Natural Resources and Environment to perform environmental radiation analysis and monitoring tasks in several northern, central and southern provinces to develop radioactive background data as a basis for evaluation and forecasting.

### **1.5. INVESTMENT PROJECTS, EQUIPMENT ENHANCEMENT PROJECTS, MINOR CONSTRUCTION AND MAJOR REPAIR PROJECTS IN 2021**

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

#### **1.5.1. RESEARCH CENTER OF NUCLEAR SCIENCE AND TECHNOLOGY**

The project's investment policy was approved by the Prime Minister in Decision No. 75/QĐ-TTg dated November 19, 2018. After a long period of carrying out the procedures for adjusting policies, arranging capital sources, preparing and approving outlines of tasks and estimates, etc. the most important bidding package in the investment preparation stage - *the FS Contract and the Site Approval Dossier*, the Request for Proposals was handed over to the Russian contractor in December 2021

. In 2022, the Proposal was submitted by the Russian contractor recommended in the Agreement signed between the two Government. However, it did not meet the financial requirements according to the criteria of the Request for Proposals, leading to the cancellation of the contractor selection results. To continue carrying out the next step, the Project Management Board has been proactive in asking for opinions from functional units and the Government Office. Organizing contractor selection for the second time was approved by the Prime Minister and will be implemented in the first quarter of 2023. Simultaneously, the PM Board keeps establishing and updating the regulations and lists of Confidential documents based on the guidance of the Ministry of Public Security as well as revising the estimates and bidding package prices in timely manner and amending the Request for Proposals under new regulations. The

implementation of the EPC Contract, construction and operation of the new research reactor will be scheduled from 2025-2030.

#### **1.5.2. CONSTRUCTION OF TECHNICAL SUPPORT FACILITY TO ENSURE SAFETY, SECURITY AND ENVIRONMENTAL PROTECTION FOR NUCLEAR POWER DEVELOPMENT**

This project was invested by INST. According to the signed contract, the EPC package should have been completed by September 14, 2021. Due to the COVID 19 epidemic, which greatly affected the construction, mobilization of resources, materials and equipment, the EPC package was impossible to be align with the contract schedule and was extended until the end of 2022. Up to now, basic construction and equipment installation work has been completed.

However, at the time of this report writing, the disbursement of the EPC package was still facing difficulties in determining the arising volumes and cost differences. Consequently, it was mandatory for the Investor and the general contractor to urgently submit the required documents to the competent authority and finish addressing the incurred costs by December 31, 2022 according to regulations.

#### **1.5.3. UPGRADING TECHNOLOGICAL SYSTEMS AND FUNCTIONAL EQUIPMENT AND ADDING FUEL TO THE DA LAT NUCLEAR REACTOR TO ENSURE ITS EFFECTIVE AND SAFE OPERATION BY 2030**

This project belongs to the list of medium-term public investment projects for the period 2021-2025, which was approved by the Ministry of Science and Technology for investment policy according to Decision No. 2250/QĐ-BKHCHN, dated September 7, 2021. At the time of this report writing, the project was in the process of investment appraisal and approval. Due to the project's purchase of nuclear fuel, the duration of verification and appraisal work is longer than expected. Following the competent authorities' comments, the project dossier was reviewed and appraised by the Appraisal Council of MOST. The Project's feasibility study report and basic design have been finalized and submitted to MOST for approval. The next step is appraisal and approval of construction technical design, detailed estimates, preparation, and approval of bidding package prices and organizing contractor selection. The contracts of fuel purchase are expected to be signed in 2023.

#### **1.5.4. EQUIPMENT ENHANCEMENT PROJECTS**

In the period of 2020-2021, NRI was basically invested in the fields of research on drug and radioisotopes preparation (which meets GMP standards), upgrading the radiation monitoring station and equipment for the IAEA Collaborating Laboratory in Vietnam in the field of water and environment, which contributes to improvement of its research capacity and application of nuclear techniques and stable isotopes.

Due to the COVID epidemic situation, the suppliers were impossible to produce the equipment in time, NRI continued to implement 02 extended projects, including (1)

Enhancing the equipment for research and production radiopharmaceuticals and (2) Enhancing the equipment for environmental research and climate change.

The investment project "National measurement standard in the field of ionizing radiation dosimetry measurement for the period 2015-2020" has been implemented by INST. The main contents and economic contracts of the project have been finalized. The equipment has been installed, tested and put into use at the level II measurement standard room since September 2021. The project is in the progress towards the ending.

Regarding the project "Adding Cobalt-60 source for research and application of radiation technology in 2020-2021 of Hanoi Irradiation Center", the Center has completed the additional loading of 200kCi of  $^{60}\text{Co}$  radioactive source.

# 2- RESEARCH REPORTS

## 2022



Source: eagetutor.com



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

## **2.1. NUCLEAR PHYSICS, REACTOR PHYSICS**

## STUDYING THE STRUCTURE OF THE NEUTRON-RICH ISOTOPES NEIGHBORING $^{49}\text{Ar}$ AND $^{78}\text{Ni}$ NUCLEI THROUGH THE EXPERIMENTS OF DIRECT NUCLEAR REACTION AT MEDIUM ENERGY REGION

**Do Cong Cuong<sup>1</sup>, Bui Duy Linh<sup>1,2</sup>, Nguyen Duc Ton<sup>1</sup>, Pham Duc Khue<sup>1</sup>,  
Pham Ngoc Dong<sup>1</sup>, Le Xuan Chung<sup>1</sup>, Nguyen Hai Ninh<sup>1</sup>**

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*<sup>2</sup>Vietnam Agency for Radiation and Nuclear Safety, 14<sup>th</sup> floor, 113 Tran Duy  
Hung, Cau Giay, Ha Noi*

### Project information:

- **Project name:** Studying the structure of the neutron-rich isotopes neighboring  $^{49}\text{Ar}$  and  $^{78}\text{Ni}$  nuclei through the experiments of direct nuclear reaction at medium energy region
- **Code:** ĐTCB 01/21/VKHKTHN
- **Managerial Level:** Ministry
- **Duration:** 24 months (Jan 2021- Dec 2022)
- **Contact email:** cuong1981us3@gmail.com
- **Published papers related to the project:**

1. B. D. Linh, A. Corsi, A. Gillibert, A. Obertelli, P. Doornenbal, et al., "Investigation of the ground-state spin inversion in the neutron-rich 47,49Cl isotopes", *Physical Review C* 104 (4), 044331. DOI: <https://doi.org/10.1103/PhysRevC.104.044331>

2. M.M. Juhász, Z. Elekes, D. Sohler, Y. Utsuno, K. Yoshida, et al., "First spectroscopic study of  $^{51}\text{Ar}$  by the (p,2p) reaction", *Physics Letters B*, Volume 814 (2021), 136108. DOI: <https://doi.org/10.1016/j.physletb.2021.136108>

3. M. Enciu, L. X. Chung, B. D. Linh, "Extended p3/2 neutron orbital and the N=32 shell closure in  $^{52}\text{Ca}$ ", *Physical Review Letters* 129, 262501 (2022). DOI: <https://doi.org/10.1103/PhysRevLett.129.262501>

4. Do Cong Cuong, Bui Duy Linh and Nguyen Duc Ton, "Evolution of nuclear shell structure in neutron-rich nuclei N=32 and N=34", accepted in *Vietnam Journal of Science and Technology-B* (in Vietnamese).

5. N. D. Ton, B. D. Linh, SEASTAR3 collaborator, "Detector corrections for particle identification in SAMURAI spectrometer" accepted in *Nuclear Science and Technology*.

6. B. D. Linh, A. Corsi, A. Gillibert, A. Obertelli, P. Doornenbal, L. X. Chung, N. T. Khai, N. D. Ton and SEATAR collaboration, "Investigation of the ground-state spin inversion in

the neutron-rich  $^{49}\text{Cl}$  isotope”, Proceedings of the 14th Vietnam Conference on Nuclear Science and Technology (VINANST 14), Dalat, 9-10/12/2021.

7. B. D. Linh, L. X. Chung, N. D. Ton and SEASTAR collaboration, “Structure of  $^{50}\text{Ar}$  from one neutron removal reaction: the first spectroscopy of  $^{49}\text{Ar}$ ”, Proceedings of the 14th Vietnam Conference on Nuclear Science and Technology (VINANST 14), Dalat, 9-10/12/2021.

8. N. D. Ton, B. D. Linh, L. X. Chung and SEASTAR3 collaboration, “Vertex position reconstruction in a thick target”, Proceedings of the 14th Vietnam Conference on Nuclear Science and Technology (VINANST 14), Dalat, 9-10/12/2021.

Studying nuclear structure of neutron-rich nuclei far from stable region (with lifetime *ms*) plays an important role in determining the influence of the tensor force component on the arrangement of nucleons in the nucleus. This subject is enhancing our knowledge about the nature of the nuclear force and nuclear structure. Besides, studying nuclear structure of neutron-rich nuclei also provides us the information of r-process that creates heavier isotopes in the universe. There are many experiments performed to study the structure of these nuclei.

Among experiments which had been done, the experiments that measures the gamma energy spectrum emitted from the nuclear excited states provide us a detailed level scheme of considered nuclei, thereby giving us better understanding on the structure of these nuclei. The international cooperation project, SEASTAR, using secondary beam systems BigRIPS, magnetic spectrometer SAMURAI, activated target system MINOS and detector DALI2+ was carried out at RIKEN to study nuclear structure of neutron-rich nuclei. Since 2014, the experimental nuclear physics group in the Institute for Nuclear Science and Technology (INST) has been an active member of this project. The main research content of this work which focuses on analyzing the nuclear isotope data  $^{47,49}\text{Cl}$  and  $^{49}\text{Ar}$  which was assigned by SEASTAR members after the third experiments in 2017.

The diagram of the third experiment in 2017 is shown in figure 1 below. The primary beam of  $^{70}\text{Zn}$  isotope was accelerated to an energy of 345 MeV/nucleon before colliding with primary target  $^9\text{Be}$  located at F0 and cause fragmentation reactions. The Cl, Ar, K and Ca neutron-rich isotopes in the region  $N = 32, 34$  were products of the fragmentation reactions identified and separated by the BigRIPS spectrometer and then directed to the secondary target in the target-detector system - MINOS [1,2] at F13. The nuclei beam coming from BigRIPS with an energy of 200 - 270 MeV/nucleon bombarded the proton secondary target in MINOS to create scattering and breakup reactions. Product nuclei were identified by SAMURAI magnetic spectrometer. The gamma emitted from the product nuclei was detected by the combination of 226 NaI crystals of the DALI2+ detector system [3] while the protons were traced in MINOS.

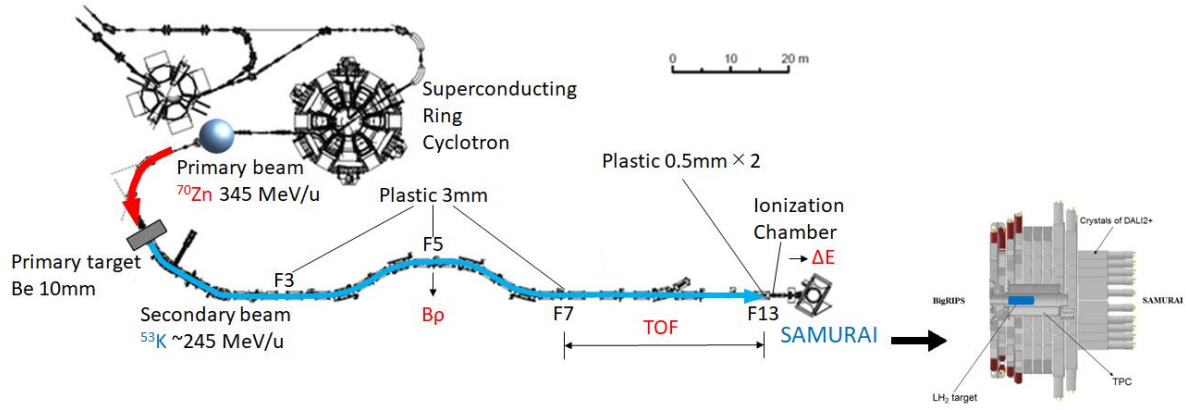


Figure 1: Diagram of SEASTAR experimental system with 4 main components: cascade accelerator system, BigRIPS magnetic spectrometer, MINOS target-detector system, DALI2+ detector and SAMURAI magnetic spectrometer system.

The nuclei before and after colliding with proton secondary target were identified by the Bp –  $\Delta E$  – ToF method. The parameters Bp –  $\Delta E$  – ToF were determined directly or indirectly through various detectors in BigRIPS and SAMURAI. The residual nuclei identified from SAMURAI are coincided with the gamma signal measured from the DALI2+ detector and the proton signal observed from the trace detector in the MINOS to determine the reaction channel, position of reaction and gamma emitters. After the source was identified, the raw gamma spectrum detected in the DALI2+ detector system was subtracted from the background and corrected Doppler to obtain the realistic gamma spectrum of the considered isotope. The gamma spectrum was matched with the response functions of DALI2+ detector in combination with the likelihood method (which is used in experiments with low statistics) to determine the experimental gamma peaks. Following that, gamma-gamma coinciding was performed to examine cascaded gammas, thereby identifying indirect excited states. Finally, combining with theoretical calculations of shell models, level scheme of neutron-rich isotopes was created.

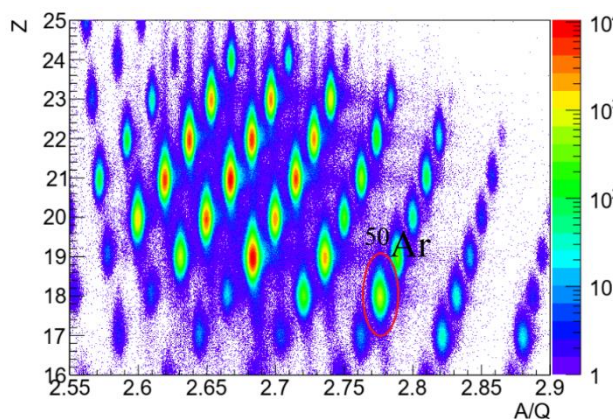


Figure 2a: Z and A/Q correlation for particle identification in BigRIPS.

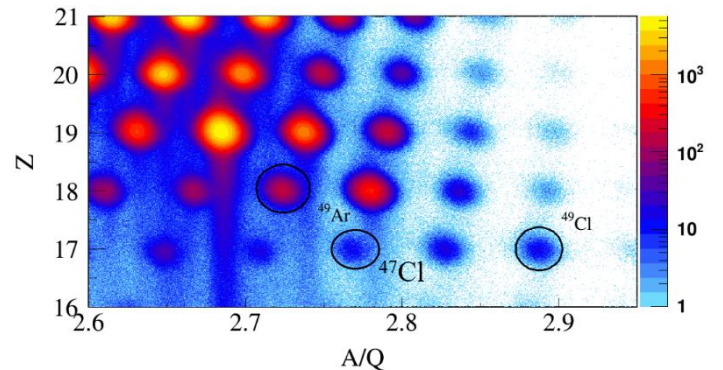


Figure 2b: Z and A/Q correlation for particle identification in SAMURAI

Figure 2 presents the results of identification at BigRIPS (Figure 2a) and SAMURAI (Figure 2b) of neutron-rich nuclei before and after colliding with the secondary target, respectively. Combining with the coincident results of proton signal traced at MINOS target and gamma detected at DALI2+, the reaction channels  $^{50}\text{Ar}(p,pn)^{49}\text{Ar}$ ,  $^{50}\text{Ar}(p,2p2n)^{47}\text{Cl}$  and  $^{50}\text{Ar}(p,2p)^{49}\text{Cl}$  were determined. Figure 3 below shows the gamma spectrum of  $^{49}\text{Cl}$  isotope which subtracted the background and Doppler correction emitted after the  $^{50}\text{Ar}(p,2p)^{49}\text{Cl}$  reaction and detected by the DALI2+ detector system. The steps of matching the experimental spectrum with the response functions of the DALI2+ detector in combination with assessing confident level of spectral peaks show that this gamma spectrum consisted of four energy peaks. Then, gamma-gamma coincident was performed, which resulted in two peaks of 350 keV and 630 keV coincide, thereby determining the energy gamma of 630 keV as the cascaded gamma derived from the excited state of 980 keV (fairly close to the 970 keV gamma) to the 350 keV excited state. Combining with the calculations of shell model, level scheme of  $^{49}\text{Cl}$  isotope (see figure 4) was developed for the first time.

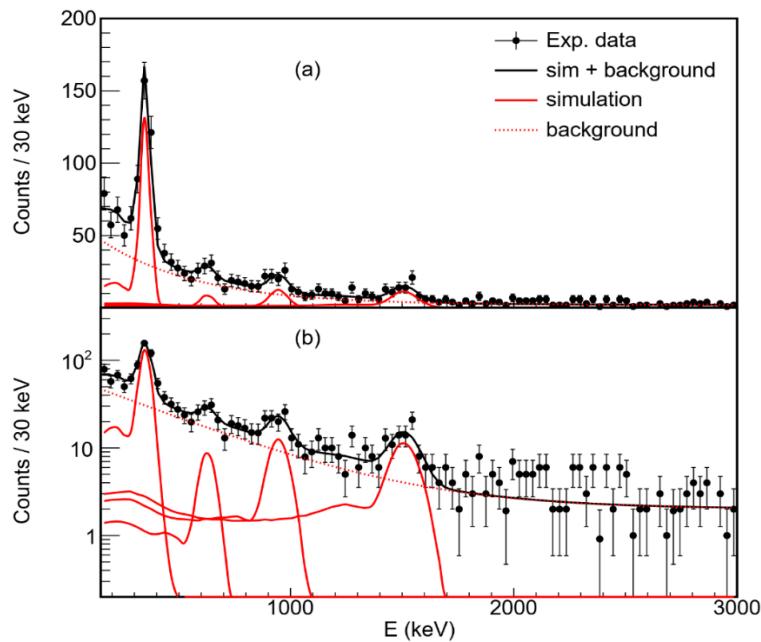


Figure 3: The gamma spectrum of  $^{49}\text{Cl}$  nuclei from the  $^{50}\text{Ar}(p,2p)^{49}\text{Cl}$  reaction channel was detected by the DALI2+ detector system+

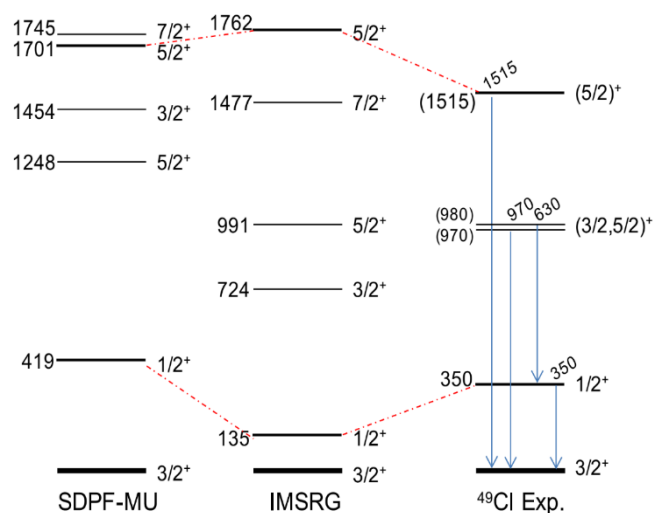


Figure 4: Level scheme of  $^{49}\text{Cl}$  isotope.

Also, the results of the level schemes of the neighboring  $^{49}\text{Ar}$  isotopes such as  $^{47}\text{Cl}$ ,  $^{50}\text{Ar}$  and  $^{51,52}\text{Ca}$  have been developed in this work. The details can be found in the summary report and product report.

## References

- [1] A. Obertelli and T. Uesaka, Eur. Phys. J. A 47, 105 (2011).
- [2] A. Obertelli *et al.*, Eur. Jour. Phys. A 50, 8 (2014).
- [3] P. Doornenbal, Prog. Theor. Exp. Phys., 03C004, (2012).

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

# DESIGN AND CONSTRUCTION OF A UNIT FOR REACTIVITY MONITORING AND REACTOR POWER REGULATION AND CONTROL, AND A UNIT FOR PROCESS PARAMETERS CONTROL OF THE DALAT NUCLEAR REACTOR CONTROL SYSTEM

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## **Project information:**

- **Project name:** Design and construction of a unit for reactivity monitoring and reactor power regulation and control, and a unit for process parameters control of the Dalat nuclear reactor control system
- **Code:** ĐTCB.10/21/VNCHN
- **Managerial Level:** Ministry
- **Duration:** 24 months (Jan 2021 – Dec 2022)
- **Contact email:** taivnchn@gmail.com
- **Published papers related to the project:**

1. Vo Van Tai, Nguyen Van Kien, Nguyen Nhi Dien, Le Van Diep, Phan La Son. Design a unit for reactivity monitoring using FPGA for the Dalat nuclear reactor, Proceedings of the 14th Vietnam Conference on Nuclear Science and Technology (VINANST-14), Dalat City, Vietnam, 2021, p.63-64 (in Vietnamese).

2. Vo Van Tai, Nguyen Van Kien, Nguyen Nhi Dien, Le Van Diep, Design of an FPGA-based digital reactivity meter for Dalat Nuclear Research Reactor, Nuclear Science and Technology, VAES, and VINATOM. Vol. 11, No. 4, December 2021, DOI: <https://doi.org/10.53747/nst.v11i4.350>

3. Vo Van Tai, Nguyen Van Kien, Nguyen Nhi Dien, Le Van Diep, Phan La Son, Developing the software that displays the information for Dalat nuclear research reactor, The seventh Conference of Nuclear Science and Technology for young nuclear energy researchers, Hanoi, Vietnam, Otc. 2022, p.18-19 (in Vietnamese).

This report summarizes the results of the design and construction of two specific electronics units of the Dalat nuclear reactor control system, including: one unit for reactivity monitoring, reactor power regulation and control (BNO-102R1N), and one unit for process parameters control (BPM-108R1N). The functional electronics circuits were designed based on a high-speed field-programmable gate array (FPGA) Artix-7 and digital signal processing (DSP). The BNO-102R1N unit was tested by using a pulse-generated simulator and by real neutron signals from the reactor. The BPM-108R1N unit was tested based on calibration devices, that compound with sensors of the process

instrument system (PIS). The test results show that the technical characteristics of the designed units are equivalent to those of the commercial BNO-102R1 and BPM-108R1 units of the Dalat nuclear reactor control system, named ASUZ-14R. In addition, the analysis and decoding of data transmission modes from three data acquisition and processing cabinets (1-UNO-251R1, 2-UNO251R1, and 3-UNO-251R1) to personal computers on the reactor control console were successfully acquired. This result allows developing a software package to display information of the reactor on computers working in the Windows environment, that is compatible with current generation computers. The developed software package has the same functions as the software working in the DOS environment, that is currently used for the ASUZ-14R. The developed software is available to replace the existing software when needed.

1) The BNO-102R1N unit performs three functions: reactivity monitoring, automatically regulation and control of the reactor power, with the applied algorithm is shown in Fig. 1.

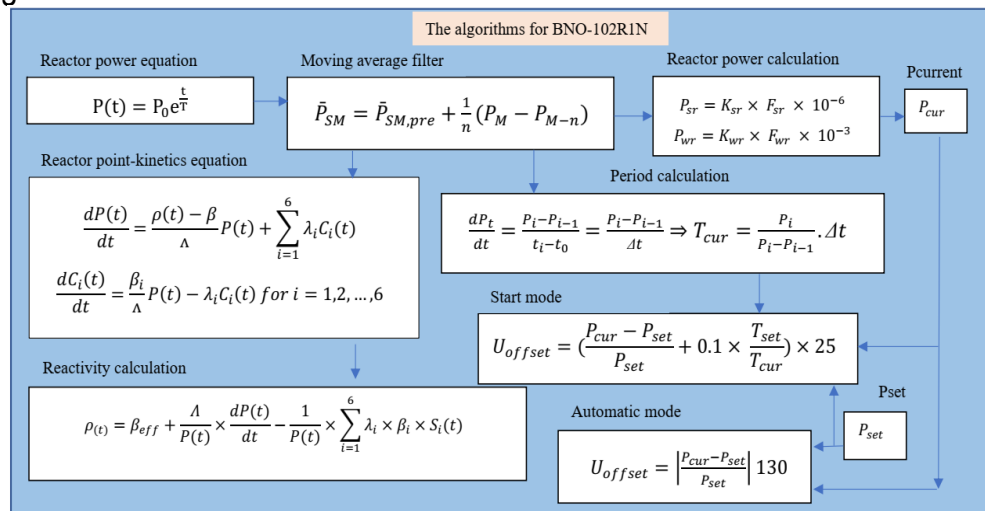


Figure. 1. Algorithm applied to BNO-102R1N unit

The reactor power of a nuclear reactor follows the exponential function. For the Dalat nuclear research reactor (DNRR), the ASUZ-14R uses the neutron detection device UDPN-27R1 which consists of a wide-range neutron detector unit BDPN-36R2 and signal conversion units BPH-61R and BPH-63R1. The BDPN-36R2, including the fission chamber (FC) and the gamma-compensated ionization chamber (CIC), monitor the neutron flux in the range of  $10^0$  to  $10^{10}$  neutrons/(cm<sup>2</sup>.s). The conversion units have a pulse amplifier coupled with the FC chamber working in pulse mode to monitor the reactor power in the starting range and the current-to-frequency converter is connected with the CIC chamber containing Boron working in current mode to monitor the reactor power at the working range. The frequency signals proportional to the neutron flux density at the chamber locations are sampled and come to a moving average filter. The current power  $P_{cur}$  is calculated by the power of the starting range  $P_{sr}$  and the power of the working range  $P_{wr}$ . The reactor period  $T_{cur}$  is also calculated by the history of the reactor power.

Reactor reactivity is monitored in the range from  $1 \times 10^{-3}$  to  $1.2 \times 10^2$  %Pnom (Pnom = 500 kW), and the relative error of reactivity monitoring in the range from minus 5 to +0.5  $\beta_{eff}$  is less than  $\pm 5\%$  and in the ranges  $(-20 \div -5) \beta_{eff}$  and  $(+0.5 \div +1) \beta_{eff}$  is not more than  $\pm 10\%$ . The BNO-102R1N performs the function of automatic start (Start mode) or automatically switch the reactor power level in the range  $1 \times 10^{-4}\%$  to  $1 \times 10^2$  % with a relative deviation less than  $\pm 5\%$  and stabilization of the reactor power at the specified level (Automatic mode) in the range from  $1 \times 10^{-1}$  % to  $1 \times 10^2$  % with relative deviation less than  $\pm 1\%$ . The BNO-102R1N unit is coupled with the neutron detector device UDPN-27R1 of the 1-UNO-251R1 cabinet of the ASUZ-14R by an isolating amplifier to monitor the reactor reactivity by solving the reactor point-kinetics equations:

$$\frac{dP(t)}{dt} = \frac{\rho(t) - \beta}{\Lambda} P(t) + \sum_{i=1}^6 \lambda_i C_i(t) \quad (1)$$

$$\frac{dC_i(t)}{dt} = \frac{\beta_i}{\Lambda} P(t) - \lambda_i C_i(t) \quad (2)$$

This unit was tested and compared in reactivity measuring to the imported reactivity meter unit BNO-102R1. The time behavior of reactivity in the full range of DNRR is addressed in Fig.2. The results obtained by the designed unit and the BNO-102R1 are equivalent with 10% difference.

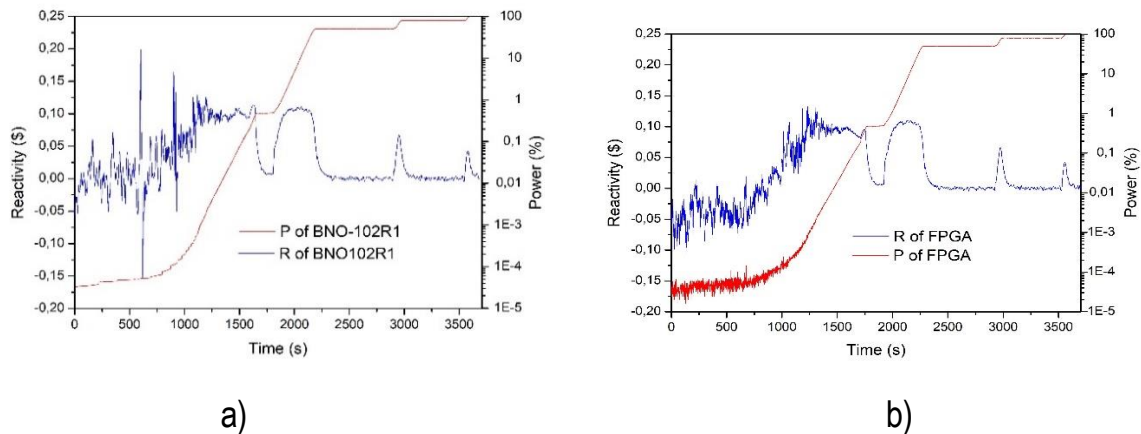


Figure. 2. Reactivity monitoring of DNRR from reactor start-up to 100% of reactor power: (a) Reactivity monitoring by the BNO-102R1 unit and (b) Reactivity monitoring by of the FPGA-based BNO-102R1N unit.

Positive reactivity is tested based on withdrawing the automatic control rod (AR) from 367 mm to 310 cm positions. Effective reactivity of 57 mm of the AR was measured by BNO-102R1 and BNO-102-R1N and compared with the calculated value according to the operator logbook (2011) as shown in Table 1.

Table 1: The maximum value of the measured reactivity when withdrawing the AR

| Reactor power<br>(% P <sub>nom</sub> )   | Regulating<br>rod position<br>(mm) | Effective<br>reactivity in the<br>calculation<br>(12/2011)<br>(\$) | Effective<br>reactivity of<br>BNO-102R1<br>(\$) | Effective<br>reactivity of<br>BNO-102R1N<br>(\$) |
|------------------------------------------|------------------------------------|--------------------------------------------------------------------|-------------------------------------------------|--------------------------------------------------|
| $4 \times 10^{-3} \div 6 \times 10^{-3}$ | 367÷310                            | 0.0703                                                             | 0.0694                                          | 0.0699                                           |

The results show that the measured values and calculated values are agreeable. The allowed relative deviation is  $\pm 5\%$  according to the ASUZ-14R system.

With the function of the DNRR's power regulation, the unbalance Uoffset value is determined by equation:

$$U = |P_{rel}| \cdot 130 \quad (3)$$

where  $P_{rel} = (P_{cur} - P_{set}) / P_{set}$ . If  $P_{rel} > 0$  then  $U_{up} = 0$  and  $U_{down} = U$ . If  $P_{rel} < 0$  then  $U_{down} = 0$  and  $U_{up} = U$ ;  $P_{set}$  is the set power by the BKC-75RN unit;  $P_{cur}$  is the current reactor power;  $U_{up}$  is the control voltage to lower the automatic rod;  $U_{down}$  is the control voltage to raise the automatic rod.

Unbalance values were tested by BNO-102R1 and BNO-102R1N units in automatic mode at 100%P<sub>nom</sub> level as shown in Fig. 3. The experimental results show that Uoffset control voltage from two units has the matching values. The difference of the experiment values between the two units is less than  $\pm 1\%$  that meets the technical document of ASUZ-14R.

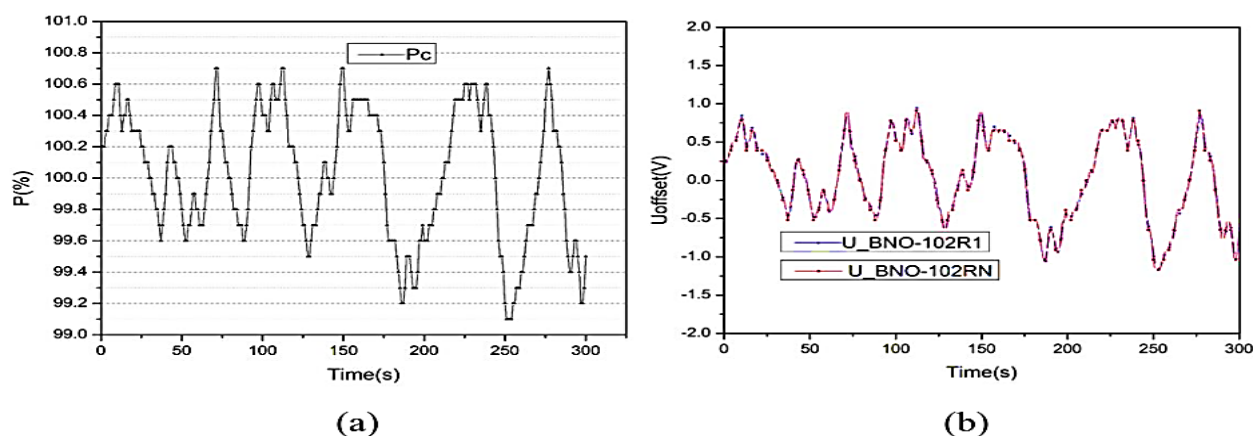


Figure 3. The testing results of BNO-102R1 and BNO-102R1N units in automatic mode:  
(a) Fluctuation during regulation of reactor power at 100%, (b) Unbalanced Uoffset value.

2) The BPM-108R1N unit is used for monitoring and generating signals of emergency protection and warning signalization depending on state and information coming from sensors of the process parameters. The FPGA-based controller receives 17 ADC values

from the analog input module. The values of process parameters are determined through conversion formulas and relative deviation evaluation results are shown in Table 2.

Table 2. Monitoring range, conversion formula, emergency, warning protection preset values by process parameter.

| Parameter                                       | Designation | Conversion formula           | Monitoring range                  | Relative deviation |
|-------------------------------------------------|-------------|------------------------------|-----------------------------------|--------------------|
| The temperature of water in the reactor pool    | Tp1         | $T1 = V_{ADC1} * 20$         | 0÷100 (°C)<br>WRN≤33              | <0.5%              |
|                                                 | Tp2         | $T2 = V_{ADC2} * 20$         | 0÷100 (°C)<br>WRN≤53              | <0.5%              |
|                                                 | Tp3         | $T3 = V_{ADC3} * 20$         | 0÷100 (°C)                        | <0.5%              |
|                                                 | Tp4         | $T4 = V_{ADC4} * 20$         | 0÷100 (°C)                        | <0.5%              |
|                                                 | Tp5         | $T5 = V_{ADC5} * 20$         | 0÷100 (°C)                        | <0.5%              |
| The temperature of 1 circuit of water           | T1_IN       | $T1\_IN = V_{ADC6} * 10$     | 0÷50 (°C)                         | <0.5%              |
|                                                 | T1_OUT      | $T1\_OUT = V_{ADC7} * 10$    | 0÷50 (°C)                         | <0.5%              |
| The temperature of 2 circuit of water           | T2_IN       | $T2\_IN = V_{ADC7} * 10$     | 0÷50 (°C)                         | <0.5%              |
|                                                 | T2_OUT      | $T2\_OUT = V_{ADC9} * 10$    | 0÷50 (°C)                         | <0.5%              |
| The temperature of ambient air                  | T_air       | $T\_air = V_{ADC10} * 10$    | 0÷50 (°C)                         | <0.5%              |
| The flow rate of 1 circuit water                | G1          | $G1 = V_{ADC11} * 12.6$      | 0÷63 (m³/h)<br>EMR≤40;<br>WRN≤45  | <0.5%              |
| The flow rate of 2 circuit water                | G2          | $G2 = V_{ADC12} * 20$        | 0÷100 (m³/h)<br>EMR≤70;<br>WRN≤80 | <0.5%              |
| The flow rate of water through 1 circuit filter | Gf          | $Gf = V_{ADC13} * 0.9$       | 0÷4.5 (m³/h)                      | <0.5%              |
| The flow rate of air in the ventilation system  | Gv1         | $Gv1 = V_{ADC14} * 800$      | 0÷4000 (m³/h)                     | <0.5%              |
| Level of water in the reactor pool              | Hp1         | $Hp1 = 400 - V_{ADC15} * 80$ | 0÷400 (Cm)<br>EMR≤60;<br>WRN≤30   | <0.5%              |
| Level of water in the reactor pool              | Hp2         | $Hp2 = 20 - V_{ADC16} * 4$   | 0÷20 (Cm)                         | <0.5%              |
| Level of backup water                           | Hsup        | $Hsup = V_{ADC17} * 0.2$     | 0÷1 (m)                           | <0.5%              |

The BPM-108R1N unit was tested based on the calibration devices of PIS. The test results respond to generate signals of emergency protection (EMR) and warning signaling (WRN) by every monitored parameter. The relative deviation in the whole range was less than 0.5% which meets the requirements of the ASUZ-14R system.

### 3) Developing software for presenting information for the DNRR on computers

The software package was developed in Window environment, written in the C# language, representing the information of the CPS in the form of graphics and digital indications, arranged into 4 screen pages. The first page shows information about neutron parameters, control rods position, the unbalanced voltage value of automatic control, reactivity value, etc; the second page shows the technological parameters; the third page shows the states of discrete signals of the reactor; and the last page shows data packets from three of UNO-251R1. The interface of the software's pages is shown in Fig. 4.



Figure. 4. Screen pages of the developed software used for the DNRR

The software has been tested at the DNRR and compared with the existing software of the ASUZ-14R control system. The experimental results show that the functions of the two software are equivalent as shown in Fig. 5.

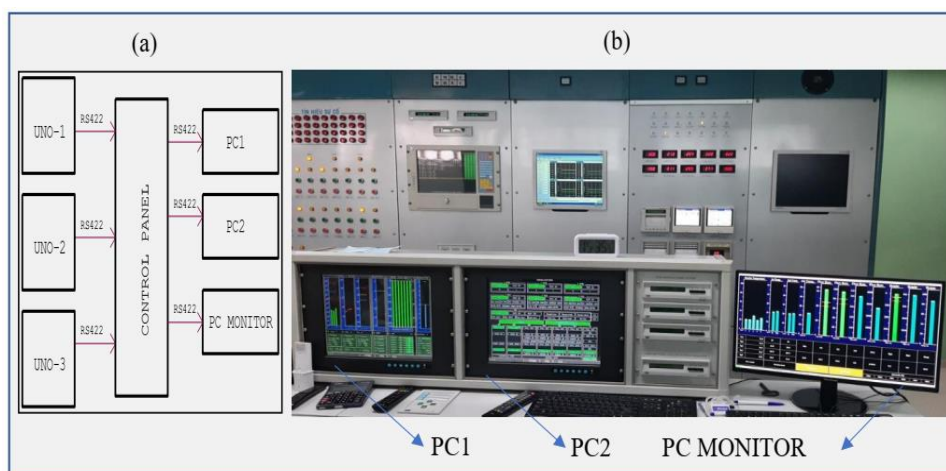


*Figure 5. Testing pictures of the developed software at the DNRR's control console*

In Fig. 5, PC1 and PC2 are the computer screens of the ASUZ-14R system, and PC MONITOR is the developed information display screen. The software is able to properly work on current computer types on the market, and the layout interface can be modified according to the requirements of the operator. It is possible for parallel running and changeover if required.

The obtained results are the foundation for further development of an independent data acquisition and processing cabinet UNO-251R1 to measure and test parameters of the CPS, as well as for research and training purposes at the DNRR.

## **2.3. INSTRUMENTATION, NUCLEAR ELECTRONICS**

## STUDY ON DESIGN AND CONSTRUCTION OF COSMIC-RAY NEUTRON DETECTOR USING MULTI-LAYERED SCINTILLATORS FOR SOIL MOISTURE MEASUREMENT

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### Project information:

- **Project name:** Study on design and construction of cosmic-ray neutron detector using multi-layered scintillators for soil moisture measurement
- **Code:** ĐTCB.08/21/VKHKTHN
- **Managerial Level:** Ministry
- **Duration:** 24 months (Jan 2021- Dec 2022)
- **Contact email:** ngdtuan108@gmail.com
- **Published papers related to the project:**

1. Nguyen Duc Tuan, Mai Van Dien, Vu Van Tien, Khuong Thanh Tuan, Vu Trung Tan, Cao Duc Viet, Nguyen Thanh Hung. Study on design, construction and testing of cosmic-ray soil moisture observing system in Vietnam. The article has been accepted for publication in Journal.

A new method which has been developed in the world for more than 10 years and called Cosmic-Ray Neutron Sensing (CRNS) is used for measuring area-average soil moisture at the hectometer horizontal scale to overcome the limitations of traditional methods and remote sensing technology. Applying this CRNS technique, a COSMOS-VINATOM system was designed and manufactured within the framework of the project of the Ministry of Science and Technology on the basis of cooperation and partial technology transfer with FINAPP SRL (Italy), quoted by the Food and Agriculture Organization of the United Nations (FAO) and by International Atomic Energy Agency (IAEA). This is an embedded system for measuring cosmic-ray neutrons in the environment to determine soil moisture. It is made up as shown in Figure 1 with functional modules including: Detector-1 (1) for thermal neutron; Detector-2 (2) for muon; Signal Processing and Data Acquisition Board (3); Solar panel (20 Watt) (5) and backup battery (6). The detectors, electronic units and weather sensors are housed in an IP66 Protection Class box enclosure (4) for outdoor use.

The neutron detector has a layered structure consisting of a thin sheet sensitive to neutron radiation and a wavelength shifter to capture light through the photomultiplier. The thin sheet which is able to detect thermal neutron consists of a homogeneous matrix of fine particles of lithium-6-fluoride ( $^6\text{LiF}$ ) and zinc sulfide phosphor ( $\text{ZnS:Ag}$ ) compactly dispersed in a colorless silicon binder. The compact neutron detector (size 140 x 140 x

50 mm) is embedded in a polyethylene box, 12 mm thick, in order to enhance the detection of the epithermal component of the environmental neutron spectrum (approximately  $0.5 \text{ eV} < E_n < 50 \text{ keV}$ ). A muons detector is used to monitor any variations of the cosmic ray incoming. It comprises a plastic scintillator cylinder 50.8 mm x 50.8 mm read by a 38.1 mm photomultiplier tube. Signal Processing and Data Acquisition Board is based on microcontroller with functions of digitizing and counting pulses from neutron and muon detectors, storing on SD memory card and transmitting data via the GSM/4G LTE modem to a data acquisition computer. This board also houses temperature, humidity and pressure sensors which are used for instrumental diagnostics and corrections. The power supply for the instrument is a 12V DC rechargeable battery pack connected to the solar panel.

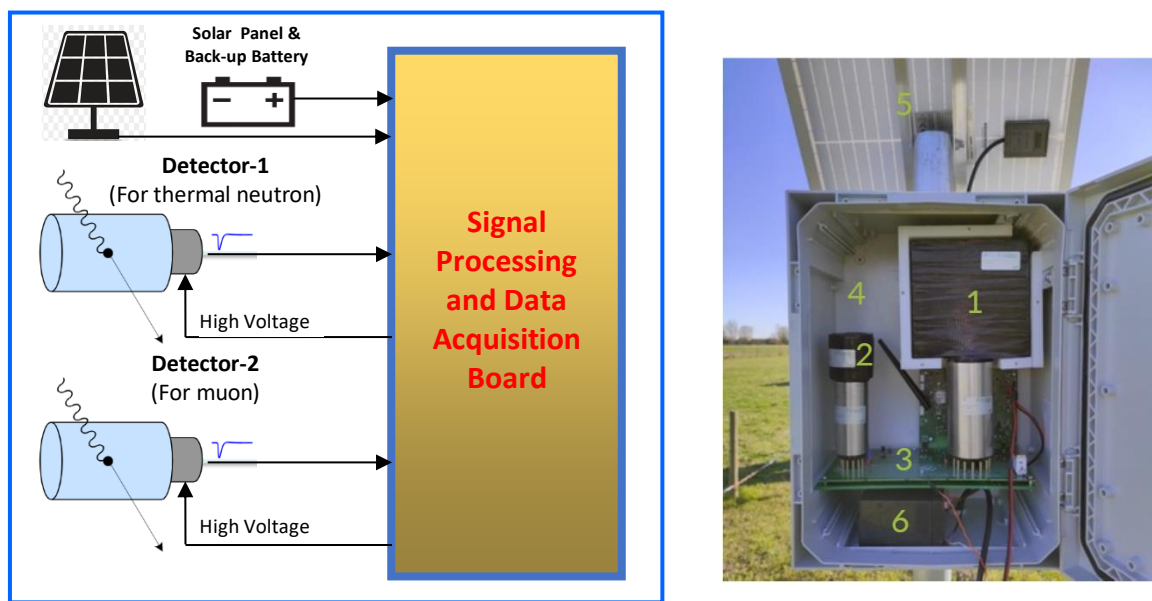


Figure 1. Function block diagram of COSMOS-VINATOM

The standard procedure to correct neutron counts ( $N_{raw}$ ) measured from the system for air pressure, air vapor and incoming variability as following factors.

$$f_{bar} = e^{\beta(P-P_{ref})} \quad (1)$$

$$f_h = (1 - \alpha(h - h_{ref})) \quad (2)$$

$$f_i = \frac{I_{ref}}{I} \quad (3)$$

$$N = N_{raw} \cdot f_{bar} \cdot f_h \cdot f_i \quad (4)$$

where,  $h$  is the absolute humidity in  $\text{g.m}^{-3}$ ,  $\beta = 0.0076$ ,  $\alpha = 0.0054$ , and  $h_{ref}$ ,  $p_{ref}$  are the mean value of humidity and pressure during the measuring period, respectively.  $I$  is the incoming flux of galactic cosmic-ray and  $I_{ref}$  is the average value of the incoming fluctuation over a long period based on muon flux measured by Detector-2. Then, corrected neutrons counting  $N$  are converted into gravimetric water content  $\theta_p(\text{g/g})$  and volumetric water content  $\theta (\text{cm}^3/\text{cm}^3)$  based on the following equation:

$$\theta_p = \left( \frac{0,0808}{\frac{N}{N_0} - 0,372} - 0,115 - \theta_{offset} \right) \quad (5)$$

$$\theta = \theta_p \cdot \frac{\rho_{bd}}{\rho_w} = \theta_p \cdot \rho_{bd} \quad (6)$$

where  $\rho_{bd}$  (g/cm<sup>3</sup>) is the soil bulk density,  $\rho_w$  (1g/cm<sup>3</sup>) is the water density,  $\theta_{offset}$  is the gravimetric water equivalent of additional hydrogen pools (e.g., lattice water, soil organic carbon), and  $N_0$  is the counting rate over dry soil. The value  $N_0$ , a site-specific parameter, could be calibrated based on an independent soil sampling campaign. The precision of the CRNS technique depends mainly on the neutron counting rate,  $N$ . Applying the error propagation formula, the precision of soil moisture determination can then be computed through the function (5), i.e.

$$\sigma_\theta = \frac{a_1 N_0 \sqrt{N}}{(N - a_2 N_0)^2} \quad (7)$$

The COSMOS-VINATOM system was installed on September 20, 2022 (Figure 2, left) in Xuan Canh, Dong Anh district, Hanoi, Vietnam, located by latitude 21°05'44.4"N and longitude 105°51'23.4"E, and at an altitude of 13 m above sea level. The calibration procedure involved obtaining an estimate of the area-averaged soil moisture content ( $\theta$ ) over the CRNS measurement footprint (by gravimetric soil sampling in locations (Figure 2, right) and the subsequent neutron intensity ( $N$ ). By the inverse of equation (5), the site-specific  $N_0$  value was calculated to be 686.46 cph.

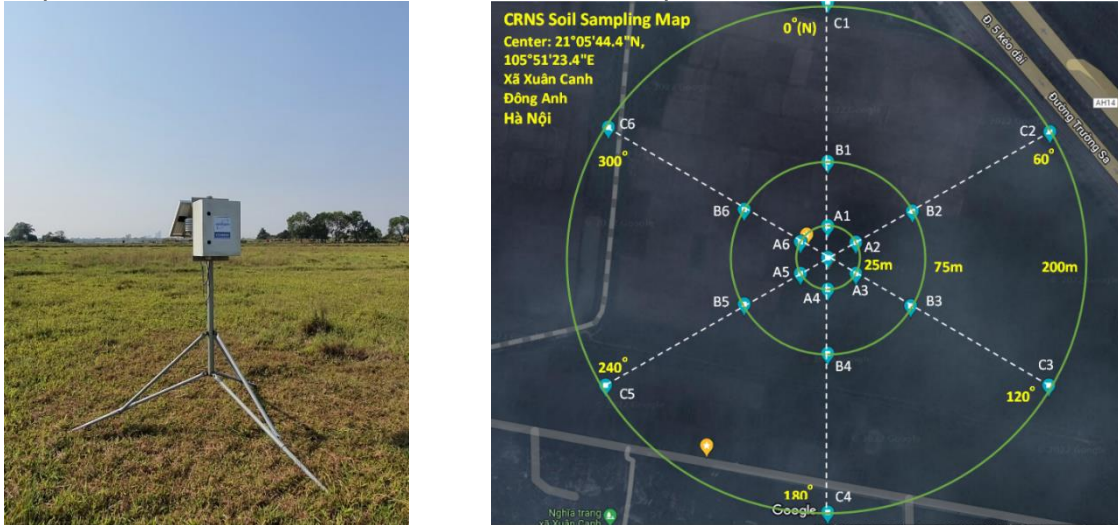


Figure 2. Xuan Canh-Dong Anh Ha Noi experimental site, with (left) COSMOS-VINATOM and (right) soil sampling locations and CRNS footprint (200 m radius)

Some of the initial results of soil moisture measurement on the COSMOS-VINATOM system for certain periods of time include the raw values obtained from the system in Table 1 and the calculated values respectively according to the formulas (1), (2), (3), (4), (5), (6) and (7) shown in Table 2.

Table 1. Raw data

| Date       | Time  | Neutrons N (cph) | Muons (cph) | Inter. Temp. (°C) | Ext. Temp. (°C) | Ur (%) | Pressure (hPa) | Absolute Humidity (g.m <sup>3</sup> ) | Corrected Muons (cph) |
|------------|-------|------------------|-------------|-------------------|-----------------|--------|----------------|---------------------------------------|-----------------------|
| 9/20/2022  | 9:42  | 417              | 1719        | 39.7              | 33.3            | 68.1   | 1007.3         | 24.58                                 | 1763                  |
| 9/20/2022  | 10:43 | 377              | 1655        | 40                | 33.1            | 66.6   | 1007.8         | 23.79                                 | 1695                  |
| 9/20/2022  | 11:45 | 409              | 1698        | 41.4              | 34.6            | 65     | 1007.2         | 25.12                                 | 1745                  |
| 9/23/2022  | 9:51  | 353              | 1693        | 38.3              | 30.5            | 66.7   | 1011.7         | 20.74                                 | 1713                  |
| 9/23/2022  | 10:52 | 348              | 1611        | 38.5              | 31.3            | 64.7   | 1011.4         | 21.00                                 | 1633                  |
| 10/18/2022 | 11:51 | 414              | 1635        | 33.1              | 29.3            | 35.9   | 1015.1         | 10.46                                 | 1639                  |
| 10/18/2022 | 12:53 | 400              | 1648        | 35.1              | 29.7            | 35.5   | 1013.7         | 10.57                                 | 1658                  |
| 10/18/2022 | 13:54 | 396              | 1610        | 37                | 30.2            | 37.7   | 1012.8         | 11.53                                 | 1624                  |
| 10/18/2022 | 14:56 | 408              | 1653        | 37.5              | 30.2            | 37.3   | 1011.8         | 11.41                                 | 1671                  |

Table 2. Calculated data

| $f_{bar}$ | $f_h$ | $f_i$ | $F = f_{bar} \cdot f_h \cdot f_i$ | $N.F$ (cph) | $\theta_p$ (g/g) | $\theta$ (cm <sup>3</sup> /cm <sup>3</sup> ) | $\theta$ (%) | $\sigma_\theta$ ( $\pm$ cm <sup>3</sup> /cm <sup>3</sup> ) | $\sigma_\theta$ (%) |
|-----------|-------|-------|-----------------------------------|-------------|------------------|----------------------------------------------|--------------|------------------------------------------------------------|---------------------|
| 0.965     | 1.133 | 0.954 | 1.043                             | 434.95      | 0.194            | 0.318                                        | 31.8         | 0.051                                                      | 15.91               |
| 0.969     | 1.128 | 0.993 | 1.085                             | 409.00      | 0.246            | 0.403                                        | 40.3         | 0.057                                                      | 14.21               |
| 0.964     | 1.136 | 0.964 | 1.055                             | 431.69      | 0.200            | 0.327                                        | 32.7         | 0.051                                                      | 15.69               |
| 0.998     | 1.112 | 0.982 | 1.090                             | 384.70      | 0.314            | 0.515                                        | 51.5         | 0.065                                                      | 12.65               |
| 0.995     | 1.113 | 1.030 | 1.142                             | 397.40      | 0.276            | 0.452                                        | 45.2         | 0.061                                                      | 13.47               |
| 1.024     | 1.056 | 1.026 | 1.110                             | 459.62      | 0.157            | 0.257                                        | 25.7         | 0.045                                                      | 17.64               |
| 1.013     | 1.057 | 1.015 | 1.086                             | 434.60      | 0.194            | 0.319                                        | 31.9         | 0.051                                                      | 15.88               |
| 1.006     | 1.062 | 1.036 | 1.107                             | 438.38      | 0.188            | 0.308                                        | 30.8         | 0.050                                                      | 16.14               |
| 0.998     | 1.062 | 1.007 | 1.067                             | 435.40      | 0.193            | 0.317                                        | 31.7         | 0.050                                                      | 15.94               |

The results show that the soil moisture data observed on the COSMOS-VINATOM system was consistent with actual observations at the site. They were at specific times such as on September 20, 2022, soil was relatively dry with measured soil moisture of about 35%; on September 23, 2022, after the previous day's rainfall, soil surface with water, mud, high soil moisture measured by the system was about 48.3%; on October 18, 2022, after 2 weeks without rain and the influence of the northeast monsoon, the soil surface was basically dry and only moist in a few places; therefore, the soil moisture according to the system was about 30%. As mentioned above, with the current neutron counting rate of about 400 cph, the counting uncertainty was 5% ( $400^{-0.5}$ ). Propagating this counting uncertainty through the calibration function (5), the error in soil moisture according to formula (7) was about 15.28% for 1-hour average. Accordingly, quadrupling the counting time would halve ( $4^{-0.5}$ ) these uncertainties. When the system is later permanently installed for continuous measurement, the error of less than 5% is given for an average of a 12-hour period as recommended. Future long-term soil moisture measurements based on this system will continue to be carried out, along with comparisons with other methods and with precipitation for a complete assessment,

so that it can be officially used in some other areas such as drought warning and smart agriculture in Vietnam.

## 2.4. INDUSTRIAL APPLICATIONS

## STUDY ON METHOD AND DESIGNING THE FABRICATION OF GAS-LIFT WELL LEAK TESTING DEVICES USING CHEMICAL TRACER TECHNIQUE

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### **Project information:**

- **Project name:** Study on method and designing the fabrication of gas-lift well leak testing devices using chemical tracer technique
- **Code:** ĐTCB. 09/21/TTUDKTHN
- **Managerial Level:** Institute
- **Duration:** Jan 2021- Dec 2022 (extended until June 2023)
- **Contact email:** tribq@canti.vn
- **Published papers related to the project:**

1. Bui Quang Tri , Huynh Thi Thu Huong<sup>1</sup>, Pham Uyen Thi<sup>1</sup>, Duong Thi Bich Chi<sup>1</sup>, Phan Thi Luan<sup>1</sup>, Le Thi Thanh Tam<sup>1</sup>, Tran Tri Hai<sup>1</sup>, Le Van Son<sup>1</sup>, Nguyen Van Muoi<sup>2</sup>, Dang Duc Nhan<sup>3</sup> "Researching and testing with tracer method for gas-lift well survey", Vietnam Journal of Science and Technology, 2023 (in Vietnamese).
2. Bui Quang Tri, Huynh Thi Thu Huong, Dang Nguyen The Duy, Nguyen Huu Quang, Le Van Son, Tran Trong Hieu, "Study on method and designing the fabrication of gas-lift well leak testing devices using chemical tracer technique", Vietnam Conference on Nuclear Science and Technology (VINANST 14), Dalat, 2021.

In the operation of gas-lift wells, various issues often arise, such as gas-lift valves that should be closed but remain open, or vice versa. Additionally, there may be instances of gas leakage into or out of the annulus. Therefore, surveying gas-lift wells to identify the underlying causes of these malfunctions is a necessary requirement in petroleum extraction. The current methods for detecting leaks in gas-lift wells often involve using devices and tools that directly intervene in the wellbore, such as pressure and temperature measurements, flow rate monitoring inside the production tubing and so on. The aforementioned methods have some drawbacks, including high costs and the need to halt well operations, at least during the deployment of the equipment into the well. That is why it is necessary to undertake research on a new method to overcome the limitations of the aforementioned approaches. The task assigned to the Ministry of Science and Technology, "Study on method and designing the fabrication of gas-lift well leak testing devices using chemical tracer technique," aims to develop a leak control

method for gas-lift wells using chemical tracer technique and to construct an online tracer measurement device to facilitate tracer experiments.



Figure 1. Online tracer analysis device

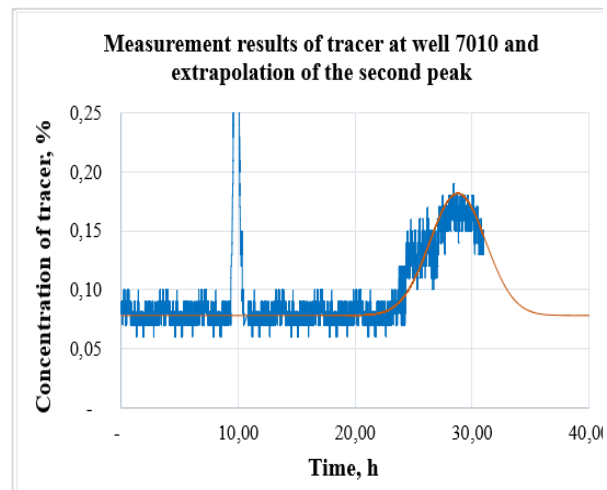


Figure 2. Tracer measurement results at the wellhead of 7010/BK-7 HM over time

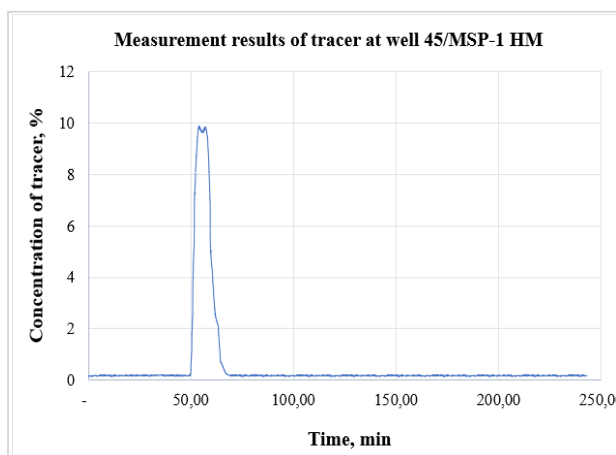


Figure 3. Tracer measurement results at the Wellhead of 45/MSP-1 HM over time

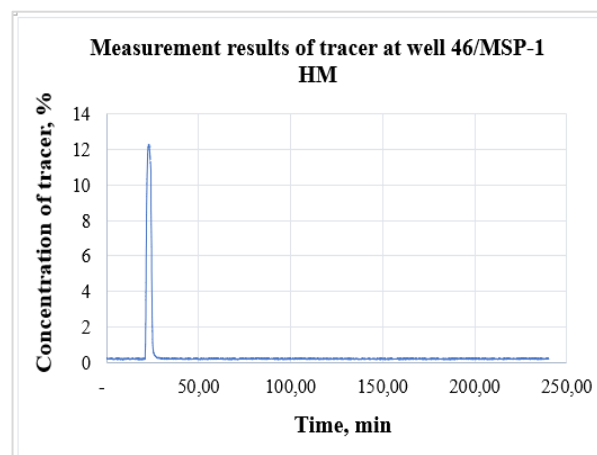


Figure 4. Tracer measurement results at the Wellhead of 46/MSP-1 HM over time

The achieved results include the successful development of a tracer method for determining gas injection points in gas-lift wells, the calculation method and the software for computing the gas injection velocities in the annulus and the production tubing (CANTI-GASLIFT). Additionally, the successful fabrication of a direct online gas tracer measurement device is depicted (Figure 1). The device consists of three modules (gas separation, filtration, and flow rate/pressure adjustment, and tracer analysis module). The device can be connected to the gas-lift wellhead, with a maximum pressure of up to 5,000 psi. It is capable of separating gas from the production stream (gas, oil, water), providing dry filtration and pressure/flow rate adjustment to supply the measurement chamber of the tracer analysis module. A gas-lift production well model has been designed and constructed in the Laboratory to facilitate method testing. Tests of the method and equipment were conducted on the model, yielding highly feasible results,

providing the basis for the Vietnam-Russia Joint Venture (VSP) to authorize industrial field testing. Field tests of the method and equipment were conducted at the gas-lift wells 7010/BK7, 45/MSP-1, and 46/MSP-1 in the Bach Ho oil field. The test results demonstrated the equipment's robust performance under challenging field conditions. The tracer experiments show that well 7010/BK-7 has two gas injection points were determined at depths of 2,971.3m and 2,247.1m, corresponding to operational valve 5. Additionally, a tubing leak was detected between gas-lift valve 3 and valve 4. Notably, 80.4% of the lift gas was pumped through the leak point, while only 19.6% of the lift gas was pumped through operational valve 5 (Figure 2). At well 45/MSP-1, a gas injection point was identified at a depth of 1,723m. This injection point could either be at gas-lift valve 2 or from a tubing leak at 1,723m (Figure 3). At well 46/MSP-1, a gas injection point was confirmed at a depth of 1,170.6m, attributed to a tubing leak (Figure 4). Consequently, all the wells exhibited inefficient performance due to the gas injection points not aligning with the original design.

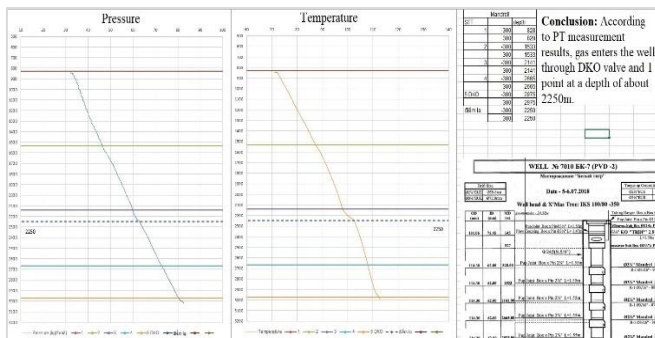


*Figure 5. Determination of gas lift injection points in well 7010/BK-7 using the method of temperature and pressure measurements in the production tubing.*

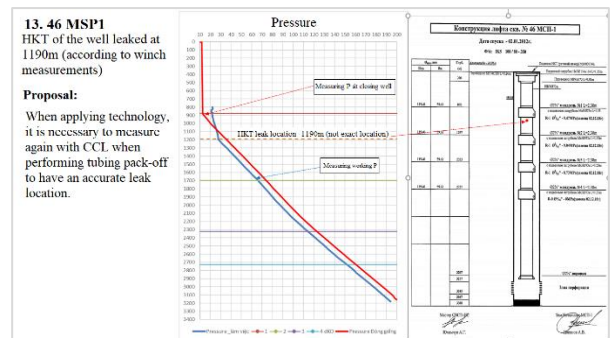


*Figure 6. Determination of gas lift injection point in well 46/MSP-1 using the method of temperature and pressure measurements in the production tubing.*

After concluding the tracer method test, VSP employed the temperature and pressure measurement method within the production tubing to survey 2 out of the 3 aforementioned wells (wells 7010/BK-7 and 46/MSP-1) in order to validate the accuracy of the tracer method. The results determined that well 7010/BK-7 had two gas injection points at depths of 2,250m and 2,975m (Figure 5), and well 46/MSP-1 had a single gas injection point at a depth of 1,190m (Figure 6). Hence, in comparison with the results obtained through the tracer method, the gas injection point positions in well 7010/BK-7 were identified with deviations of 0.13% at 2,247.1m and 0.12% at 2,971.3m. Similarly, in well 46/MSP-1, the gas injection point was pinpointed with a deviation of 1.63% at a depth of 1,170.6m. The higher deviation in well 46/MSP-1 compared to well 7010/BK-7 can be attributed to the fact that well 7010/BK-7 operated more stably in terms of production rate and pressure.

The research results have achieved the objective of the task, which is to develop a method for controlling leakage in gas-lift production wells using a tracer technique with

chemical substances and the fabrication of an online tracer measurement device. The method's testing in the test facility as well as in the field has demonstrated that the tracer method for surveying gas-lift production wells can determine the depth of the gas injection point and identify multiple injection points within the well. The accuracy of the position determination is within a range of less than 2% (though it depends on the stability of the well's operation). This method is simple, non-intrusive to the wellbore, easy to implement for personnel, requires minimal equipment, and provides easily analyzable on-site results.

The novelty here lies in the fact that, for the first time in Vietnam, a method for leak detection in gas-lift wells using chemical tracer techniques has been established, along with the design and fabrication of a direct measurement device for tracer substances (online). This method offers advantages over traditional approaches in terms of cost-effectiveness, simplicity, and absence of risks. The innovation of this project is based on utilizing the travel time of the tracer substance through experiments and the calculated velocity of the tracer substance in a model to deduce the distance, subsequently determining the leak location.

The research results using the mentioned CO<sub>2</sub> chemical tracer require the injection of tens of cubic meters of gas into the well, leading to increased costs and inconvenience in transportation. It is necessary to continue investigating to discover a new tracer substance, coupled with sensors of higher sensitivity (PPM), which would subsequently reduce the required amount of marking substance to just a few litres per well. This approach would thereby lower costs and enhance transportation convenience.

## STUDY ON THE APPLICABILITY OF THE 2D GAMMA TOMOGRAPHY TECHNIQUE TO SURVEY THE PHASES ON TRAYS IN DISTILLATION TOWER IN OIL REFINERY

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*Centre for Applications of Nuclear Technique in Industry, No. 01, ĐT723, Ward 12, Da Lat City, Lam Dong Province, Viet Nam*

### Project information:

- **Project name:** Study on the applicability of the 2D gamma tomography technique to survey the phases on trays in distillation tower in oil refinery.

- **Code:** CS/22/06-02

- **Managerial Level:** Institute

- **Duration:** 12 months (Jan 2022 - Dec 2022)

- **Contact email:** chaunt@canti.vn

### - Published papers related to the project:

1. 01 paper published in conference proceedings: "Construction a two-dimensional gamma scanning technique for survey the difference between the fluid on the tray of a distillation column in a petrochemical refinery by the Monte Carlo simulation" Conference of Nuclear Science and Technology for Young Researchers, Hanoi, October 2022. (in Vietnamese).

The traditional 1D gamma scanning technique is known as an effective and popular method for investigation of distillation tower in oil refineries. The technique is performed by measuring the intensity of gamma rays transmitting through the tower from a radioactive source positioned opposite to obtain a diagram of material density inside the tower according to its height. Based on the obtained density diagram, it is possible to determine the internal condition of the tower such as the physical state of trays, fluid level on trays, abnormal phenomena of fluid flow above and below trays, such as flooding, foaming, and downcomer backup. This technique has many advantages in terms of simplicity, fast implementation, and accuracy for the physical condition of trays. However, interpreting fluid problems is quite complicated and requires experiences, and the interpretation results are still qualitative.

The 2D gamma scanning technique has been proposed in the world in recent years as an improved solution that provides visual cross-sectional images, showing clear details of the physical hardware as well as the distribution of density of fluids inside the tower. The 2D gamma scanning technique can be considered as a supplementary solution to the 1D technique to enhance the effectiveness of tower investigation meeting the increasingly diverse needs of process investigation in oil refineries.

This research project aims to approach the 2D gamma tomography technique, evaluate its applicability on investigation of distillation towers, and provide a basis for improving the gamma scanning technique to enhance the quality of tower inspection services provided by Centre for Applications of Nuclear Technique in Industry. The mainly implemented project contents include developing the 2D gamma tomography method, constructing 2D gamma reconstruction software and conducting experiments to verify the applicability of the method.

In order to build an image of 2D gamma scanning, it is necessary to obtain the projections of the region of interest at different angles. Because the 2D gamma scanning method is essentially a computed tomography method that lacks projection, it is impossible to apply back projection algorithm to reconstruct the image. In addition, due to the lack of projection, the reconstructed images are strongly affected by artifacts and noise due to geometric calculations. To overcome this problem, the simultaneous algebraic reconstruction technique (SART) was applied in combination with the Xiaolin Wu algorithm and image matrices from the engineering drawing to reconstruct appropriate quality images and meet the technical requirements of 2D gamma scanning.

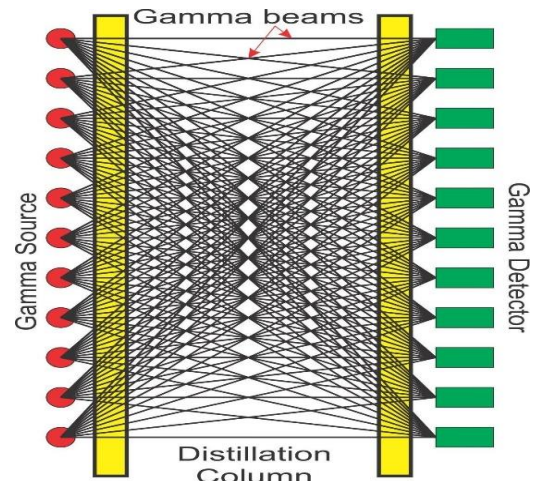
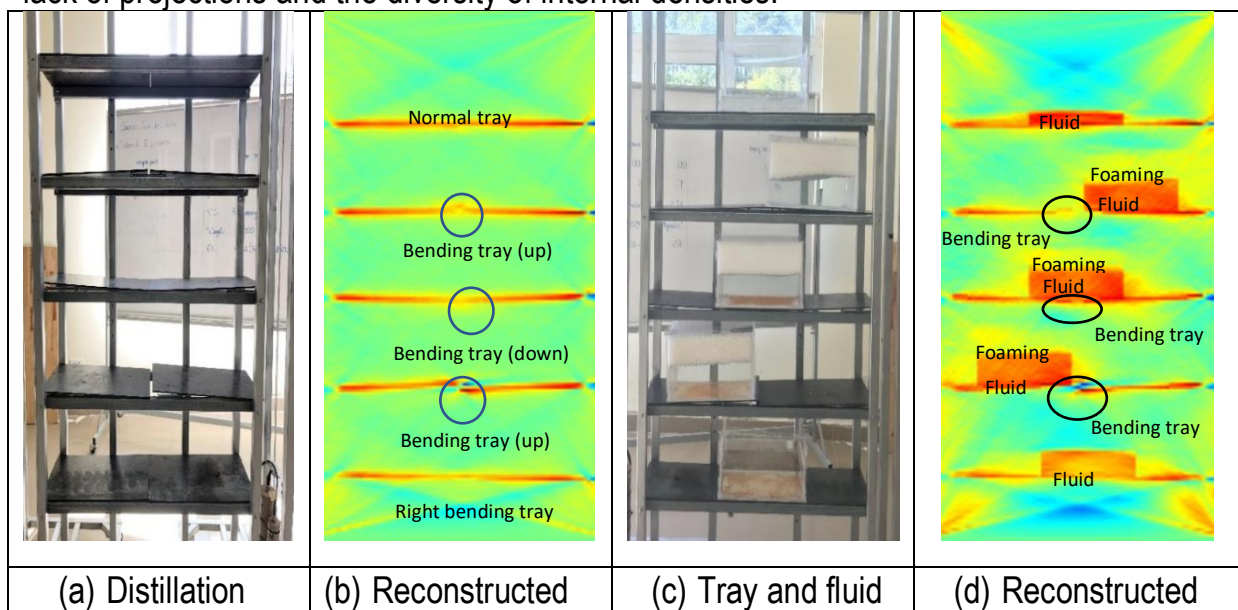


Figure 1: Gamma 2D configuration

The results showed that the reconstructed images displayed the state of the trays such as bending, collapsing, warping (Figure 2b), as well as the distribution of fluids on the tray (Figure 2d), which matched the experimental setup. However, the obtained images are also suffered from a considerable amount of noise and artifacts due to the lack of projections and the diversity of internal densities.



|              |                                                          |                                     |                                                                    |
|--------------|----------------------------------------------------------|-------------------------------------|--------------------------------------------------------------------|
| column model | image of the tray<br>inside distillation<br>column model | inside distillation<br>column model | image of the tray and<br>fluid inside distillation<br>column model |
|--------------|----------------------------------------------------------|-------------------------------------|--------------------------------------------------------------------|

*Figure 2: The results of the 2D tomography scanning image and the respective experimental models.*

All the contents and products in the project were completed as required. The details are presented as followings:

#### **Product Type I: A Distillation Column Model for 2D Tomography Method Studies**

A distillation column model for 2D tomography method studies consists of one source, one detector, a moving mechanical system including a tower part of size 500 mm x 320 mm x 2030 mm, trays, control part for detector and source movement, Nal Ludlum 2200 detector and data acquisition system.

The eTomography 2D control program allows to set up the number of projections and beam angles of the 2D tomography measurement configuration, as well as connecting, controlling the motion of the source and detector and acquisition of measurement data.

#### **Product Type IIa: 2D Tomography Image Reconstruction Software**

The image reconstruction software is programmed in C# language, using Xiaolin Wu algorithm combined with simultaneous algebraic reconstruction technique (SART).

#### **Product Type IIb: 2D Tomography Inspection Method Report**

The experimental results demonstrate the potential application of the method to survey the distillation tower. In order to establish the 2D gamma scan technology for actual object, further development studies are needed on larger and more complex laboratory models, as well as in field experiments.

From the results of the project, it can be seen that the research team initially approached the method and created the main tools for performing 2-D gamma scanning, thereby making an important contribution to improving the gamma column scanning technique as well as strengthening the capacity of CANTI in radiation source application in industrial system investigation.

## STUDY ON BUILDING THE ULTRASONIC TESTING PROCEDURE FOR AUSTENITIC WELDS - ACCORDING TO ASME BOILER AND PRESSURE VESSEL CODE

Dao Dinh Dang et al

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

### **Project information:**

**- Project name: Study on building the ultrasonic testing procedure for austenitic welds - according to ASME boiler and pressure vessel code**

**- Code: CS/22/09-01**

**- Managerial Level: Institute**

**- Duration: 12 months (Jan 2022- Dec 2022)**

**- Contact email: dang.d6dhn@gmail.com**

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

1. Dao Dinh Dang, "Research on building the ultrasonic testing procedure for austenitic welds - according to ASME boiler and pressure vessel code", 7th Conference on Nuclear Science and Technology for Young Officers of the Atomic Energy Industry.

Welds of austenitic stainless steels are difficult for ultrasonic testing due to their material properties. The ASME boiler and pressure vessel ultrasonic testing process for stainless steel welds is the timely standardization for that requirement. Based on the references, the team focuses on building a procedure for 304 stainless steel material, with a thickness of up to 25 mm, welded flat plate, which creates premise to develop examination for other austenitic materials and more complex configurations. The procedure will be proven by actual testing on the welding samples of materials at NDE Center and suitable objects at Nghi Son 1 Thermal power plant. It is also the basis for the application of advance techniques such as phased array ultrasound.

The aims of this project include: To timely standardize of NDT technical procedure according to the latest versions of world-renowned standards; to develop the professional qualifications of NDT technicians; whose capacity satisfy the testing requirements for new materials, especially in the industrial field, and to contribute to improving the capacity of NDE Center for training and implementing NDT work.

In terms of research methodology, this study was carried out as follows. Firstly, the needs of testing austenitic stainless steel welds in the industrial field were surveyed. Secondly, the technical documents related to ultrasonic testing method of austenitic materials were learned. Thirdly, a procedure for ultrasonic testing of austenitic sheet joints, meeting the requirements of ASME standards was built. Fourthly, the suitability of

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**TRUNG TÂM ĐÁNH GIÁ KHÔNG PHÁ HỦY – NDE**  
 Địa chỉ: 140 Nguyễn Trãi – Thanh Xuân – Hà Nội  
 Điện thoại: 024 35517361 Website: www.ndecenter.com.vn

**QUY TRÌNH KIỂM TRA SIÊU ÂM  
 MỐI HÀN NỐI TẮM VẬT LIỆU AUSTENITIC  
 THEO TIÊU CHUẨN ASME**

**Tài liệu số: NDE-IN-UT-ASME-05. Bản:00**

| THIẾT LẬP | PHÊ DUYỆT | KHÁCH HÀNG |
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Toàn phần bản tài liệu trong sản xuất và lắp máy tại bể, lò, nồi, bình chứa không được, trừ: lắp bản tài liệu này  
 Tài liệu số: NDE-IN-UT-ASME-05 Ngày phát hành: 05/05/2017 Bản: 00 Trang: 1/21

Figure 2. Ultrasonic testing procedure

The products of the project consist of the followings:

*Type I:* Reference block DAC according to ASME V, article 4.

*Type II:* Ultrasonic testing procedure for austenitic welds; Drawing of reference block DAC; Report on application of testing, evaluation of inspection procedures on welding samples at NDE Center; and Report on application of inspection at Nghi Son 1 thermal power plant.

*Type III:* “Researching for building the ultrasonic testing procedure for austenitic welds - according to ASME boiler and pressure vessel code”, 7<sup>th</sup> Conference on Nuclear Science and Technology for Young Officers of the Atomic Energy Industry.

In general, the products of the Project, especially the ultrasonic testing procedure for austenitic welds, were completed on schedule with the efforts of team. During the implementation of the Project, the leader and the team found that the inspection technique still has limitations and has not fully and comprehensively met the actual requirements in the industrial field. This is an important premise for the team towards building testing procedure with more advanced and newer methods and techniques for stainless steel and new materials in general.

## STUDY ON DEVELOPING THE INSPECTION PROGRAM FOR THE MAINSTEAM PIPELINES AT THERMAL POWER PLANTS BY USING NON-DESTRUCTIVE TESTING METHODS

Nguyen Van Duy et al

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

### Project information:

- **Project name:** Study on developing the inspection program for the main steam pipeline system at a thermal power plant by using non-destructive testing methods.
- **Code:** ĐTCB.16/21/TTNDE
- **Managerial Level:** Ministry
- **Duration:** 24 months (June 2021- May 2023)
- **Contact email:** duynguyenvan.nde@gmail.com
- **Published papers related to the project:**
  1. Nguyen Van Duy, “Research on developing the inspection program for the main steam pipeline system at thermal power plants by using non-destructive testing methods”, Proceedings of the 7th Conference on Nuclear Science and Technology for Young Researchers, Hanoi, October 2022.
  2. Vu Duc Vinh, Nguyen Van Duy, et al., “Research on developing the inspection program for the main steam pipeline system at thermal power plants by using non-destructive testing methods, Proceedings of the 15th Vietnam Conference on Nuclear Science and Technology (VINANST 15), Khanh Hoa, August 2023.

A main steam pipeline system is designed to be put into operation at high temperatures and high pressures (temperature of up to 610°C and pressure of up to 17.5 MPa – 27.46 MPa) and is considered a critical component in a thermal power plant. Due to harsh operating conditions, the system may suffer from a number of damages such as creep, fatigue, flow assisted corrosion, microstructure changes, welding defects, and so on. In fact, there have been many records of the accidents related to these pipelines which cause serious consequences. The main steam pipelines inspection program using NDT methods is needed in order to ensure the operation safety of the thermal power plants and energy security. The program has been applied at Nghi Son 1 thermal power plant.

The NDE Center has recently been equipped with many advanced equipment's which are widely applied to solve the difficult problems of industry. The development of the inspection program which combines the traditional and advanced techniques is a

solution suitable to the situation of Vietnam. The NDT methods have been used such as: Visual inspection, ultrasonic thickness measurement, magnetic particle testing, liquid penetrant testing, hardness testing, material chemical composition analysis, infrared thermal imaging for external-side, guided wave ultrasound, surface structure replication.

The project aims to developing an inspection program to assess the current condition of the main steam pipelines and building the data towards the lifetime prediction; thereby ensuring the operation safety and the production efficiency in the thermal power plants; The project also strength the capacity and professional qualifications of NDT technicians in order to enlarge application of this inspection to the steam pipelines system of the industrial sector.

In terms of research methodology, this study was carried out as follows. Firstly, the API standards on the inspection program framework for pipelines were researched. Secondly, the current status of the main steam pipeline inspection at some thermal power plants in Vietnam were surveyed; the locations at risk of damage or corrosion were inspected as well as the advantages and dis-advantages during inspection were collected. Thirdly, the testing systems were prepared with the test samples similar to the materials used at the plants. The samples were designed with the simulated discontinuities in order to investigate the sensitivity of the methods. Fourthly, the NDT equipment was applied on the tested samples and the results were evaluated. Fifthly, the inspection procedures were built based on the optimal parameters. Finally, the built inspection procedure was applied on the actual objects.



*Figure 1. Simulation prototyping process*

Regarding research contents, the project provides an overview of the main steam pipelines at thermal power plants. In addition, the project researched and developed the

program of inspection and maintenance for the main steam pipelines in the power plants and the effectiveness of the inspection procedure was evaluated as well; This inspection program was applied for a thermal power plant in Vietnam as evidence of the program effectiveness.

At Nghi Son 1 thermal power plant, the Project team applied the inspection program to check the super-heater output steam area of the boiler No. 1. The using NDT methods including Visual inspection, infrared thermal imaging, guided wave ultrasonic testing, hardness testing, chemical composition analysis, materials microstructure analysis, thickness measurement, fluorescence wet magnetic particle testing, liquid penetrant testing, ultrasonic testing. The Ansys software was applied to simulate the flow and to assess its impact on pipes with the elbows.

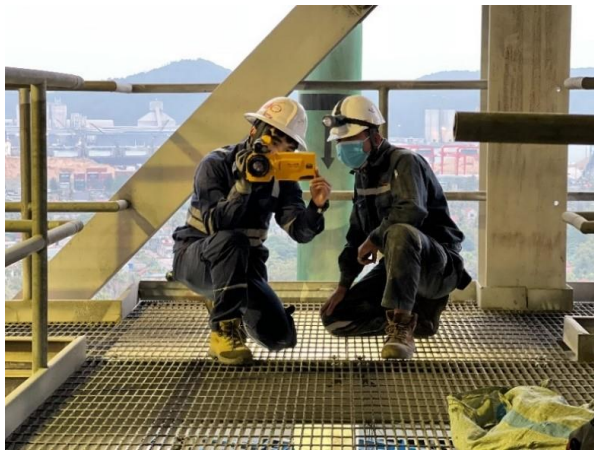


*Figure 2. Infrared thermal imaging*



*Figure 3. Fluorescence wet magnetic particle testing*

The products of the project consist of the followings:

Type I: The steel pipe sample with the artificial corrosion at the internal surface; The steel pipe sample with the crack at the external surface; The steel pipe sample with the connecting seam weld containing the defects; The steel pipe sample with mineral wool insulation and aluminum cover. The drawings are attached to the samples.

Type II: Ten NDT inspection procedures for the main steam pipelines of the thermal power plants; The inspection program by NDT methods; The report on the applying the program at Nghi Son 1 thermal power plant for the main steam pipelines containing the key positions such as the elbows or T-joints, and so on.

Type III: The Presentation "Research on building the inspection program for main steam pipeline using non-destructive testing methods at thermal power plants" at the 15th National Conference on Nuclear Science and Technology, 2023

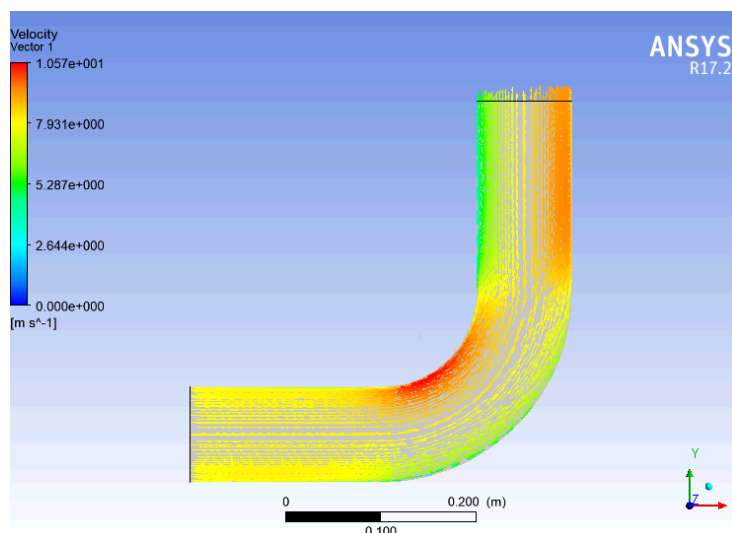


*Figure 4. Simulation results using the Ansys software.*

In general, the products of the Project, especially the inspection program for main steam pipeline, were completed on schedule with the efforts of the project team. During the implementation of the Project, the project team found that the scope of the experiment was limited in terms of approach and implementation scale, and some higher-level tests could not be performed. In addition, the lack of the input data is a common problem in the plants of Vietnam, which makes it difficult to determine the corrosion rate and lifetime of the pipelines. Therefore, the following-up studies in order to find the appropriate solutions are necessary to meet the needs of the power plants in improving the operation efficiency.

## **2.5. APPLICATIONS IN ECOLOGY, ENVIRONMENT AND GEOLOGY**

## MONITORING ISOTOPE COMPOSITION IN RAINWATER AND RIVER WATER FOR THE STUDY OF WATER RESOURCES IN THE SOUTHERN VIETNAM BY ISOTOPE HYDROLOGY TECHNIQUE

**Nguyen Van Phuc, Nguyen Kien Chinh, Tran Thi Bich Lien, Lam Hoang Quoc Viet, Nguyen Pham Tuong Minh**

*Center for Nuclear Technologies, 217 Nguyen Trai, Nguyen Cu Trinh, District 1, HCM city*

### **Project information:**

- **Project name:** Monitoring isotope composition in rainwater and river water for the study of water resources in southern Vietnam by isotope hydrology technique
- **Code:** CS/21/02/02
- **Managerial Level:** Institute
- **Duration:** 18 months (Jan 2021 – June 2022)
- **Contact email:** phucnvphys@gmail.com
- **Published papers related to the project:**

1. Nguyen Van Phuc, Nguyen Kien Chinh, Tran thi Bich Lien, Lam Hoang quoc Viet, Nguyen Pham Tuong Minh. Isotopic compositions in river water and rainwater in southern Vietnam. Ho Chi Minh City University of Education Journal of Science, Vol 19(9), 2022, p.1485-1493 (in Vietnamese).

Rainwater isotopic composition differences are governed by many factors such as altitude, latitude, and continental effects. Even at a specific sampled site, the isotopic composition varies by season, rainfall, and other weather effects. The isotopic composition of river water at a locality reflects isotopes of the water sources that make up the river such as local surface runoff (local rainwater) and upstream flow. Rainwater and river water can be a source of groundwater recharge. If there is a replenishment process, groundwater has an isotopic relationship with rainwater and river water.

The purpose of this study is to build and supplement a database of isotopic composition in the river and rainwater of the Southern Region. The isotopic data would aid studies regarding groundwater resources and the effect of climate change on them.

The isotope composition of water samples was analyzed at the Hydrological Isotope Laboratory, Center for Nuclear Technologies, Ho Chi Minh City. Analysis was done on a laser isotope ratio analyzer (Los Gatos DLT 100, USA) in combination with a high-precision vaporization module. Tritium in water samples was enriched by electrolysis and measured on a Parkard 3170 liquid scintillation counter.

Fig.1-2 shows fluctuations in stable and radioactive isotope compositions in rainwater and river water in the Southern region. The Tien and Hau rivers do not share the same isotopic composition with regional rainwater due to the lack of stable isotopes and greater tritium content.

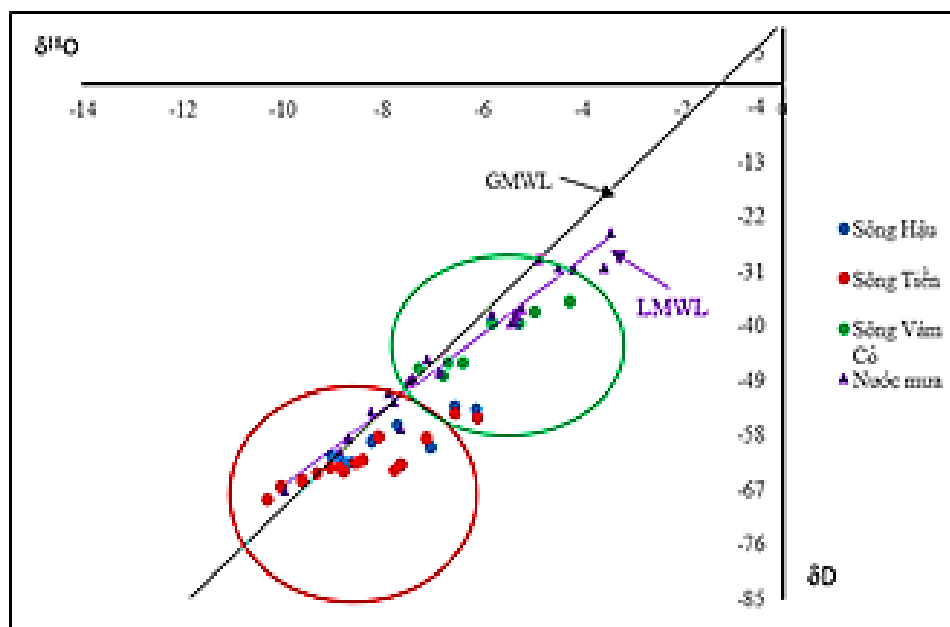


Figure 1. The relationship between  $\delta^{18}\text{O}$  and  $\delta\text{D}$  in rainwater and river water in Southern Vietnam

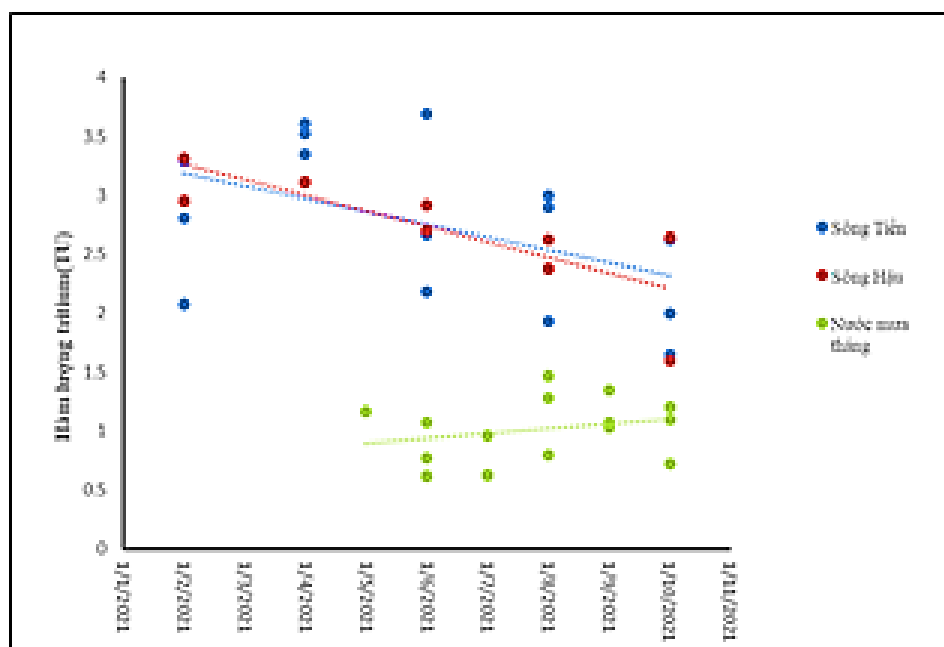


Figure 2. Tritium concentration ( $^3\text{H}$ ) in river water and monthly rainwater in Southern Vietnam

The results on isotopic composition are valuable to partly explain the hydrological processes, the origin of rainwater and river water formation, and the relationship between regional rainwater and river water, this is also data.

## STUDY ON ISOTOPE TECHNIQUE APPLICATION FOR HYDRAULIC RELATIONSHIP BETWEEN THE RED RIVER FLOW AND UNCONFINED AQUIFERS FROM SON TAY TO HUNG YEN

**Vo Thi Anh, Ha Lan Anh, Mai Dinh Kien, Vu Hoai, Dang Tran Trung, Dang Duc Nhan**  
*Institute for Nuclear Science and Technology, 179 Hoang Quoc Viet, Cau Giay, Hanoi*

### **Project information:**

- **Project name:** Study on isotope technique application for hydraulic relationship between the Red River flow and unconfined aquifers from Son Tay to Hung Yen
- **Code:** ĐTCB.18/20/VKHKTHN
- **Managerial Level:** Ministry
- **Duration:** 24 months (Jun 2020 – May 2022)
- **Contact email:** vothianhanh@yahoo.com
- **Published papers related to the project:**

1. Nguyen Thanh Cong, Ha Lan Anh, Vo Thi Anh, Vu Hoai, Mai Dinh Kien. Research on the characteristic of  $^2\text{H}$  and  $^{18}\text{O}$  stable isotopic composition of precipitation in Hanoi. The article has been accepted for publication in Journal of Science

2. Vo Thi Anh, Mai Dinh Kien, Ha Lan Anh, Vu Hoai, Truong Viet Chau, Duong Van Thang, Dang Duc Nhan. Investigation into discharge of groundwater to Red River: A case study for the river's section from Son Tay to Hung Yen using isotopic technique. Vietnam conference on nuclear science and technology Vinanst-14, December 09-10, 2021, Da Lat city, Lam Dong, Vietnam.

3. Vo Thi Anh, Ha Lan Anh, Mai Dinh Kien, Vu Hoai, Dang Duc Nhan. Baseflow separation using isotopic technique and recursive digital filter method: A case study in the Red River Delta Basin, Vietnam. The article in the Journal of Hydrology is reviewing.

The evaluation of the hydraulic relationship between the Red River flow and the unconfined aquifers from Son Tay to Hung Yen is an important job for the safety and security of clean water for human life on both sides of the river. Because the Red River from Son Tay to Hung Yen is said to be the main water source that supplies the aquifers in the rainy season, but in the dry season, on the contrary, groundwater flows into the river, baseflow flows into the river increases. Currently, there have been several studies on the hydraulic relationship between Red River and Holocene and Pleistocene aquifers in Hanoi area using traditional hydrogeological techniques. However, studies on this problem have not been done with more advanced techniques, such as isotope

techniques. That's why we built the project “*Study on isotope technique application for the hydraulic relationship between the Red river flow and unconfined aquifers from Son Tay to Hung Yen*” to evaluate the hydraulic relationship between the Red River flow and the aquifers by the isotope technique on the isotope technique application methodology basis in assessment of water resources, contributing to the implementation of Vietnam's cooperation project with the International Atomic Energy Agency (IAEA) about nuclear technology application research and related techniques in the environmental study. With the above purposes, the first project builds a methodological basis for applying  $\delta^2\text{H}$  and  $\delta^{18}\text{O}$  stable isotope techniques in water resource assessment, designing sampling areas, and using suitable equipment for sample analysis. To evaluate the hydraulic relationship between the Red River and the aquifers from Son Tay to Hung Yen, the research group collected samples at Q9 and Q9a, Q67 and Q67a, Q129, Q129a, and Q129b boreholes which have typical hydrogeological properties of the study area such as Holocene and Pleistocene, respectively. The sampling frequency is 2 times per month for 12 months from August 2020 to the end of July 2021. The samples of Red river water and rainwater were also collected at Son Tay, Long Bien, and Hung Yen hydrological stations at the same time as groundwater sampling. The main analytical parameters include  $\delta^2\text{H}$  and  $\delta^{18}\text{O}$  stable isotope composition using LIWA-24D laser spectrometer, chemical components in water samples using DX-600 ion chromatography system, and field parameters using SevenMulti pH/conductivity meter. In addition, meteorological information is also continuously collected at Son Tay, Long Bien, and Hung Yen hydrological stations such as rainfall, water level and flow of the Red River, temperature, humidity, and amount of evaporated water.

From the sample analysis results, the research group has built a local meteorological water line and a local river water line, which is a scientific basis for determining the origin of groundwater, assessing the hydraulic relationship between surface water and groundwater from the process of separation the baseflow flowing into the river and mean transit time using isotope techniques. These assessments also give similar results to be published by the research group using other research methods such as Trieu Duc Huy (2021), Nguyen Minh Luan (2014), Eckhardt (2005) ...

The main results of the study were as follow:

- + The stable isotope compositions ( $\delta^2\text{H}$  and  $\delta^{18}\text{O}$ ) in the river water ranged from -63.33‰ to -21.21‰ and -10.33‰ to 0.24‰, in rainwater the ranges were -53.85‰ to -13.07 and -8.35‰ to 1.74‰, respectively, for the study regions from Son Tay to Hung Yen.

- + The isotopic compositions in groundwater from different locations were different: at the Vinh Tuong location, the  $\delta^2\text{H}$  value in groundwater from boreholes Q9 and Q9a ranged from -29.39‰ to -35.53‰, while the  $\delta^{18}\text{O}$  value ranged from -5.32‰ to 1.80 ‰. The ranges of  $\delta^2\text{H}$  in groundwater from Q67 and Q67a boreholes at the Long Bien location were from -63.25‰ to -59.29 ‰, but for  $\delta^{18}\text{O}$  it was from -9.96 ‰ to -2.93 ‰.

Groundwater from Q129 boreholes at Hung Yen location has  $\delta^2\text{H}$  and  $\delta^{18}\text{O}$  ranged from -27.53‰ to -19.96 ‰ and -5.26 ‰ to -2.18 ‰, and in water from Q129b borehole it ranged from -51.39 to -36.39 and -8.49 to -1.35, respectively.

+ Local meteorological water line  $\delta^2\text{H} = (8.01 \pm 0.14) \times \delta^{18}\text{O} + (12.65 \pm 1.28)$ ,  $R^2 = 0.98$  and Red river water line  $\delta^2\text{H} = (5.13 \pm 0.25) \times \delta^{18}\text{O} - (13.03 \pm 2.48)$ ;  $R^2 = 0.86$

+ It was estimated that at Vinh Tuong region the main river stream gains 38% and 25% groundwater, respectively, in the rainy and the dry season from the Holocene aquifer as baseflow, while the baseflow from Pleistocene aquifer was 36% in both the seasons. At the Ha Noi location baseflow is losing to both Holocene and Pleistocene aquifers at a rate of 89%, and 70%, respectively, in the rainy dry seasons. At the Hung Yen location, there is a thick clayey layer acting as an aquitard separating Holocene from Pleistocene aquifers, and the River water from the River is not able to hydraulically interact with groundwater in the deep Pleistocene aquifer.

+ The mean transit time of base flow was estimated to be as long as 0.46 years at Vinh Tuong region, and 0.42 years at Hung Yen location. The flow rate of baseflow was estimated to be as high as 10m/day and 7.2m/day, respectively, at Vinh Tuong and Hung Yen regions.

+ Groundwater from boreholes from Holocene and Pleistocene aquifers (Q9, Q9a, Q67, Q67a) at Son Tay and Ha Noi sites as well as from Holocene aquifer (Q129) at Hung Yen site is fresh water with a total mineralization of less than 1 g/l. On the other hand, groundwater from boreholes Q129a and 129b installed into Pleistocene aquifer at Hung Yen site are brackish with total mineralization from 1-3 g/l.

## STUDY ON THE APPLICATION OF NUCLEAR TECHNIQUES AND RELATED ISOTOPES TO TRACING THE SOURCES OF SEDIMENT AND ESTIMATING THE SEDIMENTATION HISTORY IN DINH AN COASTAL AREA

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*Dalat Nuclear Research Institute*

### Project information:

- **Project name:** Study on the application of nuclear techniques and related isotopes to tracing the sources of sediment and estimating the sedimentation history in Dinh An coastal area

- **Code:** DTCTB.07/20/VNCHN

- **Managerial Level:** Ministry

- **Duration:** 24 months (Jan 2020-Dec 2021)

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### - Published papers related to the project:

1. Phan Quang Trung, Vo Thi Mong Tham, Nguyen Van Phuc, Tran Quang Thien, Nguyen Thi Hường Lan, Nguyen Minh Dao, Le Xuan Thang, Nguyen Huu Nghia, and Phan Son Hai, Research And Evaluation Of Particle Size Distribution And Its Elemental Composition In Coastal Sediments In Dinh An Of Soc Trang Province Of Vietnam, The 7th Vietnam Conference on Nuclear Science and Technology for young researchers, Hanoi, Vietnam, Oct 06 – 07th, 2022.

2. Nguyen Thi Hường Lan, Phan Quang Trung, Nguyen Minh Dao, Vo Thi Mong Tham, Sedimentation Transportation Model In Soc Trang Coastal Area By Grain Size Trend Analysis Method, Journal Water Resources and Environmental Engineering, 2022.

3. Phan Quang Trung, Vo Thi Mong Tham, Nguyen Van Phuc, Tran Quang Thien, Nguyen Thi Hường Lan, Nguyen Minh Dao, Le Xuan Thang, Nguyen Huu Nghia, and Phan Son Hai, Cao Dong Vu, Using statistical analysis to investigate grain size effect on multi-element concentration in estuarine sediments of Hau River, Vietnam, Journal of Radioanalytical and Nuclear Chemistry, 2022. DOI: <https://doi.org/10.1007/s10967-022-08609->

In recent years, the deposition and erosion processes have changed significantly, especially in the coastal areas of the Southern provinces of Vietnam. This project applies nuclear techniques and related techniques to determine trends, sources, and history of sediment in the Soc Trang coastal areas.

Thirty of 80 cm to 120 cm of sediment cores were collected, then cut into 1 to 1.2 cm slices to estimate the age and sedimentation rate for about 100 years. In addition, 169 coastal surface sediment samples were collected by Ekman grab to study the sources and the distribution of bottom topographic sediments in the study area.

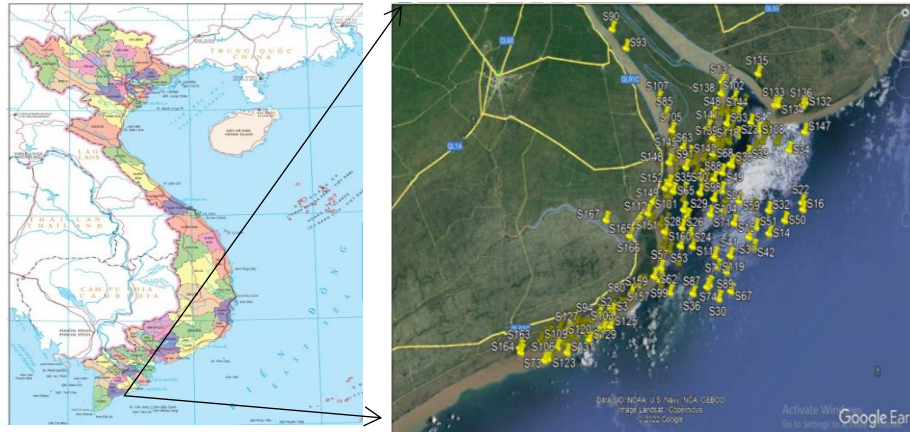


Figure 1. Study area and sampling points

The characteristics of sediment samples including radioisotopes, stable isotopes, trace elements, and grain size are studied in this research. Specifically, several methods are conducted simultaneously: i) Sampling strategy design, ii) Analysing of  $^{210}\text{Pb}$  by alpha spectrometry, iii) Analysing of radioisotopes by gamma spectrometry, iv) Analysing elements by neutron activated analysis, v) Analysing of sediment grain size, vi) Modeling sediment transport by grain size trend analysis (GSTA), vii) Multivariate statistical analysis.

The age and deposition rate of sediment in the study area are studied by using  $^{210}\text{Pb}$ . In sediment, the total amount of  $^{210}\text{Pb}$  ( $\text{Pb}_{\text{tot}}$ ) will be greater than the amount of  $^{226}\text{Ra}$  and that excess amount is called  $^{210}\text{Pb}_{\text{exc}}$ . The amount of  $^{210}\text{Pb}_{\text{exc}}$  originating from the atmosphere is estimated by the following expression:

$$^{210}\text{Pb}_{\text{exc}} = ^{210}\text{Pb}_{\text{tot}} - ^{226}\text{Ra} \quad (1)$$

The age and deposition rate of sediment were estimated through the CRS (Constant rate of Supply) model. This model assumes that the delivery rate of  $^{210}\text{Pb}_{\text{exc}}$  for the sediment is constant. Therefore, the age of the sediment layer with depth  $x$  is determined by the following expression:

$$t = \frac{1}{\lambda} \ln \frac{A(0)}{A(x)} \quad (2)$$

From the results, the  $^{210}\text{Pb}_{\text{exc}}$  activity changes strongly with the sediment depth. The study estuary is influenced by complex hydrological factors (semi-diurnal tides, river flow, wave regime, and coastal currents), so the sediment is continuously moving after settling to the bottom (bottom layer movement), which causes disturbances in the surface sediments. The thickness of the bottom sediments depends on the intensity of the above hydrological factors (usually in a few centimeters to 20 centimeters per slide).

In addition, the activities of microorganisms and humans also cause disturbance of coastal sediments. In such a context, the CRS (Constant Rate of Supply) model is most suited to estimate the age of sedimentary layers, in which the supply flux of  $^{210}\text{Pb}_{\text{exc}}$  is constant while the sedimentation rate can change. For the north of Dinh An estuary, the sedimentation rate ranges from 1.73 to 3.29  $\text{g.cm}^{-2}.\text{y}^{-1}$  with an average value of 2.34  $\text{g.cm}^{-2}.\text{y}^{-1}$ . In the estuary area, the sedimentation rate fluctuates quite largely, from 0.44 to 4.32  $\text{g.cm}^{-2}.\text{y}^{-1}$ , with an average of about 2.23  $\text{g.cm}^{-2}.\text{y}^{-1}$ . In the southern part of Hau River, the sedimentation rate ranges from 0.58 to 6.36  $\text{g.cm}^{-2}.\text{y}^{-1}$ , with an average of 2.15  $\text{g.cm}^{-2}.\text{y}^{-1}$ .

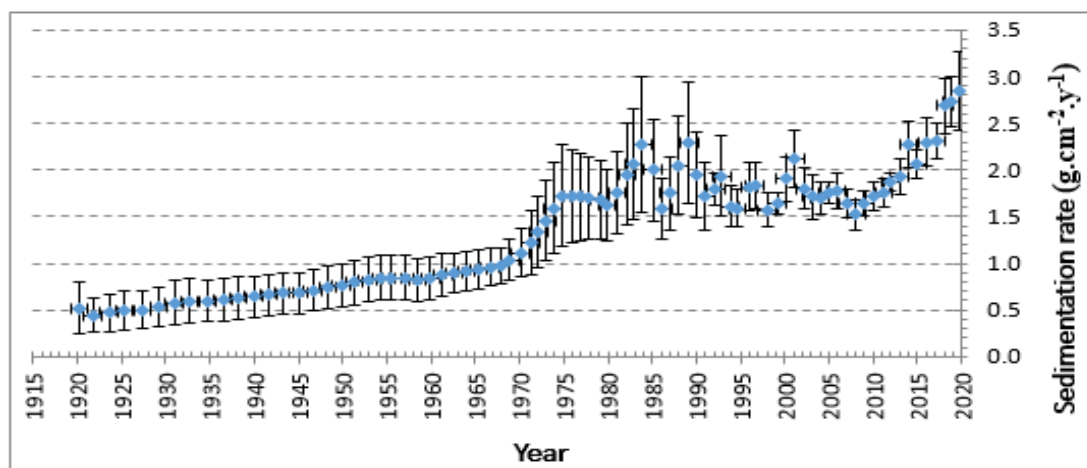


*Figure 2. Sedimentation rate at a sampling point in Soc Trang coastal*

The sedimentation rate fluctuates for each sampling location in the study area. This situation is due to a time-varying sedimentation rate and/ or a significant disturbance of the sediment layers. However, the average sedimentation rate for the whole area changes slightly and tends to decrease gradually along the distance from the estuary to the south.

The result from particle analysis, there are 103/169 samples were clay, accounting for 60.95% of the total samples, and the remaining were mainly sand, accounting for 39.05%. In the composition of sand, 35 samples are fine sand, accounting for 53.03%, and 31 samples are fine sand, accounting for 46.97%.

The spatial distribution of the surface sediment shows a clear coarsening trend from nearshore to offshore. The sediment classification coefficient is relatively poor, while the deviation closely correlates with the mean grain diameter (the negative deviation indicates that the majority of the sediments in the study area are clay components). The grain size component analysis is used to determine the surface sediment transport (GSTA) pattern in the coastal area. The results show that sediment transport is closely related to sediment from upstream of the Hau River. However, some distinctive features of the surface sediment transport process reflect the hydrological, dynamic, and bottom graphics conditions in the study area.

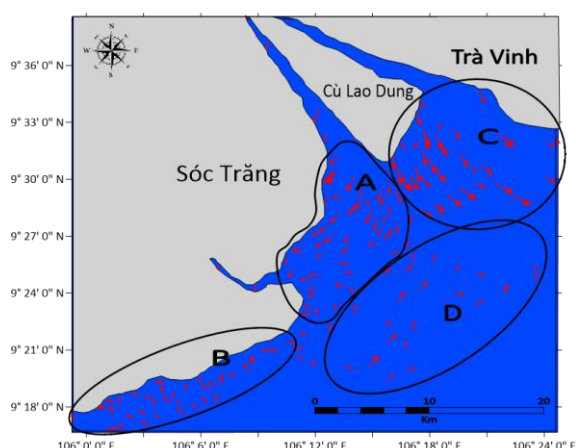


Figure 3. Sediment transport model in the study area

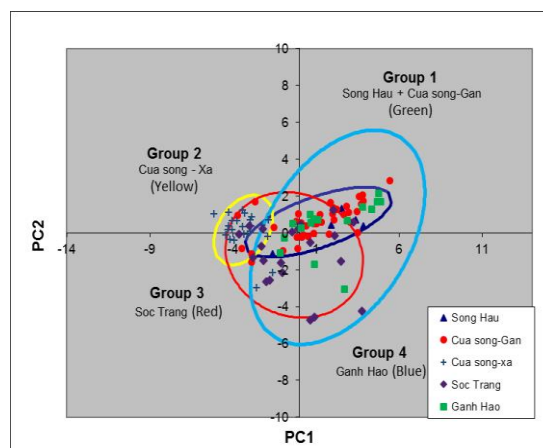


Figure 4. Groups of sediment sources

About 21 elements in 133 surface sediment samples are analyzed by NAA (neutron-activated analysis) method, including As, Br, La, Na, Sm, U, Ce, Co, Cr, Cs, Eu, Fe, Hf, Rb, Sb, Sc, Ta, Tb, Th, Yb, Zn. The results from PCA (Principle Component Analysis) show that most elements positively correlate with clay composition, except for Na, Br, and Hf. Hf and Br present high concentrations in the sand, while Na mainly comes from salt in seawater. The results from grain size distribution combined with multivariate elemental statistics also show that the sediments in the study area are mainly brought from the mainland through the Tran De and Dinh An estuaries.

In this project, surface sediments of the Soc Trang coastal area were collected and studied to understand the history, origin, and transportation process. The sediments in the study area have surface disturbance characteristics. In general, the whole study area is deposited at different rates depending on topography and geographical location. The sediments in the study area are mainly clay and tend to be coarser from onshore to offshore. The sediments originate from the mainland through the two estuaries of the Tran De and the Dinh An rivers. The transport model shows that sediments mainly transport to the southwest through coastal dynamics such as waves, wind, tides, and especially coastal currents.

## INVESTIGATION OF RARE EARTH ELEMENTS INDICATORS TO CHARACTERIZE ARCHEOLOGICAL MATERIALS AT CAT TIEN RELIC AND APPLY TO OC EO - BA THE RELIC BY NUCLEAR AND RELATED TECHNIQUES

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Duc Toan<sup>1</sup>, Vo Tran Quang Thai<sup>1</sup>, Tuong Thi Thu Huong<sup>1</sup>, Huynh Thai Kim Ngan<sup>1</sup>,  
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### Project information:

- **Project name:** Study on the application of nuclear techniques and related isotopes to tracing the sources of sediment and estimating the sedimentation history in Dinh An coastal area

- **Code:** DTCB.07/20/VNCHN

- **Managerial Level:** Ministry

- **Duration:** 24 months (Jan 2020 - Dec 2021)

- **Contact mail:** trungnri@yahoo.com.vn

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

1. Phan Quang Trung, Vo Thi Mong Tham, Nguyen Van Phuc, Tran Quang Thien, Nguyen Thi Hường Lan, Nguyen Minh Đào, Le Xuan Thang, Nguyen Huu Nghia, and Phan Son Hai, Research And Evaluation Of Particle Size Distribution And Its Elemental Composition In Coastal Sediments In Dinh An Of Soc Trang Province Of Vietnam, The 7th Vietnam Conference on Nuclear Science and Technology for young researchers, Hanoi, Vietnam, Oct 06 – 07th, 2022.

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The objective of the project is to apply nuclear and related analysis techniques in studying the characteristics and origins of archaeological materials and the chronology of

architecture to serve the conservation of archaeological sites. The Cat Tien (Lam Dong province) and Oc Eo - Ba The (An Giang province) relics are chosen as research sites because they are important architectural and residence sites of indigenous communities influenced by Indian culture through trading activities in the southwest region of Vietnam in the ancient period. The imprint of Indian culture is left at these monuments through architecture, religion and even some items in daily life.

In this project, the elemental concentrations in archaeological materials of brick, tile, pottery, and clay at the Oc Eo - Ba The relic were determined by the  $k_0$ -based neutron activation analysis method ( $k_0$ -INAA). The samples were irradiated for 10 hours at the rotary specimen rack of the Dalat research reactor. The thermal neutron flux  $\phi_{th}$ ,  $\alpha$  parameter and  $f$  value determined by a “bare triple-monitor” method were  $(3.8 \pm 0.11) \pm 10^{12} \text{ n.cm}^{-2}.\text{s}^{-1}$ ,  $0.073 \pm 0.005$  and  $37.3 \pm 3.1$ , respectively. After an appropriate decay time, irradiated samples were then counted on a gamma spectrometer using an HPGe detector with 30% relative efficiency and 2.1 keV resolution at 1332.5 keV of  $^{60}\text{Co}$ . The  $k_0$ -IAEA program was used to determine elemental concentrations of samples. The obtained data were then analysed by multivariate statistics using XLSTAT program for grouping/classification study.

Besides, three combination methods including internal standardization (IS); external calibration, also known as external calibration (EC); and isotope dilution (ID) methods were used to analyse 14 rare earth elements (REE) and Th, U in samples using the inductively coupled plasma mass spectroscopy (ICP-MS). The datasets of REE and U, Th were used to increase the ability to characterize archaeological materials by chondrite normalization (REE-pattern) to assist in deciphering the origin and classifying archaeological objects.

In the present study, the TL dating technique was applied to determine the chronology of some ancient architectures at the Oc Eo relic but with some significant improvements that match well with the actual configurations and status of the investigated architectures. A new model capable of describing the heterogeneous and multilayered architectures by combining the Monte Carlo simulation with the experimental measurements at field and in laboratory. The proposed model was tested at four ancient architectures built by fired bricks at the Oc Eo relic, two of which were known to be built in a single architectural assembly with the explicit trace of overlapped architectures. The samples such as soils, bricks and stones were collected from the heterogeneous and multilayered architectures in investigated zone and their compositions and densities were measured and calculated by X-ray fluorescence spectroscopy. In addition, the isotopic concentration measured by the low-background gamma spectroscopy was also used for determining the annual gamma dose. At each sampling position, a TLD chip containing 10 LiF:(Mn,Cu,P) detectors (Rados) was placed for recoding the annual gamma doses within 2 years. The equivalent dose and beta dose were detected by using the high-quality TL measurements, but for brick samples only. The TL measurements were directly carried out on the unique quartz crystals separated and

fabricated from the collected brick samples. By doing so, we wish to explore the important contributions of different factors that can affect the chronology of investigated architectures such as multilayered environments, excavated processes, radiation shielding, sampling positions, etc.

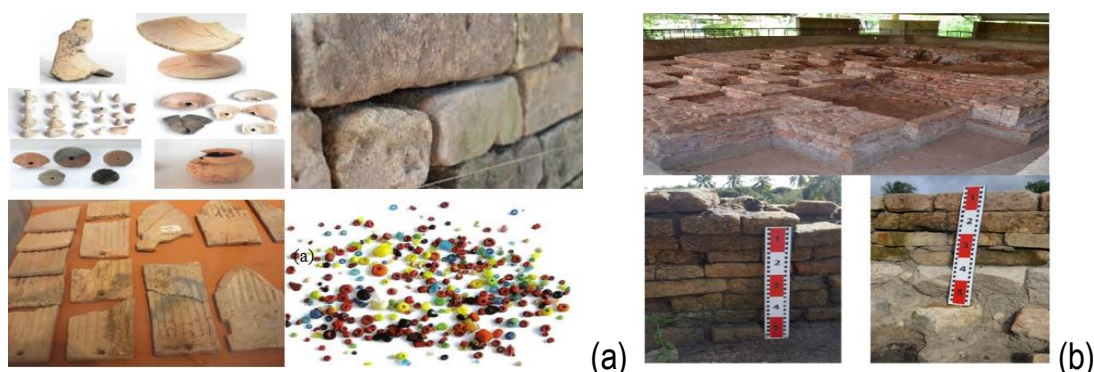


Figure 1. (a) Pottery, brick, tile, bead and (b) Ancient architectures at Oc Eo relic.

As a result, a total of 20 elements including As, Ce, Co, Cr, Cs, Eu, Fe, Hf, La, Lu, Na, Rb, Sb, Sc, Sm, Ta, Tb, Th, Yb, Zn in samples analyzed by k0-INAA method were chosen for multivariate analysis. For the imported pottery group, the classification between archaeological information and analysis of material composition is quite suitable in groups 1 (Han, Tang dynasty), 2 (Song dynasty) and 4 (Indian), and REE are typical element groups for classification. Group 3 is determined to be indigenous by archaeologists. However, the AHC based on chemical compositions shows that they were imported. After discussions with archaeologists, it can be explained that residents of Oc Eo made pottery by simulation of the shape, texture, and pattern of imported objects based on the use of local clay and this led archaeologists based on this information to classify them as imported pottery. Indigenous potteries are classified based on materials and divided into 2 main groups fine clay and clay mixed sand (Fig. 2).

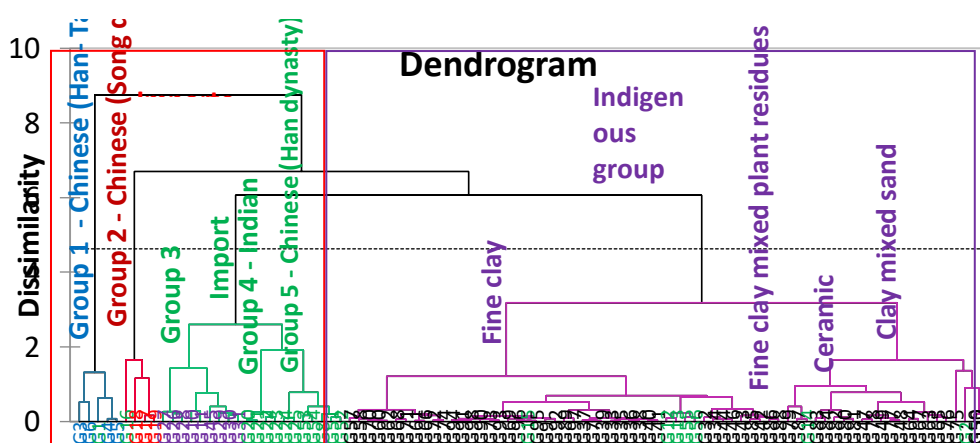


Figure 2. Results of AHC analysis for 98 pottery samples.

The chronologies of architectures of Oc Eo relic were determined by TLD method, the project has placed 21 TLDs at 06 typical architectures of the relic site. The present

study combined, for the first time, the experimental investigations at field with the computer simulations for the thermoluminescence dating of some archeological architectures with typical heterogeneous and multilayered structures. Results obtained indicate that the conventional homogeneous model could cause a virtual enhancement in the obtained chronology from ten to several hundred years. This model was also unable to distinguish the chronologies of overlapped architectures. To solve this issue, we developed the computer simulation based on the Monte Carlo (MCNP) code for the heterogeneous and multilayered models/configurations in both excavated and buried status that more accurately reflected the actual configurations/status of the investigated architectures. Consequently, the chronology obtained by using this improved model was more accurate and reliable. The chronologies of overlapped architectures were also distinguishable by using our model. In particular, with the proposed model, we found the important contributions of different environmental layers as well as the influence of excavation, destruction, radiation-shielding effect and near-surface sampling position to the annual gamma dose and chronology of investigated architectures.

Table 1. Chronologies of four investigated architectures obtained using heterogeneous and multilayered model (for excavated and buried cases) versus those obtained using homogeneous model.

| Architecture | Chronology (A.D.) |                   |                   |                   |                   |                   | AMS     |
|--------------|-------------------|-------------------|-------------------|-------------------|-------------------|-------------------|---------|
|              | Buried status     | Excavated status  | Guérin (2011)     | Liritzis (2012)   | Cresswell (2018)  | Adamiec (1998)    |         |
| TB3          | 768.74<br>± 36.37 | 752.25<br>± 35.58 | 859.98<br>± 40.92 | 855.97<br>± 41.21 | 857.87<br>± 41.30 | 860.04<br>± 41.40 |         |
| KT2.Upper    | 953.35<br>± 45.34 | 948.71<br>± 45.12 | 952.55<br>± 44.90 | 948.55<br>± 45.11 | 939.46<br>± 45.18 | 941.09<br>± 45.26 | 940-994 |
| KT2.Lower    | 794.45<br>± 37.64 | 752.54<br>± 35.62 | 803.77<br>± 38.54 | 805.74<br>± 38.77 | 807.48<br>± 38.86 | 814.06<br>± 38.98 | 893-932 |
|              | 615.47            | 582.40            | 645.31            | 650.23            | 651.95            | 654.51            |         |
| KT8          | ± 28.71           | ± 27.20           | ± 30.63           | ± 30.86           | ± 30.94           | ± 31.05           |         |

A case study for the Oc Eo relic has indicated the accurate chronologies of the TB3, KT2.Upper, KT2.Lower and KT8 ancient architectures should be about 769, 953, 794 and 615 A.D., respectively (Table 1). These values were about one to many decades smaller than those obtained by the homogenous model. Such a reduction in the chronological results obtained within our proposed model was originated from the excavation and destruction of the investigated architectures. Finally, our study provided the first scientific evidence for the formation of the KT2 architectural assembly, which cannot be achieved by using the homogeneous model. Explicitly, we showed that the KT2.Lower architecture should be constructed around 794 A.D. and lasted about 159 years before being destroyed, probably by the kingdom's historical upheavals. Since then, the KT2.Upper architecture was built on top of the KT2.Lower's foundation. Such a finding was confirmed by the *radiocarbon* dating using accelerator mass spectrometry (AMS) and thus provided the scientific arguments associated to the historical activities

happened at the ancient Funan kingdom. This study also opens a new research direction towards the exact thermoluminescence dating of heterogeneous, multilayered, and overlapped architectures.

The improvement of methods and research equipment in the investigation has contributed to the application of nuclear technology to solve social problems, specifically in this case, providing quantitative information about the composition of materials database and chronology of ancient architectures to assist archaeologists in preservation of cultural heritage.

## DEVELOPMENT OF THE METHOD FOR LOCATING PREFERENTIAL LEAK FLOW PATH UNDER DAMS AND DIKES BY COMBINING THE SALT TRACER WITH ELECTRICAL SELF-POTENTIAL MEASUREMENT

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### **Project information:**

**- Project name: Development of the method for locating preferential leak flow path under dams and dikes by combining the salt tracer with electrical self-potential measurement**

**- Code: ĐTCB.01/20/TTUDKTHN**

**- Managerial Level: Institute**

**- Duration: Jan 2020- Sep 2022**

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

1. Huynh Thi Thu Huong, Lai Viet Hai, Le Van Son, Tran Trong Hieu, Nguyen Huu Quang, Calculation of salt tracer concentrations from self-potential data, Thu Dau Mot University Journal of Science, Vol 6(55), 2021, p.110-118 (in Vietnamese).
2. Huynh Thi Thu Huong et al., A novel calculation method for determination of salt tracer concentration curve from self-potential signals, Vietnam Conference on Nuclear Science and Technology (VINANST 14), Dalat, 2021.
3. Huynh Thi Thu Huong et al., Application of the tracer method combined with self-potential measurements local pore water velocity along preferential flow in earthen dam, Conference on Nuclear Science and Technology for Young Scientists, Hanoi, 2022.
4. Huong HTT., Son LV., Hieu TT., et al., Determination of the Pore Water Velocity Using a Salt Tracer Combined With Self-potential Measurements, Journal of Geoscience and Environment Protection, 11, 2023. DOI: 10.4236/gep.2023.111002.

Due to concentrated seepage, leakage may develop over time into erosion, leading to the destruction of dykes and earth dams. When a leak is detected abnormally downstream, the survey to determine the location and velocity of the preferential leak current in the concentrated seepage area plays an important role in assessing the dam safety according to the seepage criteria as well as in preparation of repair and remedial plans. The method of use of salt tracer releasing on the upstream of the dam and monitoring the concentration of salt at the entrance of the leak zone and monitoring the presence of salt at the leak point downstream allows to determine the average travel velocity of seepage water through the dam and estimate the size of the concentrated

seepage zone. However, these data do not give information about the location of the leakage current in the dam nor the water velocity along the seepage path to assess the extent of erosion which are the issues of concern to dam managers.

Based on the electrokinetic coupling principle, the authors such as Boleve, Ikard et al. combined the self-potential measurement method with the salt releasing method to locate leakage currents in the dam. However, these studies are still quite qualitative, not clarifying the relationship between the concentration distribution of the tracer in the advection-diffusion transport process and the anomaly of the measured potential signal.

This study focused on clarifying the association of measured self-potential quantity with salt tracer movement in the preferential path of seepage under dam. The studies on analytical models describing the distribution of tracer concentrations in the process of advection - diffusion transport and the according change of potential values have found the time coincidence between these two quantities by comparing the maximal values and the maximal derivatives of the distribution (Figure 1A).

The experiments on the physical model were also conducted to verify the survey results on the analytical model. The physical model used in this study is a rectangular box with dimensions of 61.6 cm x 30 cm x 30.8 cm made of sheet glass packed with glass beads of diameter of 450 - 500  $\mu\text{m}$ , creating a porous media with a porosity of 37%, a height of 20 cm and an average permeability of  $1.95 \times 10^{-10} \text{ m}^2$ . The experiment used tap water as the fluid with an average conductivity of  $2.4 \times 10^{-3} \text{ S/m}$ . The x-axis in the direction of flow was selected; the Cu/CuSO<sub>4</sub> electrodes were placed at monitoring positions with a distance of 6.5 cm; 14.5 cm; 23 cm and 31.5 cm from upstream; the reference electrode was placed at  $x = 0 \text{ cm}$ . The potential was measured with a Fluke 87V voltmeter (USA). The flow varied in the range of 0.61 - 1.06 L/min, corresponding to the average water velocity through the porous medium  $v^* = 2.90 - 5.04 \text{ cm/min}$ . The tracer experiments were performed when 120 mL of NaCl solution of 36.8 g/L concentration was added in upstream, then the potential between the reference electrode and the measuring electrodes was recorded over time. The NaCl concentration over time at upstream and downstream locations of the electrodes and drains were measured by a conductivity meter using a Hanna HI98197 instrument (Romania).

The obtained results show that the values of the maximum potential variation  $\Delta\psi/\Delta t_{\text{max}}$  and the change in salt tracer concentration  $\Delta \ln(C/C_0)_{\text{max}}$  completely coincide in time and are quite close to water transit time with a retardation of only about 10% (Figure 1B). Thus, it can be concluded that the time when the maximum potential variation  $\Delta\psi/\Delta t_{\text{max}}$  reached reflects the peak time of the tracer concentration. In addition, these quantities are all monovalued.

The above finding allows to propose a manner to determine the time at which the maximum of the salt tracer concentration passes through the monitoring position, i.e. That is the time when the differential value of the potential reached the maximum  $\Delta\psi/\Delta t_{\text{max}}$ .

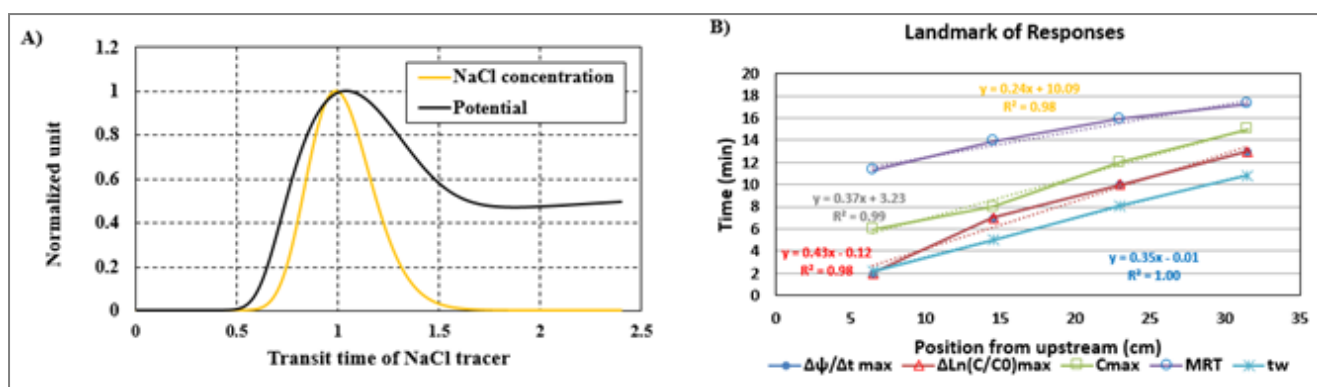


Figure 1. A. Calculated electrokinetic potential and salt tracer concentration under advection-dispersion transport, B. Time response of the landmarks at observation positions

The combination of those methods has been applied on a leak area on the Dam No. 2 of Ham Thuan Hydropower Plant. The study dam is a homogeneous earth dam of 36 m in height and a crest of 215 m in length. The downstream leak area was found at the rate about 0.5 L/min when the reservoir water elevation reached 605 m above sea level.

The tracer experiment was conducted at a reservoir water elevation of 604.5 m a.s.l. (December 18, 2021) using NaCl as tracer. The results of monitoring the salt tracer show that the entrance of the leak was 42 m from the dam landmark and the travel time of the tracer from the reservoir to the leak point was 40 days. The self-potentials were measured by 5 grid lines of Cu/CuSO<sub>4</sub> electrodes connected to an ARES II device (GF Instruments) at an area of 140 m x 50 m before and after tracer injection 18, 30 and 40 days, respectively. The potential anomalies indicate the V-shape path of tracer movement from up-stream to the leak point and the velocity of tracer passing through monitoring stations was also determined in range from  $2.1$  to  $11.9 \times 10^{-5}$  m/s (Figure 2).

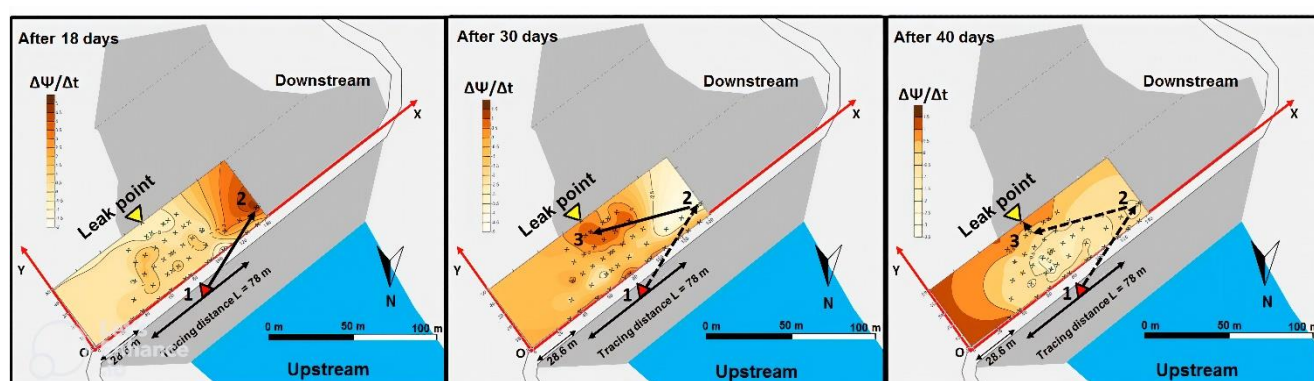


Figure 2. Variation of potential signal ( $\Delta\psi/\Delta t$ )<sub>max</sub> at the Ham Thuan dam after tracer injection 18, 30 and 40 days allow to determine the position and velocity of tracer moving along the seepage path.

The obtained results have made an important contribution to improving the method of measuring the self-potential on the ground to locate the flow carrying the tracer

solution, thereby determining the seepage velocity along the infiltration zone at field scale. The method will be a useful tool in the assessment of erosion due to preferential seepage through earth dams, contributing to the safety assurance of irrigation and hydroelectric facilities such as dams, dikes and reservoirs.

## **BUILDING THE LABORATORY FOR LOW-LEVEL RADIOACTIVITY ANALYSIS AT THE CENTER FOR NUCLEAR TECHNOLOGIES IN HO CHI MINH CITY ACCORDING TO ISO/IEC-17025:2017**

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### **Project information:**

**- Project name: Building the laboratory for low-level radioactivity analysis at the Center for Nuclear Technologies in Ho Chi Minh City according to ISO/IEC-17025:2017.**

**- Code: ĐTCB.14/20/TTHN**

**- Managerial Level: Ministry**

**- Duration: 24 months (Jan 2020 - Dec 2021)**

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

1. Van Doanh Ho, Bao Quoc Hieu Phan, Ngoc Son Pham, Van Hoang Dao, Hoang Duc Tam, Manh Dung Ho, Comparison of efficiency calibration techniques of HPGe detector for radioactivity measurement of soil sample in Marinelli geometry, Journal of Radioanalytical and Nuclear Chemistry (2022) 331:1361–1365;

2. Ho Van Doanh, Phan Bao Quoc Hieu, Doan Thi Thanh Nhan, Vo Van Tien, Nguyen Van Hoai Nam, Dao Van Hoang, Ho Manh Dung, Evaluation of efficiency calibration techniques of HPGe detector for radioactivity measurements in environmental samples, Vietnam Conference on Nuclear Science and Technology (VINANST-14).

Recognized laboratories that adhere to ISO/IEC 17025: “General requirements for the competence of testing and calibration laboratories” provides a variety of advantages. The following are the most noteworthy benefits: Improve the Testing and Calibration Laboratory's reputation and perception; Improve the technical proficiency and quality management of the Laboratory. By operating generally following with standards method, the result may guarantee correctness and dependability. Standardize laboratory processes, test methodology, examiner skills, and test equipment operation. This makes training recruits and lab staff members straightforward. Facilitate the recognition of test/calibration results on a bilateral and international level.

To achieve this purpose, the study team performed investigations, field surveys, analysis and evaluation of quality management systems, evaluation of facilities,

environmental conditions, and human resource management. Based on all of these evaluations, we carry out laboratory refurbishment, supply appropriate equipment, purchase standard samples and standard sources if required, and calibrate equipment to ensure the resource requirements meet the ISO/IEC Laboratory Management System 17025: 2017. To design the implementation of any particular content, we review the guiding documents, expert consultation, and consumer feedback. Based on the ISO/IEC 17025: 2017 guiding documents, we construct a quality management system and apply for certification of a laboratory that is effective and competent in meeting the ISO 17025 requirements. We have examined measurement instruments, assessed physical characteristics, technological, and environmental factors that affect the examination's results, concluding with the assessment and validation process. According to the established procedure, we conduct experiments on samples that were taken in the environment. The results were used to evaluate the intralaboratory and repeatability of the methodology. The laboratory has carried out an inter-laboratory comparison with the Institute of Public Health, Institute of Nuclear Science and Technology, and Dalat Nuclear Research Institute, where accredited to meet the requirements of ISO/IEC 17025: 2017.

The test procedure of choice is TCVN 6053:2011 (ISO 9696-1:2007), and TCVN 6219:2011 (ISO 9697-1:2008), which is suitable for most types of water samples, including some water, which may produce a residue that is hygroscopic or difficult to disperse after drying and ignition, making it unsuitable for measuring radioactivity. Taking, handling, and storage of water samples as specified in ISO 5667-1 and ISO 5667-3, Water is nearly evaporated, transformed to sulfate form, and then burned at 350 °C. A portion of the residue is transferred to a planchet, and the alpha/beta activity is quantified using a counting assembly calibrated against a suitable calibration standard. For the determination of gamma-emitting radioactive in soil, we apply TCVN 10758-3:2016 (ISO 18589-3:2015), this procedure is suitable for surveillance of the environment radioactivity in soil and Incident Response – quick evaluation of gamma activity. Sampling and sample handling procedures are carried out according to TCVN, in the order: TCVN 10758-1 (ISO 18589-1), TCVN 10758-2 (ISO 18589-2), TCVN 10758-3 (ISO 18589-3).

The research team applied the quality management system and established procedures for carrying out standard quality examinations, intra-laboratory comparisons, and interlaboratory comparisons, which are demonstrated below.

To evaluate the examiners' abilities, an actual sample is created, and two individuals carry out the experiment examination according to the procedure, each taking six examinations, then the principal examiner taking six additional examinations and recording the results. Comparative evaluation of similarity using the ANOVA method of analysis of variance; results are reported in Tables 1 and 2.

**Table 1.** Result of real sample analysis using the gamma-ray spectrometry and the evaluation of the result for the sample among analysts.

| Radionuclides     | Analysis results |      | Criteria parameter |         |        | Evaluation |
|-------------------|------------------|------|--------------------|---------|--------|------------|
|                   | Average          | SD   | F                  | p-value | F-crit |            |
| <sup>238</sup> U  | 22.14            | 0.36 | 0.00               | 0.96    | 4.96   | Passed     |
| <sup>232</sup> Th | 35.82            | 0.41 | 0.05               | 0.82    | 4.96   | Passed     |
| <sup>226</sup> Ra | 18.72            | 0.35 | 0.35               | 0.57    | 4.96   | Passed     |
| <sup>228</sup> Ra | 42.49            | 0.36 | 0.32               | 0.58    | 4.96   | Passed     |
| <sup>210</sup> Pb | 24.86            | 0.24 | 0.17               | 0.69    | 4.96   | Passed     |
| <sup>137</sup> Cs | 0                | 0    | 0.00               | N/A     | 4.96   | Passed     |
| <sup>40</sup> K   | 53.14            | 0.26 | 0.15               | 0.70    | 4.96   | Passed     |
| <sup>134</sup> Cs | 0                | 0    | 0.00               | N/A     | 4.96   | Passed     |
| <sup>60</sup> Co  | 0                | 0    | 0.00               | N/A     | 4.96   | Passed     |
| <sup>241</sup> Am | 0                | 0    | 0.00               | N/A     | 4.96   | Passed     |

**Table 2.** Result of the real sample analysis using the gross alpha/beta radioactivity and the evaluation of the result of the sample analysis among analysts.

|                                  | Samples         | Analysis results |       | Criteria parameter |       |        | Evaluation |
|----------------------------------|-----------------|------------------|-------|--------------------|-------|--------|------------|
|                                  |                 | Average          | SD    | Average            | SD    | F-crit |            |
| Gross beta radioactivity (Bq/L)  | Groundwater     | 0.167            | 0.008 | 0.018              | 3.682 | 0.982  | Passed     |
|                                  | Wastewater      | 0.415            | 0.013 | 0.500              | 3.682 | 0.616  | Passed     |
|                                  | Bottled water   | 0.190            | 0.011 | 0.044              | 3.682 | 0.957  | Passed     |
|                                  | Household water | 0.057            | 0.005 | 0.026              | 3.682 | 0.974  | Passed     |
|                                  | Raw water       | 0.174            | 0.007 | 0.058              | 3.682 | 0.944  | Passed     |
| Gross alpha radioactivity (Bq/L) | Groundwater 2   | 0.083            | 0.003 | 0.188              | 3.682 | 0.831  | Passed     |

At the 95% confidence level, the evaluation results show no difference in repeatability between the two examiners.

Prepared samples are divided into equal amounts before being packaged, preserved, and delivered to other laboratories for analysis. The data were divided into two categories: the interlaboratory and internal, and the similarity of the results between the two groups was evaluated using the F-test and the t-test. The F-test (F-Fisher standard) is used to assess the repeatability of two sets of data, whereas the t-test (t-Student standard) is used to compare two data sets' mean values. The following tables provide results and evaluations.

**Table 3.** Analytical results from different laboratories (Bq/Kg).

| Laboratories                                   | Inter-Laboratory results |                   |                  |                   | Internal test results |                   |                  |                   |
|------------------------------------------------|--------------------------|-------------------|------------------|-------------------|-----------------------|-------------------|------------------|-------------------|
|                                                | <sup>40</sup> K          | <sup>137</sup> Cs | <sup>238</sup> U | <sup>232</sup> Th | <sup>40</sup> K       | <sup>137</sup> Cs | <sup>238</sup> U | <sup>232</sup> Th |
| Dalat Nuclear Research Institute               | 674.40                   | 20.14             | 28.63            | 32.70             | 617.72                | 19.44             | 28.63            | 33.60             |
| Dalat Nuclear Research Institute               | 644.00                   | 19.64             | 28.41            | 35.03             | 606.80                | 19.57             | 28.41            | 32.51             |
| Institute for Nuclear Science and Technology   | 609.90                   | 18.40             | 26.69            | 34.10             | 602.19                | 19.42             | 26.69            | 31.62             |
| Institute for Nuclear Science and Technology   | 608.30                   | 19.10             | 26.76            | 33.60             | 608.00                | 19.60             | 26.76            | 32.30             |
| Institute of Public Health in Ho Chi Minh City | 573.19                   | 17.73             | 25.80            | 31.83             | 588.00                | 19.30             | 25.80            | 31.90             |

**Table 4.** Inter-laboratory comparison results in Gamma-emitting radionuclides in soil analytical

| Criteria                           | <sup>40</sup> K | <sup>137</sup> Cs | <sup>238</sup> U | <sup>232</sup> Th |
|------------------------------------|-----------------|-------------------|------------------|-------------------|
| <i>F</i>                           | 4.71            | 2.57              | 3.16             | 3.05              |
| <i>F</i> -Critical one-tail        | 6.39            | 6.39              | 6.39             | 6.39              |
| <i>t</i> -Stat                     | 0.53            | 0.95              | -2.45            | 1.64              |
| P ( <i>T</i> ≤ <i>t</i> ) one-tail | 0.31            | 2.31              | 2.31             | 2.31              |
| Evaluation                         | Passed          | Passed            | Passed           | Passed            |

**Table 5.** Results of gross alpha/beta activity in water samples from several laboratories.

| <b>Laboratories</b>                            | <b>Inter-laboratory results</b>        |                                         | <b>Internal test results</b>           |                                         |
|------------------------------------------------|----------------------------------------|-----------------------------------------|----------------------------------------|-----------------------------------------|
|                                                | <b>Gross beta radioactivity (Bq/L)</b> | <b>Gross alpha radioactivity (Bq/L)</b> | <b>Gross beta radioactivity (Bq/L)</b> | <b>Gross alpha radioactivity (Bq/L)</b> |
| Dalat Nuclear Research Institute               | 2.53                                   | 0.20                                    | 2.64                                   | 0.20                                    |
| Dalat Nuclear Research Institute               | 2.41                                   | 0.19                                    | 2.35                                   | 0.19                                    |
| Institute for Nuclear Science and Technology   | 2.59                                   | 0.22                                    | 2.47                                   | 0.22                                    |
| Institute for Nuclear Science and Technology   | 2.82                                   | 0.23                                    | 2.54                                   | 0.20                                    |
| Institute of Public Health in Ho Chi Minh City | 2.56                                   | 0.20                                    | 2.49                                   | 0.21                                    |
| Institute of Public Health in Ho Chi Minh City | 2.42                                   | 0.21                                    | 2.48                                   | 0.19                                    |

**Table 6.** Inter-laboratory comparison results in measurement of gross alpha/beta radioactivity.

| <b>Criteria</b>                           | <b>Gross beta radioactivity</b> | <b>Gross alpha radioactivity</b> |
|-------------------------------------------|---------------------------------|----------------------------------|
| <i>F</i>                                  | 2.18                            | 1.45                             |
| <i>F</i> -Critical one-tail               | 5.05                            | 5.05                             |
| <i>t</i> -Stat                            | 0.81                            | 0.94                             |
| <i>P</i> ( <i>T</i> ≤ <i>t</i> ) one-tail | 2.23                            | 2.22                             |
| Evaluation                                | Passed                          | Passed                           |

According to the evaluation results, "Passed" - there is no significant difference in the testing capacity of registered criteria between internal data and data from external laboratories at 95% confidence.

With the obtained results, the application for assessment and accreditation of the laboratory according to ISO/IEC 17025:2017 has been submitted to the Accreditation Office for Quality Standards Conformity Assessment (AOSC). The certificate of recognition of testing capacity to meet the requirements of ISO/IEC 17025:2017 has been granted by AOSC to the Low-Level Radioactivity Measurement Laboratory (Department of Radiation and Environmental Safety), the Center for Nuclear Technologies, coded VLAT-1.0909.

## THE AGE, ORIGIN, AND RECHARGE OF GROUNDWATER IN THE MEKONG DELTA.

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Lam Hoang Quoc Viet, Nguyen Pham Tuong Minh**

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### **Project information:**

**- Project name: “The age, origin, and recharge of groundwater in the Mekong Delta.”**

**- Code: ĐTCB.13/20/TTHN**

**- Managerial Level: Ministry**

**- Duration: 33 months (Jan 2020 - Sep 2022)**

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

1. Tran Thi Bich Lien, Nguyen Kien Chinh, Lam Hoang Quoc Viet, Huynh Long, Nguyen Van Phuc, Nguyen Pham Tuong Minh, Use of isotope techniques to evaluate the recharged ability of the Upper Pleistocene aquifer in the Nambo Plain; Report at the 14th Vietnam Conference on Nuclear Science and Technology (VINANST-14), Dalat 12/2021, (in Vietnamese).

2. Nguyen Pham Tuong Minh, Tran Thi Bich Lien, Nguyen Kien Chinh, Lam Hoang Quoc Viet, Nguyen Van Phuc, Huynh Long, Studying on dynamic characteristics of the Upper Pleistocene aquifer - qp3 in the northern tien river by isotopic techniques; Report at the 6th Conference on Nuclear Science and Technology for Young Scientists, Hanoi 10/2022 (in Vietnamese).

3. Tran Thi Bich Lien, Nguyen Kien Chinh, Huynh Long, Nguyen Van Phuc, Lam Hoang Quoc Viet, Nguyen Pham Tuong Minh, Use of isotope techniques to evaluate the recharged ability of the upper Pleistocene aquifer in the Nambo Plain, Nuclear Science and Technology (NST) (Accepted, 26/09/2022)

4. Tran Thi Bich Lien, Nguyen Kien Chinh, Lam Hoang Quoc Viet, Huynh Long, Nguyen Van Phuc, Nguyen Pham Tuong Minh, Nguyen Thi Dinh, Study the Upper Pleistocene groundwater dynamic in the Nambo Plain for sustainable management of groundwater resources by isotope techniques, Journal of Radioanalytical and Nuclear Chemistry (JRNC) (Reviewing).

The isotope hydrology technique using stable isotopes, radioactive isotopes of water, and water-soluble components is widely applied in the assessment of water resources and the water quality worldwide. In this study, stable isotopes such as oxygen-18 ( $^{18}\text{O}$ ), deuterium ( $^2\text{H}$ ), carbon-13 ( $^{13}\text{C}$ ), and natural radioactive isotopes tritium ( $^3\text{H}$ ) and carbon-14 ( $^{14}\text{C}$ ) were used. The data on the  $^2\text{H}$  and  $^{18}\text{O}$  compositions in precipitation and groundwater were used to identify the origin of groundwater. The contents of  $^{13}\text{C}$

and  $^{14}\text{C}$  in total dissolved inorganic carbon (TDIC) in groundwater were used to estimate groundwater age. Based on the origin combining with the spatial distribution of groundwater age that was derived by the multivariable geostatistical method, the modern recharge ability, recharge zone, velocity and movement direction of groundwater in the Upper Pleistocene aquifer within the western area of the Nambo Plain (Mekong Delta) were identified and assessed.

Seventy (70) groundwater samples of the Upper Pleistocene aquifer, 32 river water samples, and 40 precipitation samples were collected according to the Guideline of Sampling Procedures for Isotope Hydrology of the International Atomic Energy Agency during 2020-2022. The contents of  $^2\text{H}$ ,  $^{18}\text{O}$ ,  $^3\text{H}$ ,  $^{13}\text{C}$ , and  $^{14}\text{C}$  isotopes and main hydrochemical parameters in the water samples were analyzed. Stable isotope ratio ( $^{18}\text{O}/^{16}\text{O}$ ,  $^2\text{H}/^1\text{H}$ ) in water samples was quantified by the Laser Absorption Spectrometry measurements using LGR DLT 100 equipment. The results were reported as  $\delta$  notation and expressed in ‰ versus the VSMOW standard (Vienna-Standard of Mean Ocean Water). The content of radioactive isotopes ( $^3\text{H}$ ,  $^{14}\text{C}$ ) in groundwater were analyzed by liquid scintillation counting on the TRI-CARB 3170TR/SL after being enriched by electrolysis for  $^3\text{H}$  and  $\text{C}_6\text{H}_6$  synthesis for  $^{14}\text{C}$ .  $^3\text{H}$  contents are expressed in TU (Tritium Unit,  $1\text{TU}=0.119\text{ Bq/kg}$ ).  $^{14}\text{C}$  contents are expressed in percent of modern carbon (PMC), representing the proportion of  $^{14}\text{C}$  activity in the sample with respect to the  $^{14}\text{C}$  standard. Standard activity is defined as 95% of the activity of Oxalic Acid I in AD 1950. The age (transit time) of groundwater is calculated based on the radioactive decay law according to the equation:  $t = \frac{\tau}{\ln 2} \ln \frac{A_0}{A}$ , where  $\tau$  (= 5730 years) is the half-life of  $^{14}\text{C}$ ,  $A$  is the measured  $^{14}\text{C}$  specific activity, and  $A_0$  is the initial  $^{14}\text{C}$  specific activity, which is estimated by the isotope mixing model referred to as complete exchange with  $\text{CO}_2$  proposed by Gonfiantini:  $A_0 = \frac{(\delta - \delta_c)}{(\delta_G - \delta_c + \varepsilon)} \times \left(1 + \frac{2\varepsilon}{1000}\right) \times 100\text{ (PMC)}$ , where  $\varepsilon = \frac{9552}{T} - 24.10$  (‰),  $T$  is the water temperature in Kelvin.

Combining the data of stable isotopic compositions in precipitation collected on the monthly basis at 04 monitoring locations: Ho Chi Minh City, Can Tho, Ca Mau, and Da Lat that was compiled from this and other projects conducted from 2007 to present, the meteoric water lines in the Nambo Plain were built. The local meteoric water lines (LMWL) for the region followed the model of  $\delta^2\text{H} = (7.62 \pm 0.13) \times \delta^{18}\text{O} + (10.14 \pm 1.08)$ . This model was derived from the precipitation weighted least squares regression (PWLSE) and the precipitation weighted reduced major axis regression (PWRMA) developed by J. Crawford, C.E. Hughes, et al.

The analytical data showed that the stable isotope compositions of fresh groundwater samples ranged from -53.4‰ to -38.1‰ with a mean of -45.0‰ for  $\delta^2\text{H}$  and from -7.71‰ to -4.99‰ with a mean of -6.48‰ for  $\delta^{18}\text{O}$ . However, the stable isotope compositions of saline groundwater varied widely, ranging from -57.4‰ to -10.3‰ with a mean of -38.5‰ for  $\delta^2\text{H}$  and from -8.17‰ to -1.63‰ with a mean of -5.74‰ for  $\delta^{18}\text{O}$ .

The relationship between  $\delta^2\text{H}$  and  $\delta^{18}\text{O}$  in the collected groundwater samples is plotted in Figure 1 along with the LMWL and global meteoric water line (GMWL). The larger variation and more enriched stable isotope compositions of saline groundwater than those of fresh groundwater indicated a fact that saline groundwater is the mixture of fresh groundwater and water enriched in heavy isotopes. The  $\delta^{18}\text{O}$  in saline water are closely correlated to the  $\text{Cl}^-$  content ( $R^2 = 0.821$ ) and tends to cross the point representing seawater. This implied that saline groundwater in the study aquifer seems to be a mixture of fresh groundwater and sea water. This conclusion is further confirmed by the fact that in most of the saline groundwater samples the molar ratio of  $[\text{Na}^+]/[\text{Cl}^-]$  is lower than 0.8 and  $[\text{Mg}^{2+}]/[\text{Ca}^{2+}]$  is greater than 1, both indicators are characterized for seawater.

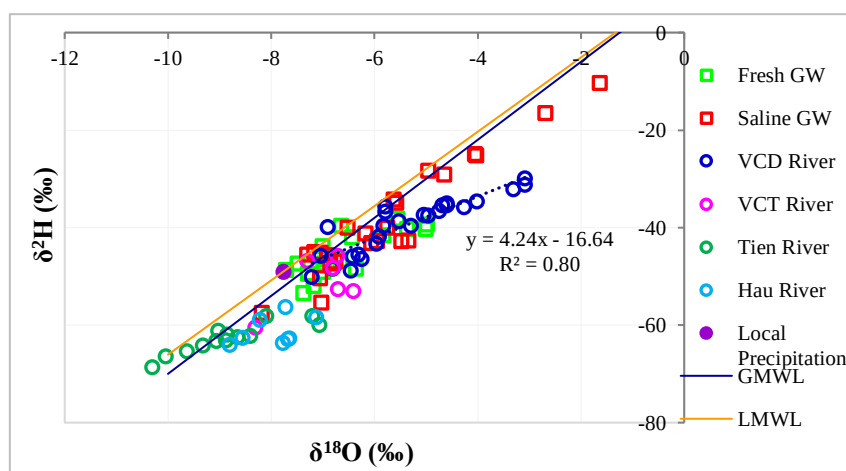


Figure 1. Relationship between  $\delta^2\text{H}$  and  $\delta^{18}\text{O}$  of groundwater and river water

The study results also revealed that the tritium content of groundwater in the exposed area of the study aquifer in the Southeast region is comparable with those of local rainwater (1.2 TU), and the  $^{14}\text{C}$  content in these samples is almost the same as that of the modern  $^{14}\text{C}$  standards. Thereby, the northeast part of the Southeast region is suggested to be a potential recharge zone.

The isotope compositions in water samples from Tien, Hau, Vam Co Dong (VCD), and Vam Co Tay (VCT) rivers are also depicted in Figure 1. The results showed that water samples from the Tien River and Hau River are depleted in heavy isotopes relative to those from the VCD and VCT Rivers. The relationship between the  $\delta^{18}\text{O}$  and  $\delta^2\text{H}$  values of water from the VCD River has a slope of 4.24 with  $R^2 = 0.80$  indicating the fact that the river's water is evaporative. Additionally, these results also showed that there is no hydraulic interrelation between Tien, Hau River's water and groundwater in the Upper Pleistocene. This is because the stable isotopic compositions in groundwater and rivers water were significantly different as they were treated by t-test. On the other hand, the  $\delta^2\text{H}$  and  $\delta^{18}\text{O}$  values in water samples from Vam Co River and Upper Pleistocene groundwater are distributed in the same range indicating there should be a hydraulic interaction between Vam Co River's water and Upper Pleistocene groundwater.

In this study the hydraulic relationship between the VCD River and groundwater tapped from Upper Pleistocene aquifer using isotope techniques was also assessed. Five monitoring points for groundwater in the Upper Pleistocene aquifer were arranged along and adjacent to the VCD River. Both river water and groundwater were collected periodically to monitor for the stable isotope compositions. The results showed that there is a hydraulic interrelation between groundwater in the Upper Pleistocene aquifer and the VCD River. River water infiltrates into the aquifer during the dry season. The mixing ratio between river water and groundwater from wells installed nearby the river was calculated using the two-end member mixing model based on the isotope balance equations. The result revealed that at the time of sampling, the contribution of river water into groundwater ranged from  $21 \pm 7 \%$  to  $53 \pm 8 \%$ .

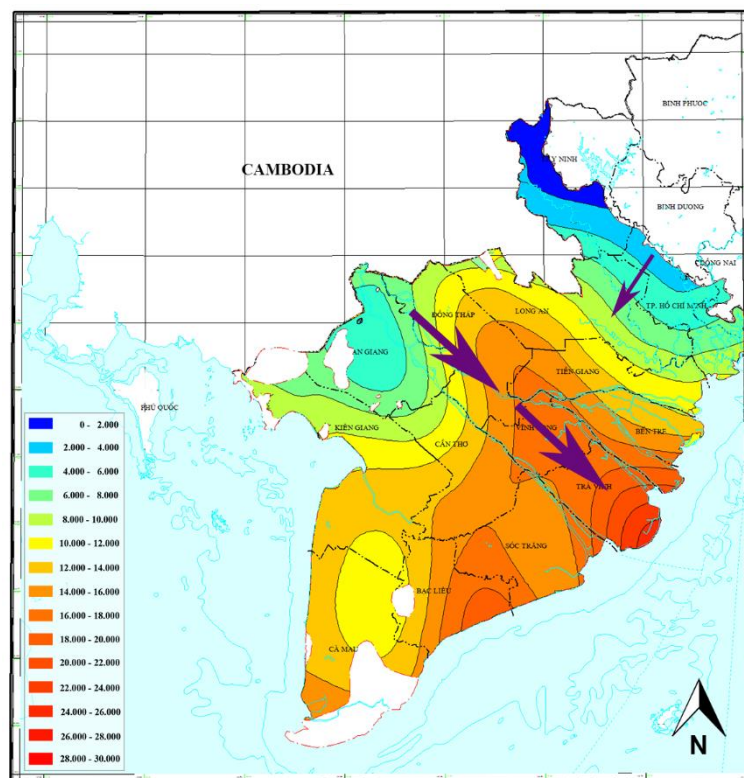


*Figure 2 The spatial distribution diagram of the Upper Pleistocene groundwater age in the Nambo Plain*

The spatial distribution of groundwater age in the entire aquifer within the study region was built using the Co-Kring technique. Based on the 39 pairs of groundwater age data for the Upper Pleistocene aquifer and a subsidiary variable of sampling depth, new points were interpolated from the 39 points. The spatial groundwater age distribution of the study aquifer with an accuracy of 0.86 is shown in Figure 2. It can be seen from the spatial distribution of water age that the groundwater in the Upper Pleistocene aquifer in the Nambo Plain flows by heterogeneous directions throughout the region and differentiates according to different hydrogeological regions. The oldest groundwater samples are distributed along the East Sea coast of Tra Vinh (28,800 years) and Bac

Lieu (24,000 years) provinces. This fact shows that groundwater from different gradation regions recharged the aquifers from different directions and empties into the East Sea. From the age distribution diagram, one can also suggest that the recharge zone of the study aquifer is possible outside Vietnam, it is from Cambodia. The direction of groundwater flow in the Nambo Plain could be from the northwest to southeast, emptying the East Sea. Also, from the age spatial distribution, it can be seen that the Upper Pleistocene aquifer in the Nambo Plain has a recharge zone in the northeast part. In this recharge zone, the age of groundwater ranges from modern to more than two thousand years old and moves by the northeast-southwest direction.

The transit velocities of groundwater movement in the Upper Pleistocene aquifer were estimated using pairs of sampling points that met the following requirements: they must be fresh water, locate in the same fresh groundwater area, and move in the same direction, as shown by the age distribution diagram of the studied aquifer (Fig. 2). These transit velocities were determined by dividing the distance between the two sampling points (two monitoring wells) along the flow line by the difference in age between the groundwater samples collected at these two wells. Calculated results showed that water moves in the aquifer with an average velocity of 7.7 m/year by the northwest-southeast flow direction. For the northeast-southwest direction, the sampling points in the study area do not meet the requirements; therefore, the groundwater velocity was estimated using the interpolated values and it was at an average of 8.1 m/year.

In order to have a better understanding of the groundwater system in the Nambo Plain, it is necessary to carry out studies for other aquifers in a broader scope, specifically to expand the groundwater sampling area to the Cambodian territory that borders the Nambo Plain.

## RESEARCH ON THE USE OF NUCLEAR AND ISOTOPE TECHNIQUES TO IDENTIFY THE ORIGIN AND HISTORY OF POLLUTION IN THE COASTAL ECOSYSTEM OF THE RED RIVER ESTUARY

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### **Project information:**

**- Project name: Research on the use of nuclear and isotope techniques to identify the origin and history of pollution in the coastal ecosystem of the Red River estuary**

**- Code: ĐTCB.02/20/VKHKTHN**

**- Managerial Level: Ministry**

**- Duration: 33 months (Jan 2020 - Sep 2022)**

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

1. Bui, D. D., Duong, D. T., Duong, V. T., Vuong, T. B., Nguyen, T. T. H., Doan, T. H., Nguyen, T. O., Le, D. C., Nguyen, H. G., & Nguyen, H. T. (2023). Use of  $^{210}\text{Pb}$  dating models for estimating sedimentation rate of a typical sediment core taken in the Ba Lat coastal area (Red River). *Nuclear Science and Technology*, 12(1), 32-40. <https://doi.org/10.53747/nst.v12i1.348>.

2. Buidac Dung, Duongduc Thang, Doanthuy Hau, Nguyenhuyen Trang, Ledinh Cuong, Nguyenvan Khanh, Duongvan Thang, Phamtuan Nam, Vuongthu Bac, Nguyenthithu Ha, Temporal trend of sediment accumulation in the Xuan Thuy Natural Wetland Reserve (Ba Lat coastal area of the Red River) and prediction on the future coastal wetland development, *Wetlands Ecology and Management* (under revision).

Nuclear and isotope techniques are widely used in research on marine environments for evaluating pollution of heavy metals, nutrients, and organic matter [1-4]. To study the history of pollutant releases to the marine environment, sediment sample cores must be taken to a certain depth by a specially designed sediment corer. Then the sediment core is thinly sliced, processed, analyzed and calculated to determine the age and sedimentation rate of each sediment slice. Also, the sediment slice samples are analyzed to determine the activity concentration of radionuclides, particle size composition, and the concentration of heavy metals, organic carbon (OC), nutrients, and isotopic composition, ect.. The results of analysis of sediment samples with the same time period of formation are used to identify the origin and history of sediment pollution as well as to evaluate the impact of pollution on the coastal ecosystem [5, 6].

One of the most commonly used techniques to calculate the age and sedimentation rate is the  $^{210}\text{Pb}$  technique. This technique has become popular and has proved to be an important tool in determining the rate of recent sedimentation during the past 100 years. On the basis of temporal sedimentation rate, it is possible to restore the history of pollution of heavy metals and other pollutants [7, 8]. This technique is also used in combination with other techniques such as  $^{137}\text{Cs}$ ,  $^{241}\text{Am}$ ,  $^{14}\text{C}$  to compare and to verify the results of calculating sediment age as well as the sediment rate [9-10].

This report presents the results of the ministerial-level project "**Research on the use of nuclear and isotope techniques to identify the origin and history of pollution in the coastal ecosystem of the Red River estuary**" implemented in the years 2020-2022 with two main objectives i) Developing procedures and guidelines for effective application of nuclear and isotope techniques to determine sedimentation rates and ii) Identifying the origin and the history of delivery of organic compounds, nutrients and heavy metals into the water and sediment environments that could cause pollution to the coastal ecosystem of the Red River estuary.

Sediment cores were taken in the area of Xuan Thuy National Park (XTNP), which is a wetland located to the south of the Ba Lat estuary coastal area of the Red River (Figure 1). XTNP covers an area of about 120 km<sup>2</sup>, including Con Ngan, Con Lu and Con Xanh tidal flats, with an average elevation of 0.5 - 0.9 m and some sand dunes from 1.2 to 1.5 m. The tidal regime of the region is diurnal with a period of about 25 hours, the average amplitude is 1.5 - 1.8 m, the maximum amplitude is 4.0 m [11]. The Vop River tributary and Tra River tributary flow from the Red River through the wetland to the sea. Control sediment cores were taken in the freshwater area of the Ngo Dong town, about 20 km upstream of the Red River from Ba Lat estuary, to determine the origin of sediment and pollutant source fluxed to the Ba Lat estuary.

Sample cores were taken with a sediment corer of diameter of 5.90 cm. The coring depth was estimated based on previous studies reporting average sedimentation rate of 0.77 cm yr<sup>-1</sup> at the Ba Lat estuary [12, 13]. Therefore, the coring depth was chosen as 90-100 cm to get the sedimentation period within the last 100-120 years. In our study, 11 sediment cores were collected in the coastal area of Ba Lat estuary, including 04 sample cores on tidal creeks with water depths of 1.5 to 3 m and 07 sample cores in the mangroves (Figure 1). Sample cores were taken at locations where disturbances caused by the Red River flow and ocean waves would have minimum effects on sedimentation process. In the area of the Ngo Dong town, two control cores were collected. Sediment cores were cut into slices of 2 cm and 4 cm thickness to obtain at least 20 sediment slices from each core. Sediment slices were transported to the laboratory, placed in porcelain bowls to dry naturally in the air. All sample slices were then analyzed to determine the activity concentrations of radionuclides  $^{238}\text{U}$ ,  $^{232}\text{Th}$ ,  $^{137}\text{Cs}$ ,  $^{226}\text{Ra}$  on a low background gamma spectrometer [14].  $^{210}\text{Pb}$  was determined by alpha spectrometry through  $^{210}\text{Po}$  [15].

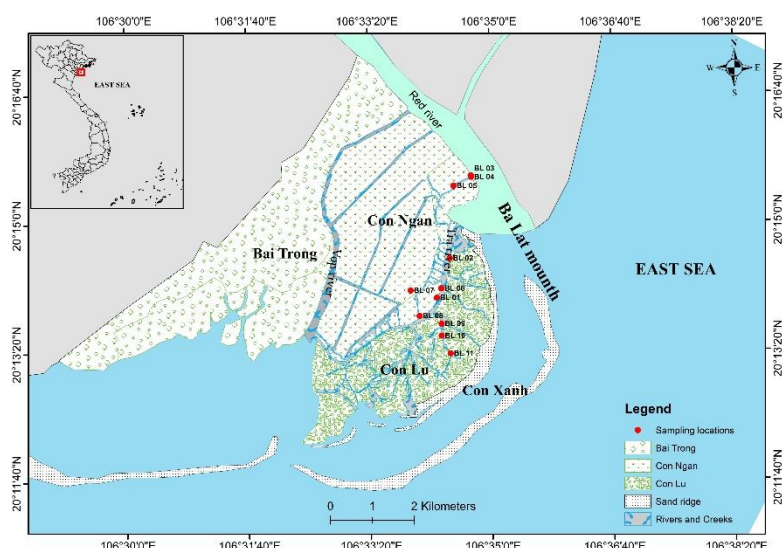


Figure 1. Map of the Ba Lat estuary (Red River) and the sampling locations in the XTNP.

From the analytical results of total  $^{210}\text{Pb}$  and  $^{226}\text{Ra}$  (supported  $^{210}\text{Pb}$ ), the unsupported (or excess)  $^{210}\text{Pb}$  concentration ( $^{210}\text{Pb}_{\text{ex}}$ ) in each sample slice was derived. The concentration of  $^{210}\text{Pb}_{\text{ex}}$  was used to calculate the age and sedimentation rate of each sediment slice by different computational models [8, 9] to identify the most optimal model used in this study. Based on the results of calculating the age and the sedimentation rate, representative sediment cores were selected, and along with 3 suspended matter samples collected in both areas, were analyzed for the concentrations of heavy metals (As, Cd, Pb, Zn, Hg, Cr, Cu), OCs, nutrients (N, P, K), and isotopic composition (C-13, N-15, O-18). Priority in selecting representative cores was given first by sub-region, then by the number of years of the whole sediment column formation, and then by the degree of fluctuation in sedimentation rates. These analysis results were used to assess the sediment origin and the pollution history that may affect the coastal ecosystem of the Red River estuary.

The analysis results of radionuclides in all 13 sediment cores showed that the activity concentrations of radionuclides  $^{238}\text{U}$ ,  $^{232}\text{Th}$ , and  $^{226}\text{Ra}$  were almost unchanged, indicating that the source of sediment fluxing to the Ba Lat estuary is stable. These results are quite similar to the average activity concentrations of  $^{238}\text{U}$ ,  $^{232}\text{Th}$ , and  $^{226}\text{Ra}$  in Vietnam's surface soils [16]. The concentrations of radionuclide  $^{137}\text{Cs}$  in the samples were very small, possibly due to the brackish water environment that causes  $^{137}\text{Cs}$  in the early formation stage to dissolve and wash away or penetrate into deeper sediment layer.

Results of the test on the use of different computational models in  $^{210}\text{Pb}$  dating showed that, in an environment with a continuous change in sedimentation process such as in the coastal area of the Ba Lat estuary, the Constant Rate of Supply (CRS) model is the most suitable for use. The Constant Flux Constant Sedimentation (CFCS) model could be used to estimate the average sedimentation rate of a particular constant sedimentation period of the whole core. Figure 2 shows the results of applying CRS

model to calculate sedimentation rate (SR), including mass accumulation rate (MAR,  $\text{g cm}^{-2} \text{yr}^{-1}$ ) and sediment accumulation rate (SAR,  $\text{cm yr}^{-1}$ ). Cores BL01 to BL04 (taken on tidal creeks with water depths of 1.5 to 3 m) have a continuously fluctuating SR over time (Figure 2a). Cores BL05 to BL11 (taken in mangroves) have smoother SR curves compared to those on tidal creeks (Figure 2b). All sediment cores in XTNP have the same sedimentation trend of small SAR before the 1960s, about  $0.5 \text{ cm yr}^{-1}$ . From the 1960s, the SAR began to gradually increased and reached the average value of 1.5 to  $2.0 \text{ cm yr}^{-1}$  in the period from 1990 to present. The control sediment core ND02 in Ngo Dong town has a sediment accumulation rate with an average value of about  $0.3 \text{ cm yr}^{-1}$  in the period from 1910 to 1950, gradually increasing and reaching the highest value of  $2.3 \text{ cm yr}^{-1}$  in 2004, then started to decrease and is now at around  $1.0 \text{ cm yr}^{-1}$  (Figure 2c).

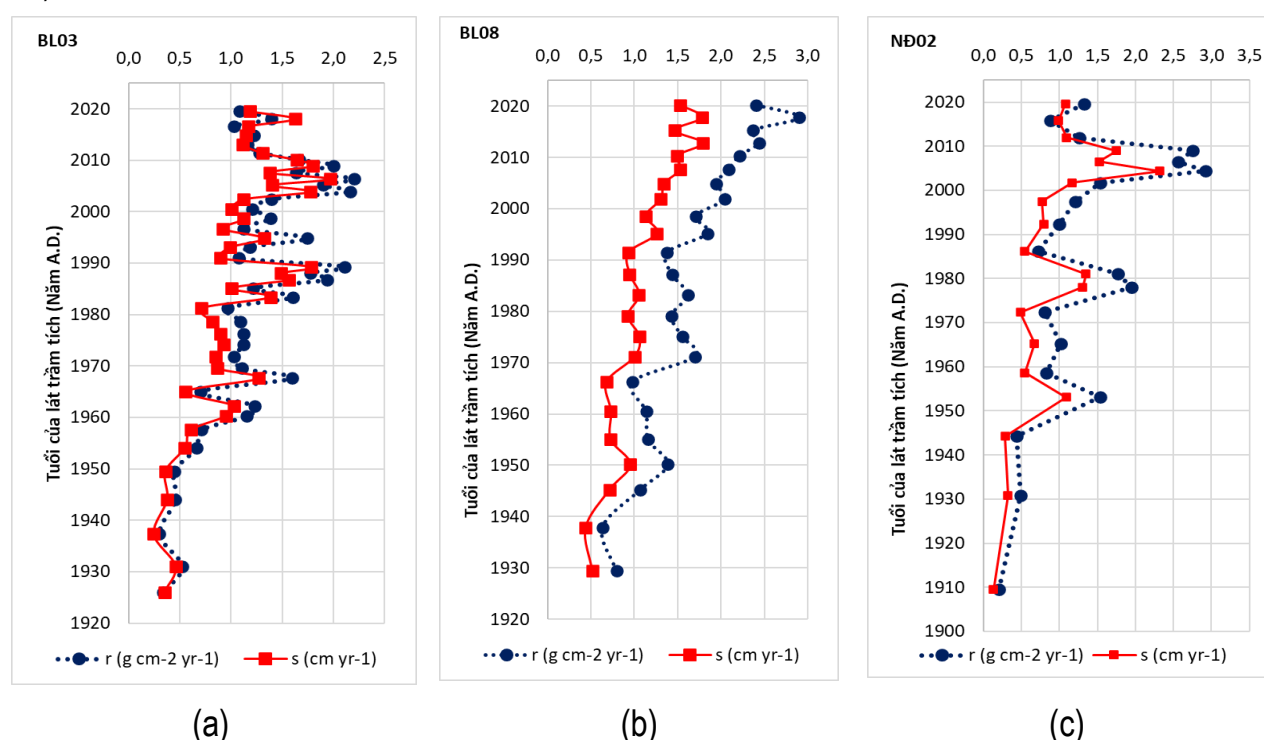


Figure 2. MAR (denoted as  $r$ ) and SAR (denotes as  $s$ ) at the cores taken in tidal creeks (a), in mangroves (b) and in Ngo Dong town (c).

The results of analysis for the concentrations of heavy metals, OCs, nutrients, isotopic compositions, the assessments of pollution levels, origin and history of pollution in the Ba Lat coastal area of the Red River are summarized as follows:

- Almost all the sediment samples have low concentrations of heavy metals (As, Cd, Pb, Zn, Hg, Cr, Cu), below the limits set by the Vietnam Regulation on Sediment Quality [17] and are not or slightly polluted according to the geological accumulation index. The concentrations of OCs and nutrients in the sediments as well as in the suspended matter samples are relatively low and almost unchanged in space and time.

- Based on the correlation between  $^{13}\text{C}$  in OC with C:N ratio in the sediment cores, it is interpreted that most of OC origin in sediments is from the freshwater algae and partly from C3 plants on the mainland. In addition, because the concentrations of heavy metals, OCs, and nutrients are low and do not change over time, it could be assumed that these components in the sediment cores are of natural origin and have not been affected by human activity. Thus, it could be concluded that all sediments fluxed to the Ngo Dong area and to the Ba Lat estuary have the same natural origin (from the mainland), and the properties of these sediments have not changed over time, at least in the last 100 years.

Testing of the computational models in  $^{210}\text{Pb}$  dating technique shows that the CRS model is the most suitable for calculating the age and the sedimentation rate of the sediment cores taken in the coastal area of Ba Lat estuary (Red River). All the cores taken in the XTNP wetland have the same sedimentation trend of small SAR before the 1960s, about  $0.5 \text{ cm yr}^{-1}$ . From the 1960s, the SAR began to gradually increased and reached the average value of 1.5 to  $2.0 \text{ cm yr}^{-1}$  in the period from 1990 to present. Correlation between the age and the rate of sediment accumulation with the results of analysis for the concentrations of heavy metals, OCs, nutrients, isotopic composition in the sample slices allowed determining the origin of the sediments and the history of sediment pollution. Sediments fluxed to the Ngo Dong area and to the Ba Lat estuary are of the same natural origin (from the mainland), unchanged in composition over time, and have not been polluted by heavy metals due to human activities.

## REFERENCES

- [1]. Nobi E.P., Dilipan E., Thangaradjou T., Sivakumar K., Kannan L. "Geochemical and geo-statistical assessment of heavy metal concentration in the sediments of different coastal ecosystem of Andaman Islands, India", *Estuarine, Coastal and Shelf Science*, 87, 253-264, 2010.
- [2]. Buccolieri A., Buccolieri G., Cardellicchia N. "Heavy metals in marine sediments of Taranto Gulf (Ionian Sea, Southern Italy)", *Marine Chemistry*, 99, 227-235, 2006.
- [3]. Farmer J.G. "Metal Pollution in Marine Sediment Cores from the West Coast of Scotland", *Marine Environmental Research*, 8, 1-28, 1983.
- [4]. Fukue M., Nakamura T., Kato Y., Yamasaki S. "Degree of pollution for marine sediments", *Engineering Geology*, 53, 131-137, 1999.
- [5]. Ligeró R.A., Barrera M., Casas-Ruiza M., Sales D., López-Aguayoc F., "Dating of marine sediments and time evolution of heavy metal concentrations in the Bay of Cádiz, Spain", *Environmental Pollution*, 118, 97-108, 2002.
- [6]. Zourarah B., Maanan M., Carruesco C., Ajjane A., Mehdi K., Freitas M.C. "Fifty-year sedimentary record of heavy metal pollution in the lagoon of Oualidia (Moroccan Atlantic coast)", *Euarine, Coastal and Shelf Science*, 72, 359-369, 2007.

- [7]. Mil-Homens M., Stevens R.L., Boer W., Abrantes F., Cato I. "Pollution history of heavy metals on the Portuguese shelf using  $^{210}\text{Pb}$ -geochronology", *Science of the Total Environment*, 367, 466-480, 2006.
- [8]. Sanchez-Cabeza J.A., Ruiz-Fernandez A.C. " $^{210}\text{Pb}$  sediment radiochronology: An integrated formulation and classification of dating models", *Geochimica et Cosmochimica Acta*, 82, 183-200, 2012.
- [9]. Appleby P. G. (2001), *Chronostratigraphic techniques in recent sediments*, In: Tracking Environmental Change Using Lake Sediments, vol. 1 (eds. W. M. Last and J. P. Smol), 171– 201. Basin Analysis, Coring and Chronological Techniques. Kluwer Academic Publishers, Dordrecht, The Netherlands.
- [10]. Craft, C. B., Richardson, C. J. "Recent [ $^{137}\text{Cs}$ ] and long-term [ $^{210}\text{Pb}$ ,  $^{14}\text{C}$ ] organic soil accretion and nutrient accumulation in the Everglades", *Soil Science Society of America Journal*, 62, 834-843, 1998.
- [11]. Dao, M. S., Nguyen, D. T., Nguyen, Q. H. (2008), *The environmental impact assessment of shrimp farming development in the core zone of Xuan Thuy National Park (Nam Dinh, Vietnam)*, Technical report number 12.2008, Xuan Thuy National Park, Vietnam.
- [12]. Nhon Dang Hoai, Thanh Tran Duc, Huy Dinh Van, Hai Phan Son, Ha Nguyen Manh, Lan Tran Dinh, Duan Xiaoyong, Ve Nguyen Dac "Sedimentation Rates and Heavy Metal Concentrations in the Tidal Flats of North Vietnam", *Pol. J. Environ. Stud.*, 28 (5), 3721-3733, 2019.
- [13]. van Santen P., Augustinus P.G.E.F., Janssen-Stelder B.M., Quartel S., Tri N.H. "Sedimentation in an estuarine mangrove system", *Journal of Asian Earth Sciences*, 29, 566–575, 2007.
- [14]. De Corte F., Umans H., Vandenberghe D., De Wispelaere A., Van den haute P. "Direct gamma-spectrometric measurement of the  $^{226}\text{Ra}$  186.2keV line for detecting  $^{238}\text{U}/^{226}\text{Ra}$  disequilibrium in determining the environmental dose rate for the luminescence dating of sediments", *Appl. Radiat. Isot.*, 63(5), 589–598, 2005.
- [15]. Martin P. & Hancock G. (1992), *Routine analysis of naturally occurring radionuclides in environmental samples by alpha-particle spectrometry*, Research Report 7, Supervising Scientist for the Alligator Rivers Region.
- [16]. N. Q. Huy, P. D. Hien, T. V. Luyen, et al. "Natural radioactivity and external dose assessment of surface soils in Vietnam", *Radiation Protection Dosimetry*, 151 (3), 522–531, 2012.
- [17]. QCVN 43: 2012/BTNMT, National Technical Regulation on Sediment Quality, Hanoi, 2012 (in Vietnamese).

## RESEARCH ON THE DETERMINATION OF CARBON ISOTOPE COMPOSITION ( $\delta^{13}\text{C}$ ) IN SOME PLASTIC WASTES OF DIFFERENT ORIGIN

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### **Project information:**

**- Project name: Research on the determination of carbon isotope composition ( $\delta^{13}\text{C}$ ) in some plastic wastes of different origin**

**- Code: CS/22/04-03**

**- Managerial Level: Institute**

**- Duration: 12 months (Jan 2022 - Dec 2022)**

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

1. Ha Lan Anh, Vu Thi Hien, Vu Hoai, Mai Dinh Kien, Vo Thi Anh. Evaluation of carbon stable isotope composition ( $\delta^{13}\text{C}$ ) in some type of microplastic. 7th National Conference on Nuclear Science and Technology for young staff of atomic energy, Hanoi, October 2020. (In Vietnamese)

2. Ha Lan Anh, Vu Thi Hien, Vu Hoai, Mai Dinh Kien. Evaluation of carbon stable isotope composition ( $\delta^{13}\text{C}$ ) in some type of microplastic in Vietnam. Annual Scientific Conference 2022, University of Water Resources, Ho Chi Minh City, November 2022.

Differences in carbon and hydrogen stable isotope ratios have been found for petroleum-based precursor resins and biomaterials. Therefore, it is possible to support the classification of plastics according to their source material. The isotope composition value  $\delta^{13}\text{C}$  has been recognized as a useful tool for the investigation of plastics and microplastics in the environment, and in the food chain, as well as for the assessment of plastic degradation. This study aims to develop a method for analyzing the stable isotope composition of carbon ( $\delta^{13}\text{C}$ ) in microplastic using an isotope ratio mass spectrometer (EA-IRMS). In this study, some types of plastic waste were determined for their  $\delta^{13}\text{C}$  values to support investigating the source of plastic wastes that are polluting the environment.

The experimental method used in this study is based on the difference in the density of microplastics and aqueous solutions used to decant microplastics from environmental samples. For this the environmental samples were subjected to suspension in an aqueous solution of high density and allowed the microplastics to overflow then filtered it. The microplastics separated from the aqueous solution and then was subjected to the analysis for carbon isotope composition ( $\delta^{13}\text{C}$ ) on an isotope ratio mass spectrometer equipped with an elemental analyzer (EA-IRMS).

The isotope composition is calculated by the following formula:

$$\delta = \frac{R_s - R_{Std}}{R_{Std}} \cdot 1000 (\text{‰})$$

In which:

$R_s$  is the ratio of  $^{13}\text{C}/^{12}\text{C}$  of the sample to be measured;

$R_{Std}$  is the ratio  $^{13}\text{C}/^{12}\text{C}$  of the standard sample.

The standard samples used in this study are USGS 62 ( $\delta^{13}\text{C}$ :  $-14,79 \pm 0,04 \text{ ‰}$ );, IAEA CO-9: ( $\delta^{13}\text{C}$ :  $-47,14 \pm 0,15 \text{ ‰}$ ), IAEA 600: ( $\delta^{13}\text{C}$ :  $-27,77 \pm 0,04 \text{ ‰}$ ). These  $\delta^{13}\text{C}$  values of the standards were compared with the  $\delta^{13}\text{C}$  value of the V-PDB (Vienna Pee Dee Belemnite) standard which was assigned to be 0.

The study has achieved the goal of establishing a procedure for the determination of  $\delta^{13}\text{C}$  in plastics suspended in water samples. The procedure was successfully applied in analyzing the isotope composition of carbon in some types of plastic wastes with a bias and precision to be less than 1% and 0.3‰, respectively. The results showed that there is a clear difference in  $\delta^{13}\text{C}$  values in microplastics such as PP, HDPE, LDPE, ABS, PVC, PMMA, PET, HIPS, and HIPS tech (Figure 1). The maximum  $\delta^{13}\text{C}$  value was -26.80 ‰ in recycled PP plastic and the minimum value was -40.34 ‰ in recycled PMMA. With the same plastic type, recycled ABS microplastics have a  $\delta^{13}\text{C}$  value of -27.58 ‰, which is richer in the  $\delta^{13}\text{C}$  compared to those in primary ABS microplastics that was -29.99‰. The difference in  $\delta^{13}\text{C}$  values for different types and ages of microplastics in the environment has proven a fact that the isotopic technique is a promising tool in the study of the origin and properties deterioration of plastics in the environment.

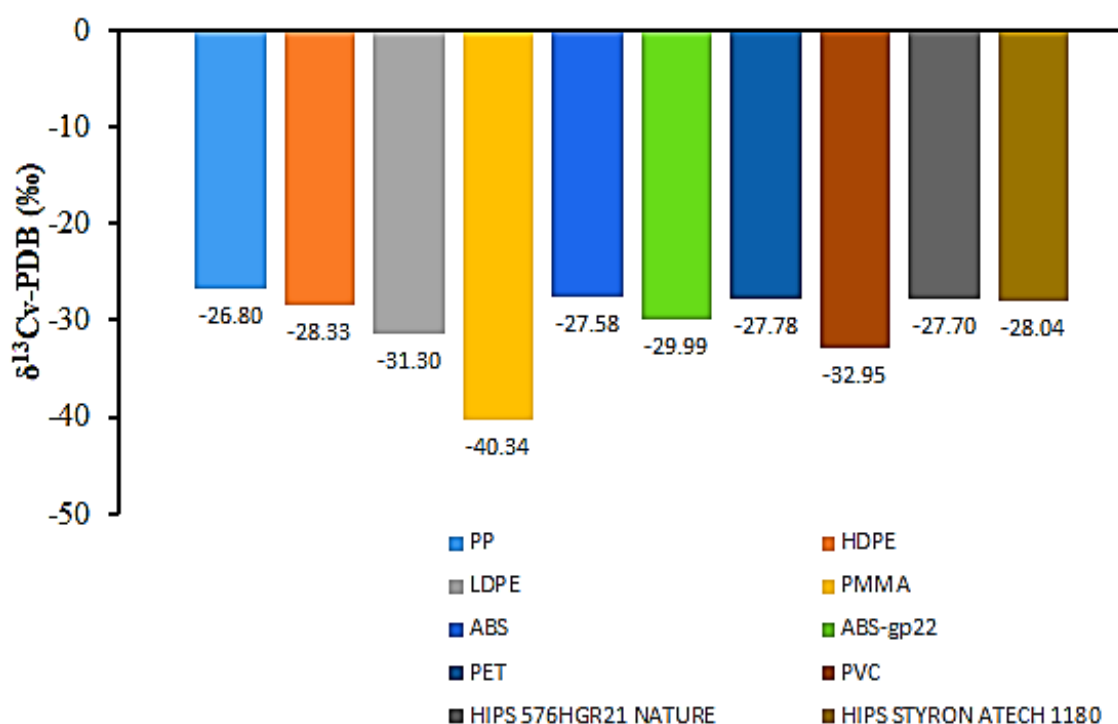


Figure 1. The value of stable isotope composition of carbon ( $\delta^{13}\text{C}$ ) in some types of plastics

## CREATING A SUMMARY REPORT ON ENVIRONMENTAL RADIATION MONITORING DATA OF THE INSTITUTE FOR NUCLEAR SCIENCE AND TECHNOLOGY FROM 2000 TO 2022

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### **Project information:**

**- Project name: “Creating a summary report on environmental radiation monitoring data of the Institute for Nuclear Science and Technology from 2000 to 2022”**

**- Code: CS/22/04-01**

**- Managerial Level: Institute**

**- Duration: 12 months (Jan 2022 - Dec 2022)**

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

1. Vuong Thu Bac, Nguyen Thi Oanh, Nguyen Van Khanh, Nguyen Huyen Trang, Bui Duc Dung. “Online environmental radiation monitoring data from 2016 to 2022”. The 7th Nuclear Science and Technology Conference of young scientist, Hanoi, October 2022.

Environmental radiation monitoring (ERM) has been widely deployed since the 80s of the last century through various scientific and technological research projects and tasks in our country. The Center for Radioactivity Monitoring and Environmental Impact Assessment under the Institute of Nuclear Science and Technology (INST) has developed a number of technical procedures for quantifying radioactivity in a number of key environmental objects. However, up to now, some technical points in these processes are no longer relevant to reality due to changes in technical infrastructure and practical requirements. The obtained results of the implemented projects are also inconsistent in terms of measurement units, measurement errors, detection limits and have not been centrally stored, etc.

It is necessary to review and compile radioactive analytical methods that previous projects and tasks have used to obtain data on the environmental radioactivity. Accordingly, the review and evaluation would point out the limitations in the environmental radioactivity analysis that need to be updated for the projects and tasks which might be implemented in the future. The Department of Planning, Scientific Management and International Cooperation, INST has compiled all the data produced through the projects and tasks implemented in the period 2000 to 2022 including online monitoring data; built and standardized tables for data management; standardized and

unified measurement units of quantities, errors and detection limits of each radionuclide that can be analyzed in the laboratories of the Institute.

The project *"Creating a summary report on environmental radiation monitoring data of the Institute for Nuclear Science and Technology from 2000 to 2022"* implemented in 2022 has completed its objectives and main contents. The main products the project has achieved consists: 1) A set of forms with a uniform format to manage and store laboratory data according to space/time, the object of analysis and radioactive indicators. The set is comprised of i) A form to store the results of measurement of radioactive indicators in the field; ii) A form to store the radioactive analytical results in the laboratory; iii) A form for storing the results of online monitoring of radioactive indicators. 2) A set of environmental radiation data from research results of scientific and technological projects and tasks performed at the INST from 2000-10/2022 in unified forms of reliable and clear excel tables which are consistent and user-friendly. 3) Several limitations in the environmental radioactive analysis that need to be updated in the projects which might be conducted in the future. 4) One report was released at the scientific conference of young researchers working in the field of Nuclear Energy held in October 2022 in Hanoi.

Basically, the project created the first set of environmental radiation data sets to look up, exploit, use, store and manage data about environmental radiation with consistency. The results of the project are expected to bring benefits to many aspects and become significant for long-term use, serving research on environmental protection. In fact, some environmental radiation data, especially those produced about 20 years ago remain inaccessible to the project.

We hope that leaders at all levels pay more attention to the management and storage of data from the research projects, and environmental radiation protection tasks , invest more for this point and require all the tasks in the future to use the agreed forms to store the data for management.

## DEVELOPING AN INTERNSHIP PROGRAM AND OPERATING INSTRUCTIONS FOR A WATER STABLE ISOTOPE RATIO LASER ANALYZER

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### Project information:

- **Project name:** Developing an internship program and operating instructions for a water stable isotope ratio laser analyzer

- **Code:** CS/22/10-01

- **Managerial Level:** Institute

- **Duration:** 12 months (Jan 2022 - Dec 2022)

- **Contact email:** thom.nguyen1008@gmail.com

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

1. Nguyen Thi Thom, Dam Thi Thanh Thuy, Trinh Anh Duc, Trinh Hong Quan, Nguyen Nho Lan, Dao Thi Thu Thuy; Assessment of the water stable isotopes in the Day River basin using water isotope analyzer, The 7th Conference on Nuclear science and Technology for young reserachers, October- 2022 (in Vietnamese).

Water stable isotope analysis is one of the most advanced techniques being widely applied in research on the hydrological process, water source tracing and the water cycle. The technique advantages provide highly accurate and reliable results; especially, Isotope Ratio Laser Spectroscopy (IRLS) instruments are preferred to Isotopes Ratio Mass Spectroscopy (IRMS) instruments because the time is faster and the cost is much cheaper. Picarro L2130i water isotope analyzer, which has been set up at Nuclear Training Center recently, provides high quality measurements of water stable isotopes. This study aims to review the safety parameters of the equipment, establish an internship program and operating instruction in order to facilitate researchers and students a better assess with the instrument and strengthen research collaboration with international and domestic partners.

This study outcome is based on the consultation with experts and a systematic evaluation including sourcing, selecting, evaluating and synthesizing data related to operating principles and application of Picarro L2130i water isotope analyzer (Picarro

User's guide, articles, TCVN guidance for instruction handling and sample, treatment and storage of sample). Stable isotope ratios of O and H in river water were measured by the Picarro L2130i water isotope analyzer using the VSMOW international standards and the results are exported as composition of stable isotopes ( $\delta_{\text{VSMOW}}$ );  $\delta^{\text{NE}} = [(R_{\text{sample}}/R_{\text{standard}}) - 1] \times 1000$  (‰), where N is the mass unit of element E,  $R_{\text{standard}}$  is the ratio of the heavy-to-light stable isotope abundances ( $^2\text{H}/^1\text{H}$ ,  $^{18}\text{O}/^{16}\text{O}$ ) in standards,  $R_{\text{sample}}$  is the ratio of the heavy-to-light stable isotope abundances ( $^2\text{H}/^1\text{H}$ ,  $^{18}\text{O}/^{16}\text{O}$ ) in samples. It should be noted that the isotope composition ( $\delta$ ) values are expressed as “permil” (‰) (Fry, 2006).

To ensure the safety and optimal performance of the analytical system, the amount of injected liquid was about  $20000 \pm 1000$  ppmv and was controlled by Autosampler. Dry nitrogen (<50ppmv water concentration) was supplied to the instrument at the pressure of  $2.5 \pm 0.2$  psi ( $17.2 \pm 1.4$  kPa). Sample injection volume (controlled by Autosampler) was set at  $\sim 2 \mu\text{L}$ . On the other hand, the temperature and humidity of laboratory and the power source were controlled as recommended by Picarro Inc. Up to now, the rainwater and river water samples of the northern region have been continuously analyzed by the system to ensure accurate measurements and develop the internship programme and the procedure of operating instructions for Picarro L2130i water isotope analyzer.

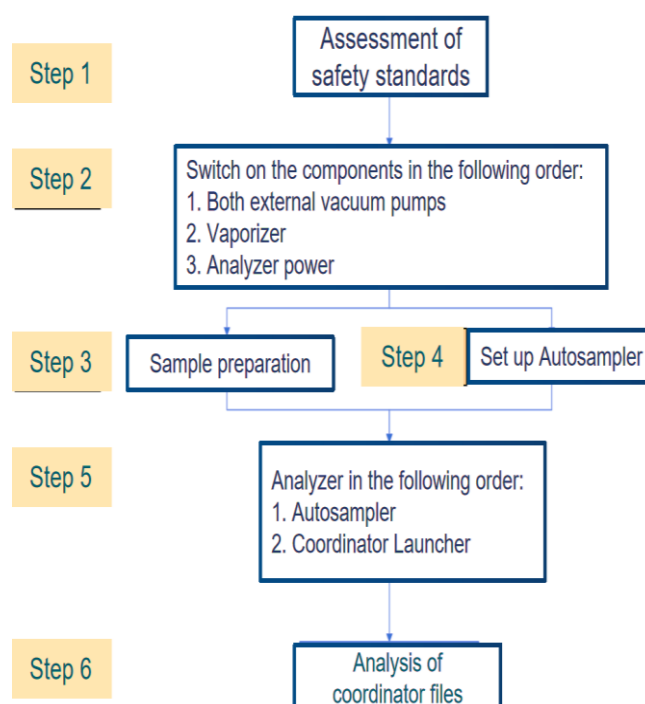


Figure 1. The procedure of operating instructions

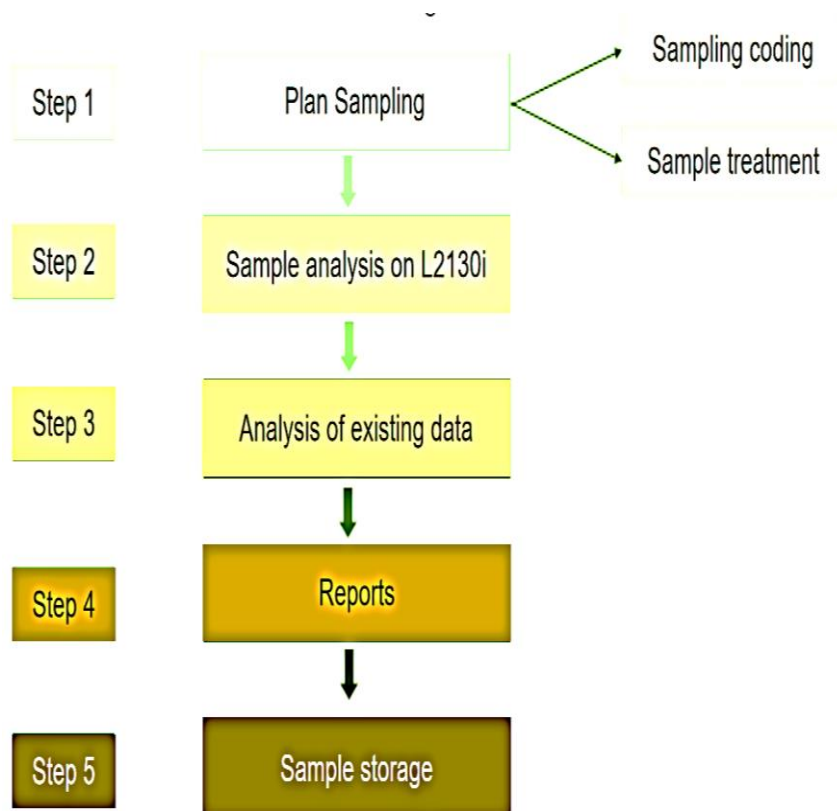


*Figure 2. The procedure of the internship program*

This research project has helped us to master the equipment and successfully conduct several practical training courses for students and graduate students of the Hanoi University of Science and short courses on stable isotope analysis for researchers at the Vietnam Atomic Energy Institute. In our other research, we have obtained good results in analyzing the isotopic composition of water molecules ( $\delta^2\text{H}$  and  $\delta^{18}\text{O}$ ) of the Red and Day Rivers. Our results are similar to those of other domestic studies such as the research of Trinh Anh Duc et al. (2017), These results have been recognized and published in prestigious journals including Nguyen Nho Lan et al. (Water, 2021), Trinh Anh Duc and Do Thu Nga (Conference: 39th IAHR World Congress, 2022).

Our research group have successfully set up the operating instruction procedure and the internship program at the Nuclear Training Center. In near future, it is recommended to continue sampling and analyzing the stable isotope composition of river surface water and rain water in some northern river basins and expand the objects of analysis of stable isotope composition of water in beverages such as beer, alcohol for the purpose of product traceability.

## **2.6. APPLICATIONS IN BIOLOGY, AGRICULTURE AND MEDICINE**

## POSSIBILITY OF USING MG-28 RADIOISOTOPE ENZYME INACTIVATION METHOD IN CANCER TREATMENT

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### Project information:

- **Project name:** Study of the possibility of using enzymatic inactivation with the radioactive isotope <sup>28</sup>Mg in the treatment of cancer

- **Code:** CS/21/02-03

- **Managerial level:** Institute

- **Duration:** 18 months (Jan 2021 – June 2022)

- **Contact email:** truong.hoang.tuan@cenutech.vn

### - Published papers related to the project:

1. Tran Van Luyen, Truong Hoang Tuan. Proposing the possibility of inserting <sup>28</sup>Mg radioisotope into hexokinase, DNA polymerase, RNA polymerase enzymes: prospects for cancer treatment and SARS COV2. Vietnam Conference on Nuclear Science and Technology, Dalat, Vietnam, 2021 (in Vietnamese).

Enzyme inactivation via their metal cofactors is a novel idea. The stable metal ion cofactors will be replaced by their radioisotopes. These isotopic ions would decay into another element and the cofactor role is lost, leading to the inactivation of enzyme. The method of inactivating metal enzyme cofactors by replacing stable metal ions Mg with radioactive isotope <sup>28</sup>Mg has been proposed in recent scientific publications by author Tran Van Luyen (Vietnam Atomic Energy Institute) [1, 2]. <sup>28</sup>Mg beta (–) decays, that can travel 0.36 cm in water at various energy levels: 211.48 keV, 458.85 keV, and 859.42 keV, to form the intermediate radioactive isotope <sup>28</sup>Al, which then decays beta (–) at 2863.21 keV to become the stable element Si. This process inactivated the catalytic function of the enzyme-Mg cofactor, leading to the interruption of the metabolism catalyzed by the enzyme. The radiations are produced by the decay of <sup>28</sup>Mg and <sup>28</sup>Al, is capable of destroying enzyme-containing cells and neighboring cells by direct ionizing effect [3]. The free radicals generated by this ionizing radiation will further oxidize the protein molecules along their trajectory. However, there has not been a detailed study by calculation, simulation or experiment to show the conditions, the scientific basis of the mechanisms and the clinical application of this method. Therefore, the calculations and simulations of radiation physics and the effect of radiation dose on tumor create the basis for further studies in the future towards the approach to cancer treatment by enzyme inactivation. using the isotope <sup>28</sup>Mg.

In Table 1 presented the effective systemic and visceral doses – estimated by the ICRP recommendation [4] with SUNDIALS library [5] – of 1 Mbq in the ideal case, that reaches 100% target tissues. At that time, there were about 108.626 billion enzymes inactivated but the effective dose was very low. In addition,  $^{28}\text{Mg}$  and  $^{28}\text{Al}$  have short half-lives (21 hours and 2.25 minutes), so after about 1.25 weeks, corresponding to 10 half-lives of  $^{28}\text{Mg}$ , the patient is considered radioactive free.

Table 1. Effective dosage (mSv) in Vietnamese male and female

|                   | 10 half-lives (male) | 10 half-lives (female) |
|-------------------|----------------------|------------------------|
| Full body         | 1.876                | 2.500                  |
| Bone marrow (red) | 14.043               | 20.006                 |
| Colon             | 54.767               | 62.088                 |
| Lung              | 14.055               | 20.322                 |
| Stomach           | 109.534              | 128.812                |
| Chest             | 657.206              | 36.011                 |
| Gonad             | 280.857              | 128.934                |
| Bladder           | 109.534              | 150.047                |
| Esophageal        | 136.918              | 171.482                |
| Liver             | 3.043                | 4.287                  |
| Thyroid           | 273.836              | 353.052                |
| Bone surface      | 0.249                | 0.375                  |
| Brain             | 0.944                | 1.154                  |
| Salivary glands   | 17.115               | 21.435                 |
| Skin              | 0.415                | 0.652                  |

The radioisotope  $^{28}\text{Mg}$  has great potential for cancer treatment by inactivating enzymes in cancerous tissues. They can make cells stop providing energy by inactivating enzymes, affecting DNA and RNA replication to limit cell proliferation and irradiating at the target, minimizing effects on surrounding tissues. In addition, due to the short half-life of  $^{28}\text{Mg}$  (21 hours) and the fission product  $^{28}\text{Al}$  (2.25 minutes), the internal irradiation dose is quite low.

The method of enzyme inactivation using  $^{28}\text{Mg}$  isotopes is still very new, it is necessary to perform the following steps such as 1) isolating and analyzing enzyme components on cancer and host tissues; 2)  $^{28}\text{Mg}$  radio-labeled in-vitro experiments on different cancer tissues; 3)  $^{28}\text{Mg}$  radio-labeled in-vivo experiments on animals; 4) pre-clinical and clinical trials; 5) experimental treatment on patients.

## DESIGN AND FABRICATION OF A MINI-SPECT PROTOTYPE DEVICE APPLIED IN MICE SPECIMENS FOR MEDICAL RESEARCH

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### Project information:

- **Project name:** Design and fabrication of a mini-SPECT prototype device applied in mice specimens for medical research.

- **Code:** ĐTCB.04/20/TTUDKTHN

- **Managerial Level:** Ministry

- **Duration:** January 2020- January 2021 (extended to September 2022)

- **Contact email:** theduy@canti.vn

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

1. Bui Ngoc Ha, Dang Nguyen The Duy, Lai Viet Hai, Research and manufacture of the mini gamma camera using multi-anode photo multiplier tube (Ma-PMT), Journal of Nuclear Science and Technology (NST) (accepted for publication)

2. Nguyen Ngoc Nhat Anh, Dang Nguyen The Duy, Nguyen Thanh Chau, Pinhole design for small animal Single Photon Emission Computed Tomography using MCNP5 simulation, Thu Dau Mot University Journal of Science, to be published on Vol.2, 04/2023 (in Vietnamese)

3. Nguyen Thanh Chau, Dang Nguyen The Duy, Nguyen Ngoc Nhat Anh, Le Thao Huong Giang, Studies of reconstruction methods for pinhole small animal Single Photon Emission Computed Tomography, Thu Dau Mot University Journal of Science, to be published on Vol.3, 06/2023 (in Vietnamese).

Single Photon Emission Computed Tomography (SPECT) is one of the many tomographic techniques widely used in medicine and various scientific fields. In medicine, clinical SPECT is a nuclear imaging technique that uses gamma ray emitting radioactive tracers to produce 3D images of organs and tissues inside the human body. The technique involves injecting the radiotracer into the patient's bloodstream, and then using gamma camera to measure the radiation emitted by the tracer around the patient's body. The 3D image is reconstructed from the measured data and used to diagnose and monitor various conditions including cancer, heart disease, and neurological disorders. Small animal SPECT is a similar technique used in preclinical research to study diseases and treatments in small laboratory animals such as mice and rats. Small animal

SPECT systems are designed to produce high resolution 3D images of small animal organs for studying drugs, disease mechanisms, and evaluate the efficacy of potential treatments. Although small animal SPECT operates on the same principles as clinical SPECT in humans, there are many differences due to the requirement for high-resolution images appropriate for small sample sizes. Small animal SPECT devices have smaller gamma cameras with narrow fields of view, so pinhole collimators are often used. As a result, the image reconstruction geometry is also different from that of parallel-hole collimators.

This project was carried out with the aim of designing and manufacturing a mini SPECT device for use on mouse models, as a basis for the development and completion of a SPECT device that can serve preclinical research in Vietnam. The main contents that have been implemented include: research for designing the device; manufacturing of the gamma cameras and pinhole collimators; development of software for SPECT image reconstruction using pinhole geometry; and testing of the device to survey its technical specifications.

Figure 1a describes the overall design and schematic diagram of the mini SPECT prototype. The device is designed with the following main components: a gamma detector head and signal processing circuitry; a pinhole collimator block; a mechanical rotation system (gantry) and gantry operation; data acquisition software, device control, and SPECT image reconstruction software. Figure 1b illustrates the structure of the pinhole collimator block with gold pinholes of diameter 0.75mm, height 2mm, and  $53^\circ$  acceptance angle. The collimator block is surrounded by a 2mm thick layer of lead to shield gamma rays.

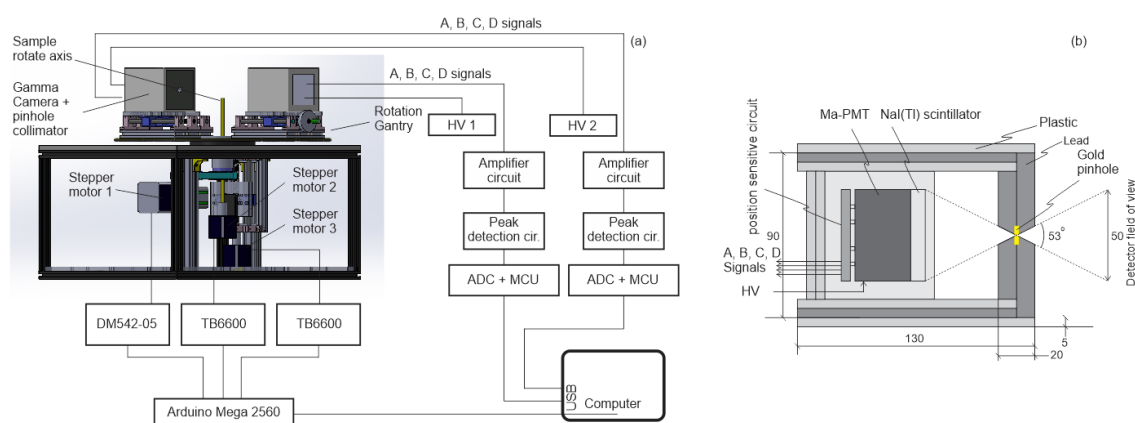


Figure 1. (a) overall design the device, (b) structure of pinhole collimator and gamma camera

The gamma detector head and signal processing circuits consist of 2 gamma cameras arranged opposite each other. This design allows for a 50% reduction in measurement time compared to a single gamma camera device. Each gamma camera is based on a multi-anode photomultiplier tube (Ma-PMT) H12700 from Hamamatsu Photonics, coupled with a 50mm x 50mm x 8mm monolithic NaI(Tl) crystal. The Ma-PMT has a total of 64 anodes arranged in 8 columns by 8 rows with an effective area of

48.5mm x 48.5mm. The signal processing circuits collect and process the electrical signals from the Ma-PMT. The 64 outputs of the Ma-PMT are connected to a network of resistors known as the position detection circuit. The circuit generates four output signals, A, B, C, and D, based on the electronic signals that depend on the position of the radiation interaction. These signals are used to determine the coordinates of the radiation interaction position on the scintillation crystal using common Anger formulas [1]. These four signals are called position-sensitive signals. The total A, B, C, D signals represent the total energy of the gamma ray absorbed completely on the NaI(Tl) crystal.

$$X = \frac{A+C}{A+B+C+D}, Y = \frac{C+D}{A+B+C+D} \quad [1]$$

The device is operated with two automatic rotating modes: sample rotation or detector rotation with the gantry rotating table. The field of view of the detector can be changed from 35mm to 50mm by manually adjusting the distance between the pinhole and the sample, corresponding to an image magnification from 1.6 to 1. The rotation mechanism of the sample or detector is operated by stepper motors controlled by software on the computer.

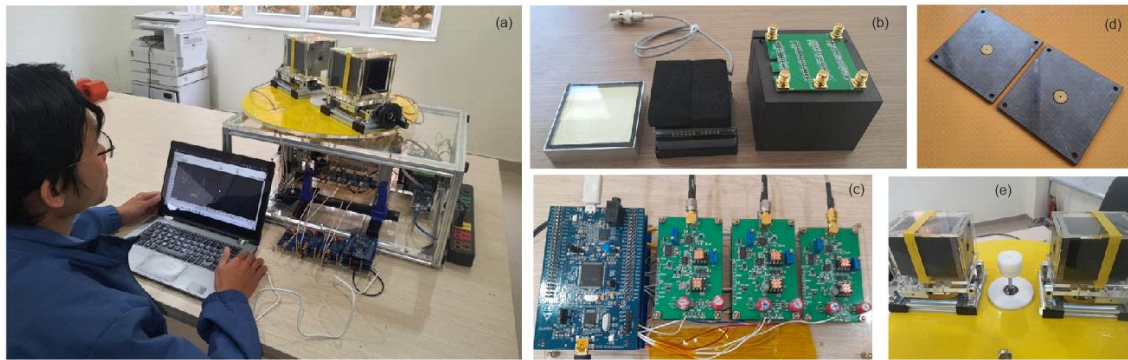


Figure 2. (a) The mini SPECT prototype device, (b) NaI(Tl) crystal, Ma-PMT and position sensitive circuit, (c) Peak detection circuit and MCU, (d) gold pinhole collimator 0.75mm in diameter, (e) 2 pinhole collimators and gamma cameras.

The SPECT image reconstruction software is programmed with the Simultaneous Algebraic Reconstruction Technique (SART) and Expectation Maximization (EM) algorithms. Equation [2] describes the SART algorithm, and equation [3] describes the EM algorithm. The core of the SPECT image reconstruction is to build a 3D image geometry with parameters corresponding to the device's geometry parameters.

$$f_j^{(k+1)} = f_j^{(k)} + \lambda \frac{1}{\sum_{i \in I_\theta} w_{ij}} \cdot \sum \frac{p_i - \sum_{l=1}^N w_{il} f_l^{(k)}}{\sum_{l=1}^N w_{il}} \cdot w_{ij} \quad [2]$$

Where:  $f_j^{(k+1)}$  is calculated value,  $p_i$  is the measured data,  $w_{il}$  is the weight factor of the ray distributed to the pixel being calculated,  $\lambda$  is the relaxation factor.

$$\lambda_j^{n+1} = \frac{\sum_{i \in j_j} N_{ij}}{\sum_{i \in j_j} c_{ij}} = \frac{\lambda_j^n}{\sum_{i \in j_j} c_{ij}} \sum_{i \in j_j} \frac{c_{ij} Y_i}{\sum_{k \in I_i} c_{ik} \lambda_k^n} \quad [3]$$

Where:  $\lambda_j^{n+1}$  is the calculated value,  $Y_i$  is the measured data, the remaining parameters are related to the expectation and maximum step of the algorithm.

Experiments have been carried out to investigate the parameters of the device. The energy resolution of the two detector blocks was determined to be 12.3% FWHM, 14.8% FWHM, and 18.7% FWHM, respectively, corresponding to the energy peaks of 662keV, 364keV, and 140keV. The sensitivity of the device was determined to be 0.24 cps/ $\mu$ Ci/0.05ml, 0.86 cps/ $\mu$ Ci/0.05ml, and 1.45 cps/ $\mu$ Ci/0.05ml for a Tc-99m source with a volume of 0.05ml at distances of 200mm, 100mm, and 80mm, respectively.

The spatial resolution of SPECT imaging was studied with a Derenzo phantom simulating a mouse specimen. The phantom was made of PE in the shape of a cylinder 35mm in diameter and 25mm in height. The drilled holes on the phantom had diameters of 1mm, 1.5mm, 2mm, and 2.5mm with a depth of 20mm, filled with approximately 2mCi of Tc-99m solution in total. The center of rotation of phantom was placed 50mm away from the pinholes. The SPECT data acquisition time was 120 seconds per projection and the projection images were collected at 5.625° increments over 360°. The 3D SPECT images were reconstructed using SART and EM algorithms with 30 iterations.

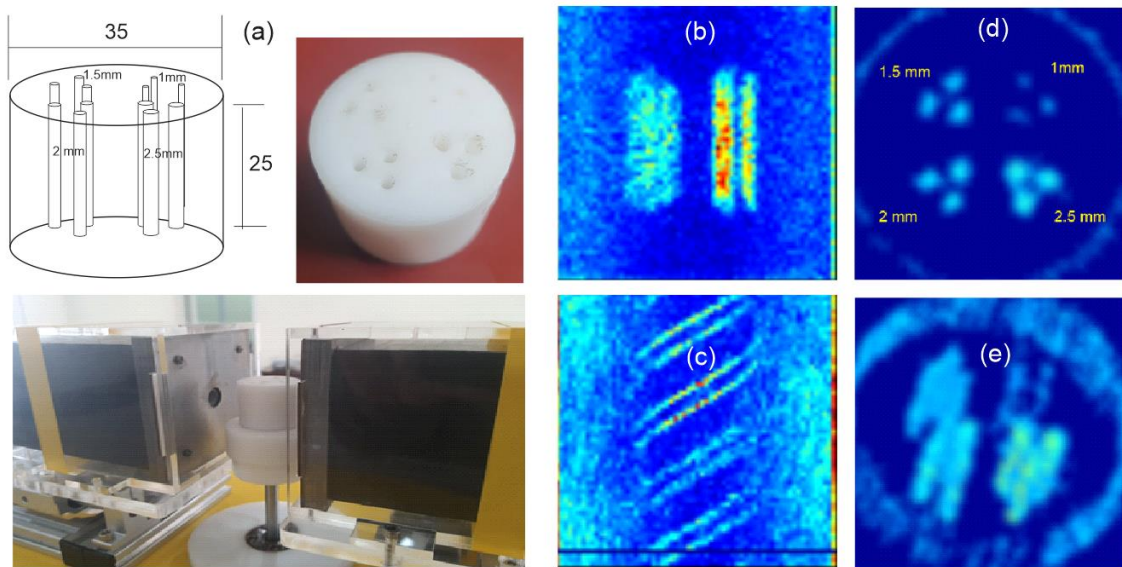


Figure 3. (a) Derenzo phantom (b) a measured projection, (c) reconstructed sonogram from projection data, (d) 2D SPECT image was reconstructed (e) 3D SPECT image of the distribution of Tc-99m in Derenzo phantom.

Figure 3(d) clearly shows the image of Tc-99m radiotracer in the 1mm-diameter hole. Therefore, the spatial resolution of the SPECT image was determined to be approximately 1mm. The image of the 2.5mm hole was more blurred due to the much higher radiotracer concentration in these holes compared to the other holes. In the figure 3(e), 3D SPECT image can distinguish columns of radiotracer at different sizes.

The results achieved by the project meet the requirements set out. However, the parameters of the device are still inferior compared to similar studies in the world,

including issues with sensitivity and spatial resolution. To manufacture a complete SPECT device that can effectively serve medical research on real mouse specimens, there are still many issues that need to be further researched and developed, including improving sensitivity to reduce measurement time, increasing the size of the detector to improve spatial resolution through image magnification coefficient, studying attenuation correction methods to improve contrast, and quantitatively determining the distribution of radioactive tracer within the research specimens.

## STUDY ON THE ANALYSIS OF SMALL AMOUNT OF RARE EARTH ELEMENTS IN FERTILIZER AND IN BREEDING FEED PRODUCTS USING ICP-MS METHOD

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### Project information:

- **Project name:** “Study on the analysis of small amount of rare earth elements in fertilizer and in breeding feed products using ICP-MS method”

- **Code:** CS/21/06-03

- **Managerial Level:** Institute

- **Duration:** 18 months (May 2021 - Nov 2022)

- **Contact email:** luanpt@canti.vn

### - Published papers related to the project:

1. Nguyen Thi Kim Dung, Phan Thi Luan, Do Tam Nhan, Nguyen Le Anh, Nguyen Giang “Determination of rare earth element traces in breeding feed using ICP-MS method”, Journal of Analytical Sciences, Vol. 27, No. 3, 2022, p.11-17, ISSN-0868-3224 (in Vietnamese);

2. Nguyen Thi Kim Dung, Phan Thi Luan, Do Tam Nhan, Nguyen Le Anh, Nguyen Giang “Study on the analysis of rare earth element traces in breeding feed using ICP-MS method”, Proceeding of the 14th Vietnam Conference on Nuclear Science and Technology, VINANST-14, Dalat city, Lam Dong, Vietnam, Dec. 9-10, 2021, Agenda and Abstracts, page 214-215.

Rare earth elements (REEs) have been studied and applied in the agriculture from the years of 1980s due to their catalytic ability for the development of plant roots and for the increase of growth as well as for the improvement of livestock production for meat (cattle) and eggs (poultry). Nowadays, REEs have been widely used in various fields, and they are indispensable ingredients in the inorganic and organic synthetic fertilizers as well as in the additives of breeding feed products. The application of REEs in the agriculture urgently requires the analytical procedures for the control of REEs composition in the products mentioned above, as well as the practical demand for a number of laboratories capable of performing these testing methods needed to be assigned by the regulatory authority. The study in this project aims to develop two standard procedures to analyze the small amount of REEs in fertilizer and in poultry feed containing rare earth products for practical testing projects, to support the applied studies of rare earth compounds in Vietnamese agriculture.

Fertilizer and feed containing rare earth product samples were pretreated by two different processes due to the different matrices. The samples of solid organic fertilizers and poultry feed samples were processed by ashing at 650°C for 4 hours before the digestion with aqua regia. The samples of solid inorganic fertilizers were finely ground, dried at  $100 \pm 5^\circ\text{C}$  to get the constant weight before being decomposed by a mixture of  $\text{HNO}_3$ ,  $\text{HClO}_4$  and HF acids. The liquid samples of foliar fertilizer were evaporated until they got dry then followed by digestion with aqua regia. The sample solutions after decomposition were evaporated to remove the excess of acid to a moist residue then were dissolved in 2%  $\text{HNO}_3$  solution and were filtered through a 0.45  $\mu\text{m}$  membrane. This sample solution was made up to the volume of 50 mL or 25 mL depending on the initial weight for each sample. Further dilution with 2%  $\text{HNO}_3$  might be made if necessary, so that the counting numbers of REEs spectroscopic mass are within the calibration range. The  $^{115}\text{In}$  internal standard was added into the sample solutions prior to the measurement in order to overcome the effect of the matrix when the simultaneous quantification of the individual REEs was carried out using the ICP-MS method.

The ICP-MS instrument was operated under the optimized conditions. When the samples and the standard solutions were measured under the identical conditions, the data obtained from instrument (ICP-MS) software were the ratio of the count at each REE mass index and the count of  $^{115}\text{In}$  internal standard.

The estimated correlation coefficient ( $R^2$ ) of the internal standard calibration curve, the instrumental detection limit (LOD), as well as the method limit of detection (MDL), the method quantification limit (MQL) and the spiked recovery in each matrix were shown in Table 1.

Table 1. The correlation coefficient (R<sup>2</sup>) of internal calibration, method detection limit (MDL), method quantification limit (MQL) and spiked recovery

| No | Index Isotope of REE | Correlation coefficient of Internal Calibration (R <sup>2</sup> ) | Limit of Detection of Instrument (LOD) (ppb) | Fertilizer Matrix                    |                                           |                    | Breeding Feed Matrix                 |                                           |                    |
|----|----------------------|-------------------------------------------------------------------|----------------------------------------------|--------------------------------------|-------------------------------------------|--------------------|--------------------------------------|-------------------------------------------|--------------------|
|    |                      |                                                                   |                                              | Method Detection Limit (MDL) (mg/kg) | Method Quantification Limit (MQL) (mg/kg) | Spike recovery (%) | Method Detection Limit (MDL) (mg/kg) | Method Quantification Limit (MQL) (mg/kg) | Spike recovery (%) |
| 1  | <sup>45</sup> Sc     | 0.9994                                                            | 0.09                                         | 0.38                                 | 1.27                                      | 106.0              | 0.36                                 | 1.19                                      | 102.3              |
| 2  | <sup>89</sup> Y      | 0.9995                                                            | 0.03                                         | 1.87                                 | 6.24                                      | 97.5               | 0.12                                 | 0.40                                      | 99.1               |
| 3  | <sup>139</sup> La    | 0.9998                                                            | 0.12                                         | 0.24                                 | 0.81                                      | 96.9               | 0.48                                 | 1.58                                      | 106.8              |
| 4  | <sup>140</sup> Ce    | 0.9999                                                            | 0.02                                         | 0.49                                 | 1.62                                      | 95.7               | 0.08                                 | 0.26                                      | 101.0              |
| 5  | <sup>141</sup> Pr    | 0.9998                                                            | 0.03                                         | 0.72                                 | 2.40                                      | 96.5               | 0.12                                 | 0.40                                      | 99.4               |
| 6  | <sup>142</sup> Nd    | 1.0000                                                            | 0.30                                         | 1.33                                 | 4.42                                      | 110.2              | 1.20                                 | 3.96                                      | 110.2              |
| 7  | <sup>152</sup> Sm    | 0.9999                                                            | 0.01                                         | 0.41                                 | 1.36                                      | 97.4               | 0.04                                 | 0.13                                      | 98.6               |
| 8  | <sup>153</sup> Eu    | 0.9997                                                            | 0.01                                         | 0.20                                 | 0.67                                      | 99.9               | 0.04                                 | 0.13                                      | 100.1              |
| 9  | <sup>158</sup> Gd    | 1.0000                                                            | 0.04                                         | 0.87                                 | 2.89                                      | 97.2               | 0.16                                 | 0.53                                      | 98.9               |
| 10 | <sup>159</sup> Tb    | 0.9999                                                            | 0.04                                         | 0.10                                 | 0.32                                      | 98.4               | 0.16                                 | 0.53                                      | 99.2               |
| 11 | <sup>164</sup> Dy    | 0.9996                                                            | 0.04                                         | 0.51                                 | 1.72                                      | 103.5              | 0.16                                 | 0.53                                      | 98.4               |
| 12 | <sup>165</sup> Ho    | 0.9999                                                            | 0.01                                         | 0.03                                 | 0.11                                      | 106.1              | 0.04                                 | 0.13                                      | 103.2              |
| 13 | <sup>166</sup> Er    | 0.9997                                                            | 0.04                                         | 0.03                                 | 0.11                                      | 98.9               | 0.16                                 | 0.53                                      | 99.1               |
| 14 | <sup>169</sup> Tm    | 0.9999                                                            | 0.05                                         | 0.02                                 | 0.06                                      | 98.8               | 0.20                                 | 0.66                                      | 98.9               |
| 15 | <sup>174</sup> Yb    | 0.9999                                                            | 0.03                                         | 0.16                                 | 0.52                                      | 97.5               | 0.12                                 | 0.40                                      | 98.5               |
| 16 | <sup>175</sup> Lu    | 0.9999                                                            | 0.05                                         | 0.04                                 | 0.13                                      | 98.9               | 0.20                                 | 0.66                                      | 98.1               |

The correlation coefficients of REE calibration curves using the internal standard technique ranged from 0.9994 to 1,0000. The recovery efficiency of each REE calculated by spiking REE standards into the matrix of fertilizer and breeding feed as well as analyzing the standard reference materials (SRM) was from 95.7 to 110.2 %, which met the requirement of the Association of Official Analytical Chemists (AOAC) guideline for method validation. The internal standard technique with  $^{115}\text{In}$  enhanced the precision of replicate measurement on fertilizer and breeding feed matrix that decreased the overall error. ICP-MS method was thus sufficient for the analysis of small amount of REEs in fertilizer and animal feed product samples.

The analysis results of the individual REE compositions in several samples of root and foliar fertilizer containing rare earth products, as well as in poultry feed containing rare earth product samples using the above studied procedures were described in Table 2 and Table 3.

Table 2. Individual REE content in some samples of fertilizer products containing rare earth

| REE       | REEs content in root fertilizers (mg/kg) |                  |                  |                |                      |
|-----------|------------------------------------------|------------------|------------------|----------------|----------------------|
|           | PBG_HC0                                  | PBG_HC1          | PBG_HC2          | PBG_VC0        | PBG_VC1              |
| Sc        | 26.7 $\pm$ 1.0                           | 33.8 $\pm$ 0.6   | 34.5 $\pm$ 2.7   | 3.8 $\pm$ 0.9  | 11.0 $\pm$ 2.2       |
| Y         | 21.2 $\pm$ 0.9                           | 25.9 $\pm$ 0.7   | 25.7 $\pm$ 0.9   | 8.3 $\pm$ 2.4  | 146.8 $\pm$ 28.6     |
| La        | 197.7 $\pm$ 36.0                         | 203.5 $\pm$ 37.2 | 237.7 $\pm$ 58.4 | 35.3 $\pm$ 4.5 | 20592.1 $\pm$ 1365.5 |
| Ce        | 287.7 $\pm$ 40.1                         | 310.6 $\pm$ 44.3 | 308.0 $\pm$ 41.6 | 69.1 $\pm$ 4.1 | 35170.6 $\pm$ 2777.5 |
| Pr        | 29.0 $\pm$ 3.2                           | 32.8 $\pm$ 3.3   | 31.9 $\pm$ 3.3   | 4.9 $\pm$ 0.6  | 1593.7 $\pm$ 112.5   |
| Nd        | 113.4 $\pm$ 9.0                          | 119.2 $\pm$ 10.5 | 118.7 $\pm$ 9.5  | 17.9 $\pm$ 1.5 | 4298.1 $\pm$ 276.6   |
| Sm        | 17.91 $\pm$ 1.2                          | 20.4 $\pm$ 1.2   | 20.3 $\pm$ 1.7   | 3.5 $\pm$ 0.2  | 411.1 $\pm$ 17.1     |
| Eu        | 5.7 $\pm$ 0.9                            | 7.0 $\pm$ 1.0    | 6.3 $\pm$ 1.0    | 0.6 $\pm$ 0.2  | 74.7 $\pm$ 1.7       |
| Gd        | 31.5 $\pm$ 3.7                           | 35.6 $\pm$ 4.5   | 35.9 $\pm$ 5.8   | 6.9 $\pm$ 0.4  | 2215.3 $\pm$ 128.2   |
| Tb        | 2.5 $\pm$ 0.2                            | 3.0 $\pm$ 0.2    | 3.1 $\pm$ 0.4    | 0.6 $\pm$ 0.1  | 74.7 $\pm$ 4.4       |
| Dy        | 8.3 $\pm$ 0.8                            | 10.2 $\pm$ 0.8   | 10.4 $\pm$ 1.0   | 2.0 $\pm$ 0.3  | 51.6 $\pm$ 0.4       |
| Ho        | 1.2 $\pm$ 0.2                            | 1.6 $\pm$ 0.1    | 1.6 $\pm$ 0.2    | 0.4 $\pm$ 0.1  | 6.4 $\pm$ 0.5        |
| Er        | 2.6 $\pm$ 0.2                            | 3.3 $\pm$ 0.2    | 3.3 $\pm$ 0.3    | 0.9 $\pm$ 0.2  | 22.4 $\pm$ 0.4       |
| Tm        | 0.3 $\pm$ 0.1                            | 0.4 $\pm$ 0.1    | 0.4 $\pm$ 0.1    | 0.1 $\pm$ 0.01 | 1.3 $\pm$ 0.2        |
| Yb        | 1.0 $\pm$ 0.2                            | 1.5 $\pm$ 0.3    | 1.8 $\pm$ 0.6    | 0.4 $\pm$ 0.3  | 6.0 $\pm$ 1.7        |
| Lu        | 0.1 $\pm$ 0.01                           | 0.2 $\pm$ 0.1    | 0.2 $\pm$ 0.1    | 0.1 $\pm$ 0.01 | 0.8 $\pm$ 0.2        |
| Total REE | 747.0                                    | 809.1            | 833.7            | 154.7          | 64676.7              |

| REE       | REEs content in foliar fertilizers (mg/kg) |                |                |                |             |             |                |
|-----------|--------------------------------------------|----------------|----------------|----------------|-------------|-------------|----------------|
|           | PBL_HC<br>0                                | PBL_HC1        | PBL_HC2        | PBL_VC1        | PBL_VC<br>2 | PBL_VC<br>3 | PBL_VC4        |
| Sc        | -                                          | -              | -              | 1.0 ± 0.2      | 1.2 ± 0.3   | 1.8 ± 0.7   | 0.4 ± 0.1      |
| Y         | -                                          | -              | -              | 72.7 ± 6.5     | 39.7 ± 6.2  | 51.1 ± 8.9  | 31.9 ± 5.1     |
| La        | 3.1 ± 0.5                                  | 4344.4 ± 221.7 | 3385.5 ± 153.4 | 6576.8 ± 298.8 | 2.7 ± 0.5   | 3.6 ± 0.5   | 1852.0 ± 76.8  |
| Ce        | 4.1 ± 0.7                                  | 5468.3 ± 392.5 | 3637.3 ± 188.9 | 8574.9 ± 367.8 | 14.3 ± 1.6  | 12.5 ± 2.7  | 3872.3 ± 176.4 |
| Pr        | 0.2 ± 0.01                                 | 444.9 ± 65.2   | 274.8 ± 38.9   | 657.3 ± 54.6   | 0.7 ± 0.2   | 0.5 ± 0.1   | 180.8 ± 34.6   |
| Nd        | 0.6 ± 0.3                                  | 1191.0 ± 95.4  | 695.5 ± 69.8   | 1804.6 ± 142.1 | 3.7 ± 0.4   | 2.2 ± 0.2   | 575.9 ± 43.5   |
| Sm        | 0.1 ± 0.01                                 | 73.2 ± 6.2     | 46.8 ± 4.5     | 151.2 ± 12.1   | 1.0 ± 0.2   | 0.6 ± 0.2   | 59.3 ± 9.8     |
| Eu        | 0.1 ± 0.01                                 | 8.9 ± 0.8      | 8.0 ± 0.8      | 30.1 ± 3.4     | 0.5 ± 0.1   | 0.3 ± 0.1   | 13.0 ± 3.9     |
| Gd        | 0.3 ± 0.01                                 | 346.7 ± 52.6   | 296.0 ± 45.3   | 618.6 ± 35.6   | 3.6 ± 0.3   | 2.3 ± 0.3   | 256.2 ± 53.7   |
| Tb        | 0.1 ± 0.01                                 | 10.8 ± 1.1     | 9.6 ± 0.9      | 24.1 ± 2.2     | 0.7 ± 0.2   | 0.4 ± 0.1   | 9.4 ± 0.7      |
| Dy        | -                                          | -              | -              | 25.6 ± 2.8     | 4.4 ± 0.3   | 3.6 ± 0.2   | 10.7 ± 0.8     |
| Ho        | -                                          | -              | -              | 3.0 ± 0.2      | 1.0 ± 0.2   | 1.0 ± 0.2   | 1.4 ± 0.2      |
| Er        | -                                          | -              | -              | 10.3 ± 0.8     | 2.9 ± 0.3   | 3.4 ± 0.3   | 4.2 ± 0.3      |
| Tm        | -                                          | -              | -              | 0.6 ± 0.2      | 0.4 ± 0.1   | 0.5 ± 0.2   | 0.3 ± 0.1      |
| Yb        | -                                          | -              | -              | 2.6 ± 0.3      | 2.5 ± 0.2   | 3.3 ± 0.4   | 1.7 ± 0.2      |
| Lu        | -                                          | -              | -              | 0.3 ± 0.1      | 0.3 ± 0.1   | 0.5 ± 0.1   | 0.2 ± 0.1      |
| Total REE | 8.3                                        | 11888.2        | 8353.6         | 18551.6        | 79.7        | 87.6        | 6868.9         |

Note: Symbol (-) denoted < MDL

The individual REEs content in organic and inorganic root fertilizers were very different, and higher than that of the reference sample (sample 0). However, this difference in foliar fertilizers was much clearer when the content of light REEs (La, Ce, Pr, Nd, Sm) was predominant in this fertilizer sample, while the content of heavy REEs (Tb, Dy, Ho,...) was either below MDL (organic foliar fertilizer samples) or quite low (inorganic foliar fertilizer samples). The content of REEs in the poultry feed matrix sample (sample CG0 in Table 3) was at the trace amount due to the contribution of rock mineral powder (gravel) as an ingredient of poultry feed.

Table 3. Individual REE content in some samples of poultry feed products containing rare earth

| REE       | REEs content (mg/kg) |             |             |             |
|-----------|----------------------|-------------|-------------|-------------|
|           | CG0                  | CG2         | CG4         | CG6         |
| Sc        | 0.1 ± 0.1            | 0.03 ± 0.02 | 0.08 ± 0.05 | 0.06 ± 0.02 |
| Y         | 0.2 ± 0.2            | 1.4 ± 0.2   | 1.3 ± 0.5   | 0.6 ± 0.5   |
| La        | 1.1 ± 0.3            | 29.1 ± 2.8  | 25.3 ± 4.9  | 17.5 ± 0.2  |
| Ce        | 2.1 ± 0.6            | 63.6 ± 6.2  | 52.6 ± 9.8  | 35.4 ± 1.3  |
| Pr        | 0.3 ± 0.1            | 7.1 ± 1.0   | 6.0 ± 1.4   | 3.9 ± 0.3   |
| Nd        | 1.0 ± 0.2            | 26.4 ± 3.6  | 22.0 ± 4.8  | 14.4 ± 1.1  |
| Sm        | 0.1 ± 0.04           | 4.8 ± 0.7   | 4.0 ± 1.0   | 2.6 ± 0.3   |
| Eu        | 0.02 ± 0.01          | 0.2 ± 0.02  | 0.2 ± 0.02  | 0.2 ± 0.04  |
| Gd        | 0.2 ± 0.07           | 7.6 ± 1.2   | 6.6 ± 1.7   | 4.1 ± 0.6   |
| Tb        | 0.02 ± 0.01          | 0.5 ± 0.1   | 0.4 ± 0.1   | 0.3 ± 0.04  |
| Dy        | 0.08 ± 0.07          | 1.1 ± 0.2   | 1.0 ± 0.25  | 0.6 ± 0.1   |
| Ho        | 0.01 ± 0.01          | 0.1 ± 0.02  | 0.1 ± 0.03  | 0.1 ± 0.01  |
| Er        | 0.02 ± 0.01          | 0.2 ± 0.03  | 0.2 ± 0.1   | 0.1 ± 0.02  |
| Total REE | 6.0                  | 151.1       | 127.7       | 84.7        |

The product of this project consists of two basic standards named “Fertilizers containing small amount of rare earth elements – Determination of rare earth elements Content by Inductively Coupled Plasma-Mass Spectrometer (ICP-MS)” (TCCS-REEFERTILIZER-2022) and “Poultry Feed containing small amount of rare earth elements – Determination of rare earth elements Content by Inductively Coupled Plasma-Mass Spectrometer (ICP-MS)” (TCCS-REEPOULTRYFEED-2022), which have been built up and approved by VILAS-519 for the laboratory use. In near future, these basic standards would be further studied and developed in order to be approved by the ministry of Science and Technology as the national standards on rare earth elements testing method for the control of quality of fertilizer and breeding feed containing rare earth elements in the domestic market.

## APPLICATION AND DEVELOPMENT OF TECHNOLOGICAL PROCESS FOR EXTRACTION AND SEPERATION OF RARE EARTHS FROM TOTAL RARE EARTHS BEN DEN

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### Project information:

- **Project name:** Application and development of technological process for extraction and seperation of rare earths from total rare earths Ben Den
- **Code:** ĐTCB.07/21/VCNXH
- **Managerial Level:** Ministry
- **Duration:** 24 months (Jan 2020- Dec 2020)
- **Contact email:** lxdinh79@gmail.com
- **Published papers related to the project**

1. Nguyen Van Tung, Nguyen Dinh Viet, Ngo Quang Huy, Nguyen Thi Lien, Bui Cong Trinh, Luu Xuan Dinh, "Calculation, design and manufacture of system box-type mixer-settler used in rare earth solvent extraction process at laboratory scale", Proceedings of the 14th Vietnam Conference on Nuclear Science and Technology, Da Lat, Vietnam, 2021, p228.

2. Nguyen V.T., Nguyen D.V., Ngo Q.H., Nguyen T.L., Luu X.D, "Separation of Nd from mixture chloride solution with 70% saponified PC88A: mixer-settler experiments", J. Internauka, 42(265) 2022. DOI:10.32743/26870142.2022.42.265.347248

3. Nguyen Van Tung, Nguyen Dinh Viet, Ngo Quang Huy, Nguyen Thi Lien, Bui Cong Trinh, Luu Xuan Dinh, "Calculation, design and manufacture of system box-type mixer-settler used in rare earth solvent extraction process at laboratory scale", Nuclear Science and Technology (in Vietnamese) (accepted).

This study presents the results of solvent extraction process to obtain rare earth elements of La, Pr, Nd, Sm, Dy and Gd from chloride solution (dissolved from total rare earth oxides in Ben Den) by using PC88A (concentration 20%, diluted in IP2028) 70% saponification. For this purpose, two box-type mixer-settler systems which were used in this research include a 120-stage system (Japan supported) and a 100-stage system (manufactured by Vietnam). (Fig.1.)



(a) Box-type mixer-settler 120 stage-system  
(Japan supported)



(b) Box-type mixer-settler 100 stage-system  
(Vietnam manufactured)

Figure 1. Extraction equipment systems.

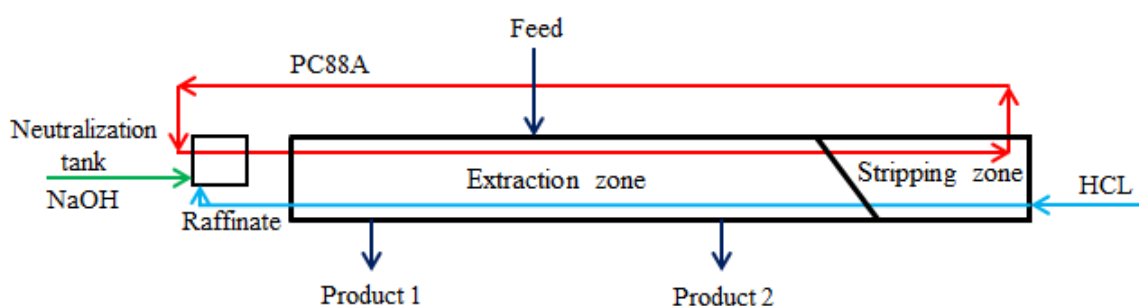


Figure.2. Extraction flow of rare earth elements.

Rare earth solvent extraction flowsheets usually consist of a saponification stage, an extraction stage, a scrub stage, and a strip stage. Saponification is a pre-treatment step for pH control during extraction. The extraction stage provides bulk separation of the desired rare earths (REE) from the aqueous phase. The spent aqueous phase exits the extraction section as the raffinate. Loaded organic solvent enters the scrub stage, where undesirable REE that were co-extracted in the extraction stage are scrubbed from the loaded organic phase. Scrubbing is accomplished by contacting the loaded organic phase with an aqueous solution that alters the acid or REE equilibrium conditions. Undesired REE species are transferred to the aqueous phase, which is typically recombined with the extraction aqueous feed to recover any desired REE that were unintentionally scrubbed out of the loaded organic phase. Finally, the scrubbed loaded organic enters the strip stage, where the REE is recovered from the organic phase as a rich liquor (RL) product. The organic phase, now stripped of any solutes, is recycled for reuse.

Based on the analytical calculation method, the extraction parameters for each stage have been calculated including:

- ✓ Number of stages of extracting, scrubbing and tripping
- ✓ Solvent flow rate, feed solution flow (rare earth chloride solution), 4.5N NaOH and 4N HCl solutions flow.

- ✓ Flow of feeding and taking products.

Total rare earths Ben Den was used as raw materials for the extraction and separation of rare earth elements. The feed solution has the same composition as in Table 1. The composition of rare earth elements La, Pr, Nd, Sm, Dy and Gd is 36.12%; 7.21%; 23.62%; 5.03%; 2.85% and 4.79%, respectively. The main impurity is Ca, but it does not affect the extraction and separation of rare earth elements.

Table 1. Rare earth content and composition for initial feed solution

| Elements     | Content (ppm)    | Composition (%) | Elements | Content (ppm) |
|--------------|------------------|-----------------|----------|---------------|
| Sc           | 0.08             | 0.03            | Al       | 4.63          |
| Y            | 13518.75         | 12.16           | Fe       | 0.08          |
| La           | 46676.51         | 36.20           | Mg       | 1.07          |
| Ce           | 338.76           | 1.00            | Si       | 30.33         |
| Pr           | 5601.83          | 7.21            | Ca       | 8690.71       |
| Nd           | 21402.62         | 23.62           |          |               |
| Sm           | 3853.83          | 5.03            |          |               |
| Eu           | 485.70           | 0.42            |          |               |
| Gd           | 3691.11          | 4.79            |          |               |
| Tb           | 591.73           | 0.57            |          |               |
| Dy           | 2898.72          | 2.85            |          |               |
| Ho           | 537.76           | 0.44            |          |               |
| Er           | 1063.95          | 1.05            |          |               |
| Tm           | 123.63           | 0.11            |          |               |
| Yb           | 655.61           | 0.57            |          |               |
| Lu           | 81.07            | 0.07            |          |               |
| <b>TREEs</b> | <b>101521.50</b> | <b>100.00</b>   |          |               |

The extraction process diagram was shown in Fig.3. The specific extraction process was as follows:

- ✓ Stage 1: Separation of the La-Nd/Sm-Y group from the initial feed solution (table 1)
- ✓ Stage 2: Separation of La from La-Nd group to obtain  $\text{LaCl}_3$  product
- ✓ Stage 3: Separation of Ce from Ce-Nd group
- ✓ Stage 4: Separation of Pr and Nd from Pr-Nd group to obtain  $\text{PrCl}_3$  and  $\text{NdCl}_3$  individual products.
- ✓ Stage 5: Separation of the Sm-Dy/Ho-Y group
- ✓ Stage 6: Separation of Sm from Sm-Dy group to obtain  $\text{SmCl}_3$  product.
- ✓ Stage 7: Separation of Dy from Eu-Dy group to obtain  $\text{DyCl}_3$  product.
- ✓ Stage 8: Separation of Tb from Eu-Tb group.
- ✓ Stage 9: Separation of Eu-Gd group to obtain  $\text{GdCl}_3$  product.

The stages from (1) to (4) were performed on a 120-stage system, and the stages from (5) to (9) were performed on a 100-stage system.

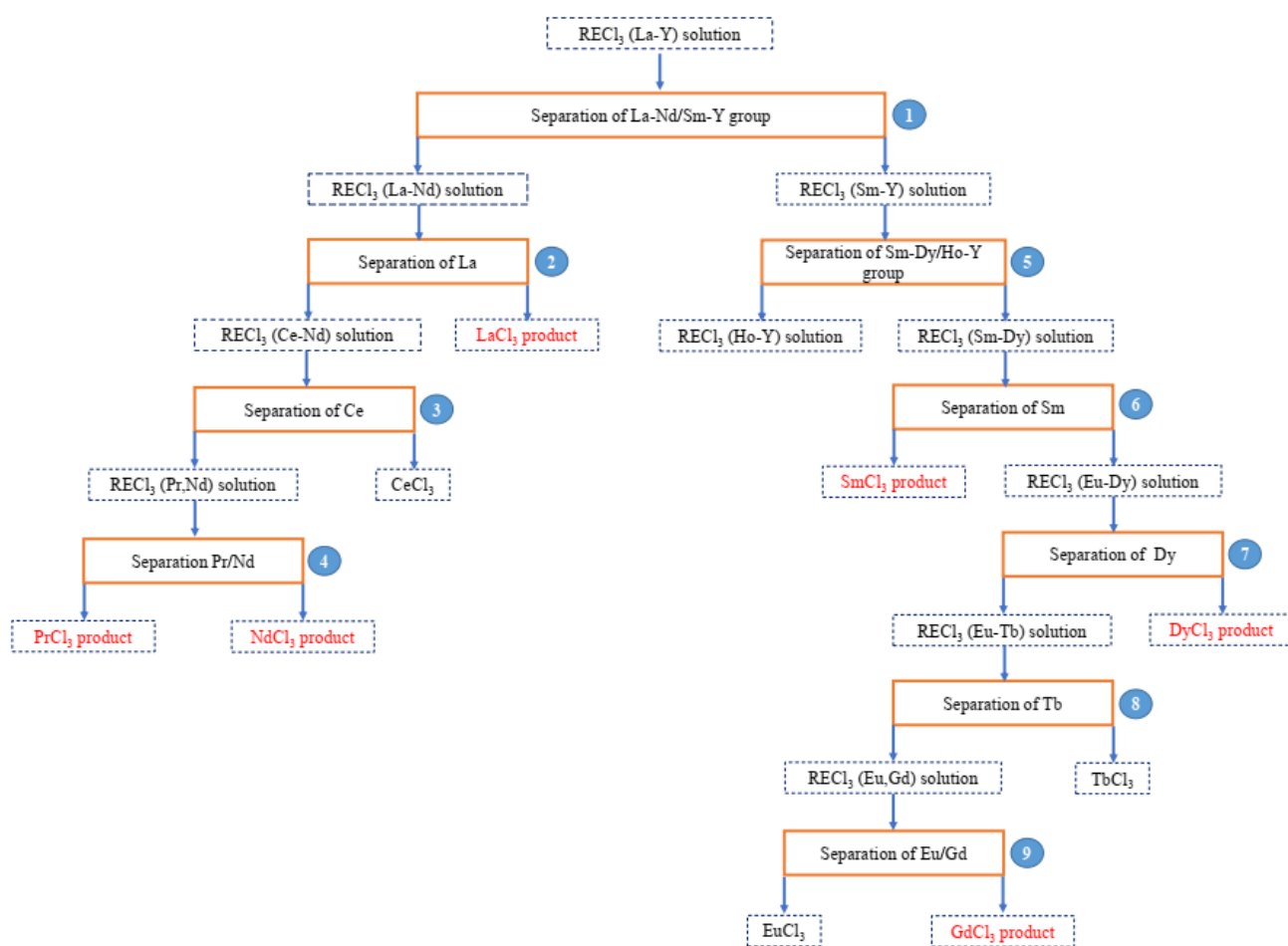


Figure 3. Flowchart of the technological process for extraction and collection of La, Pr, Nd, Sm, Dy and Gd from the total rare earth Ben Den.

The rare earth products include: La, Pr, Nd, Sm, Dy and Gd. Rare earth solutions containing individual elements were precipitated as carbonate and calcined to decompose into oxides. The obtained products were analyzed for purity. The obtained results were shown in Table 2. The obtained results showed that the purity of the individual rare earth oxide products is more than 99%.

Table 2. Summary of products of the extraction and division of rare earth elements from the total rare earth Ben Den.

| Number | Rare earth oxides               | Weight (g) | Purity (%) |
|--------|---------------------------------|------------|------------|
| 1      | La <sub>2</sub> O <sub>3</sub>  | 2100       | 99.73      |
| 2      | Pr <sub>6</sub> O <sub>11</sub> | 592        | 99.38      |
| 3      | Nd <sub>2</sub> O <sub>3</sub>  | 1100       | 99.45      |
| 4      | Sm <sub>2</sub> O <sub>3</sub>  | 120        | 99.17      |
| 5      | Dy <sub>2</sub> O <sub>3</sub>  | 105        | 99.11      |
| 6      | Gd <sub>2</sub> O <sub>3</sub>  | 145        | 99.24      |

**STUDY ON THE DETERMINATION OF TRACE AMOUNT OF SOME RARE EARTH ELEMENTS RESIDUE IN MEAT AND SOME PIG ORGANS USING FEED CONTAINING RARE EARTHS BY ICP-MS METHOD**

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**Project information:**

**- Project name: “Study on the determination of trace amount of some rare earth elements residue in meat and some pig organs using feed containing rare earths by ICP-MS method”**

**- Code: CS/22/03-01**

**- Managerial Level: Institute**

**- Duration: 12 months (Jan 2022- Dec 2022)**

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

1. Ngo Quang Huy, Nguyen Thi Lien, Nguyen Thi Men, Nguyen Thi Hang, Do Thi Anh Tuyet, Le Quoc Viet, Tran Hoang Mai, Phung Vu Phong, “Determination of trace amount of some rare earth elements in meat and pig organs using feed containing rare earths by ICP-MS techniques”, Journal of Analytical Sciences, No.4, ISSN-0868-3224 (inVietnamese);

2. Ngo QuangHuy, Nguyen Thi Lien, Nguyen Thi Men, Le Quoc Viet, Nguyen Nho Lan, Nguyen Thi Hang, Do Thi Anh Tuyet, Tran Hoang Mai, Phung Vu Phong, “Studying on process for determination of trace contents of some rare earth elements in meat and some pig organs by ICP-MS”, reported inthe 7th Conference of Nuclear Science and Technology for young researcher, 6-7, Oct. 2022, Hanoi, Vietnam.

Rare earth elements (REEs) have been widely used in industry (such as electronics, superconductors, catalysts, ceramics...), in medical (making medicine and herbal medicine) and in agriculture (fertilizer, animal husbandry). The extensive use of rare earths in fertilizer and feed additives have brought many benefits and economic values. However, the accumulation of rare earth elements has increased in environmental and some biological tissues might cause the high risks to human health through the food chain. The median lethal dose (LD50) was reported between 10 and 7650 mg/kg for different kinds of REE metals or their different types of compounds. Therefore, the project “*Study on the determination of trace amount of some rare earth elements residue in meat and pig organs using feed containing rare earths by ICP-MS method*” was carried out.

The optimization of ICP-MS operating conditions, the digestion of pork and pig organs sample with acidic solutions of HNO<sub>3</sub> 65% and H<sub>2</sub>O<sub>2</sub> 30% using microwave ovens or kjeldahl flasks on hot plate were carried out. Pork and pig organs samples were carefully hand-cleaned, oven - dried at 100±5°C for 4 hours, then ground and stored at 0-4°C. Due to the advantages of , minimizing analyte cross-contamination and time consuming the microwave ovens technique was applied in further studies with the following procedure: about 0.5grs of sample was placed in a teflon pressure vessel with 3ml HNO<sub>3</sub> 65% and 2ml H<sub>2</sub>O<sub>2</sub> 30%, and the working condition of microwave power at 400W for 12 minutes. After being allowed to cool, the samples were diluted to 25ml with deionized water and filtered before analysis by ICP-MS.

The results of correlation coefficient (R<sup>2</sup>), the method detection limit (MDL), the method quantification limit (MQL) and the recovery were shown in Table 1.

Table 1. The correlation coefficient (R<sup>2</sup>), method detection limit (MDL), method quantification limit (MQL) and the recovery

| Element | Correlation coefficient (R <sup>2</sup> ) | Limits of detection (µg/kg) | Limits of quantification (µg/kg) | Spike recovery (%) | Element | Correlation coefficient (R <sup>2</sup> ) | Limits of detection (µg/kg) | Limits of quantification (µg/kg) | Spike recovery (%) |
|---------|-------------------------------------------|-----------------------------|----------------------------------|--------------------|---------|-------------------------------------------|-----------------------------|----------------------------------|--------------------|
| Sc      | 0.9999                                    | 0.153                       | 0.509                            | 100.3              | Gd      | 0.9997                                    | 0.028                       | 0.092                            | 99.9               |
| Y       | 0.9999                                    | 0.020                       | 0.066                            | 99.3               | Tb      | 0.9999                                    | 0.160                       | 0.534                            | 100.2              |
| La      | 1.0000                                    | 0.092                       | 0.306                            | 113.8              | Dy      | 0.9999                                    | 0.065                       | 0.217                            | 100.4              |
| Ce      | 0.9999                                    | 0.049                       | 0.164                            | 113.0              | Ho      | 1.0000                                    | 0.019                       | 0.063                            | 100.2              |
| Pr      | 0.9999                                    | 0.137                       | 0.458                            | 112.7              | Er      | 0.9998                                    | 0.022                       | 0.072                            | 100.9              |
| Nd      | 0.9996                                    | 0.401                       | 1.336                            | 99.5               | Tm      | 1.0000                                    | 0.015                       | 0.049                            | 100.0              |
| Sm      | 0.9999                                    | 0.148                       | 0.494                            | 99.9               | Yb      | 0.9998                                    | 0.019                       | 0.062                            | 100.5              |
| Eu      | 0.9998                                    | 0.049                       | 0.164                            | 100.7              | Lu      | 0.9998                                    | 0.015                       | 0.052                            | 100.1              |

The correlation coefficient was calculated from the calibration curves with values from 0.9997 to 1.0000 for ICP-MS. The recovery was obtained between 81.6 and 107.3 % by the certified reference material (CRM-BCR-668). The results showed that the ICP-MS technique is suitable for the analysis of trace amounts of REEs in pork and some pig organs samples.

The results of analysis of some REEs in meat samples and some pig organs (kidney, meat, spleen, lung, liver, heart) showed that the contents of Sm to Lu were low (0.07 to 4.93 µg/kg) and the content of Sc to Nd were high (6.03 to 248.07 µg/kg) in the meat and pig organs. The contents of the REEs in liver (15.33 ± 0.59µg/kg of Sc, 12.78 ± 0.42µg/kg of Y, 248.07 ± 8.66µg/kg of La, 97.81 ± 4.53µg/kg of Ce, 18.33 ± 1.85µg/kg of Pr) were higher than REEs in meat and other organs at a statistical significance (Table 2).

Table 2. REEs content in meat and some pig organs samples

| Element | Content in Fresh Weight ( $\mu\text{g/kg}$ ) |                  |                   |                   |                  |                   |
|---------|----------------------------------------------|------------------|-------------------|-------------------|------------------|-------------------|
|         | Kidney sample                                | Lung sample      | Meat sample       | Liver sample      | Spleen sample    | Heart sample      |
| Sc      | $11.40 \pm 0.64$                             | $13.15 \pm 0.47$ | $12.37 \pm 0.79$  | $15.33 \pm 0.59$  | $11.52 \pm 0.63$ | $14.95 \pm 1.08$  |
| Y       | $11.51 \pm 0.66$                             | $6.94 \pm 0.18$  | $13.41 \pm 0.66$  | $12.78 \pm 0.42$  | $10.22 \pm 0.16$ | $18.98 \pm 0.99$  |
| La      | $61.43 \pm 1.06$                             | $50.05 \pm 0.71$ | $75.77 \pm 0.47$  | $248.07 \pm 8.66$ | $55.68 \pm 0.53$ | $105.16 \pm 3.12$ |
| Ce      | $45.93 \pm 1.28$                             | $39.98 \pm 1.01$ | $124.11 \pm 0.81$ | $97.81 \pm 4.53$  | $60.24 \pm 0.43$ | $141.20 \pm 1.73$ |
| Pr      | $17.81 \pm 0.41$                             | $9.39 \pm 0.37$  | $15.84 \pm 0.34$  | $18.33 \pm 1.85$  | $12.26 \pm 0.16$ | $36.08 \pm 0.42$  |
| Nd      | $8.18 \pm 0.84$                              | $7.82 \pm 0.33$  | $16.02 \pm 0.88$  | $21.68 \pm 1.31$  | $11.10 \pm 0.26$ | $27.03 \pm 1.12$  |

The REEs content in some pig organs samples (liver, heart, spleen, kidney) using feed containing rare earth elements were about two to three times higher than the compared samples (without using feed containing rare earth elements). The REEs content in the meat sample were negligible.

In summary, within the project framework, our study has developed the procedure of determining trace amount of REEs in meat and some pig organs by ICP-MS technique. In addition, the study has contributed its data to the dataset tracking the accumulation of rare earths in agricultural products. Accordingly, it is possible to calculate the appropriate amount of rare earths to use in animal husbandry to improve productivity and minimize the impact on human health.

In the future, we will continue to do further research on the accumulation of rare earth elements in other agricultural products with inputting rare earth.

## SYNTHESIS OF SOME RARE EARTH COMPLEXES FOR MAKING RARE EARTH BIOFERTILIZERS AND TESTING THEIR EFFICACY ON MEDICAL PLANTS

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### Project information:

- **Project name:** “Synthesis of some rare earth complexes for making rare earth micro organic fertilizers and testing their efficacy on medicinal plants”

- **Code:** DTCTB.20/22/TTCXHN

- **Managerial Level:** Ministry

- **Duration:** 24 months (Jun 2020 - May 2022, extended 9 months to 28th Feb, 2023)

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

1. Pham Quang Minh, Vuong Huu Anh, Ngo Van Tuyen, Cao Dinh Thanh, Phung Vu Phong, Duong Dinh Tho, “Synthesis of glutamate rare earth complexes from total Dongpao rare earth carbonates and additional application to organic fertilizers for Morinda Officinalis”, Journal of Chemistry and Application, 2023.

2. Vuong Huu Anh, Ngo Van Tuyen, Cao Dinh Thanh, Nguyen Huu Duc, “Research on the synthesis of rare earth glutamate complexes (La, Ce) from rare earth carbonates (La, Ce)”, 14th Vietnam Conference on Nuclear Science and Technology, 2021.

Rare earth products are widely applied in the industry and agriculture, and rare earth applications in agriculture have been studied both at domestic and foreign. The use of organic ligands bonding rare earth, especially, lactate and glutamate rare earth complexes have been studied and applied on agricultural plants. These are organometallic complexes that it is easily absorbed and good adhesion on leaves, increasing the effectiveness of rare earth micronutrient fertilizers. Based on the real requirements and research capability, the project “Synthesis of some rare earth complexes for making rare earth micro organic fertilizers and testing their efficacy on medical plants” were carried out.

The synthesis reaction of the rare earth glutamate and lactate complexes is based on the reaction of the activated rare earth hydroxides with glutamic acid and lactic acid from the raw material which is the total rare earth carbonate obtained from the

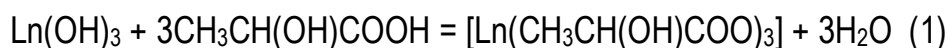
preparation process DongPao rare earth ore ( $\text{La}_2\text{O}_3$  18.35%;  $\text{CeO}_2$  29.12%,  $\text{Nd}_2\text{O}_3$  6.93%;  $\text{Pr}_2\text{O}_3$  3.53%).

The synthesis processing of complexes are two steps:

Step 1: Dissolution of rare earth carbonate and precipitation of the activated rare earth hydroxides

Step 2: The synthesizing of rare earth complexes from the activated rare earth hydroxides with glutamic acid and lactic acid

- The reaction equation between rare earth hydroxides and lactic acid:



- The reaction equation between rare earth hydroxides and glutamic acid:

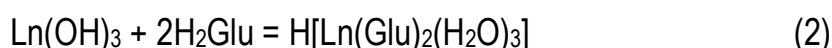


Diagram of technological for synthesizing rare earth lactate and rare earth glutamate: (Fig1.)

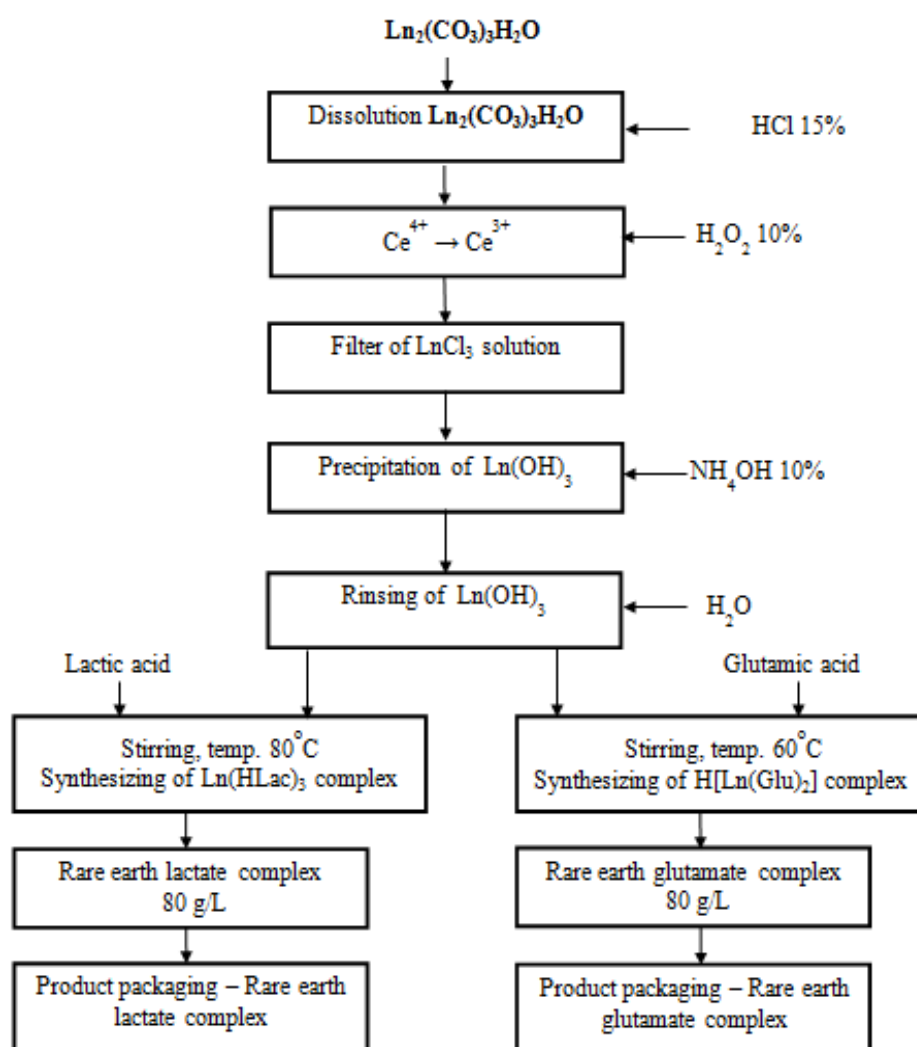


Figure 1. Diagram of technological for synthesizing rare earth lactate and rare earth glutamate

The synthesizing conditions of at the scale of 10kg of input materials/batch with technological parameters are shown in Table1.

Table 1. The synthesizing conditions of rare earth complexes

| Parameter             | Value                        |                            |
|-----------------------|------------------------------|----------------------------|
|                       | Rare earth glutamate complex | Rare earth lactate complex |
| pH reaction           | 6,5                          | 4,5-5                      |
| Temperature reaction  | 60°C                         | 80°C                       |
| Molar ratio (acid/Ln) | 2,15/1                       | 3/1                        |
| Time reaction         | 6 hours                      | 5 hours                    |
| Efficiency            | 90%                          | 90%                        |
| Product weight        | 20kg crystal                 | 19 kg crystal              |

By the obtained products, the procedure of making root organic fertilizers containing rare earth microelements based on organic fertilizer of *Thin Phat Fertilizer Joint Stock Company* and the basic standard (TCCS) about the root fertilizer containing rare earths with 200ppm total rare earth content were built. At the same time, the procedure of making foliar fertilizers containing rare earth microelements and TCCS about the foliar fertilizer with 12000ppm total rare earth content.

The organic root fertilizer and foliar fertilizer containing rare earth glutamate and rare earth lactate complexes were tested at the narrow area on the growth of 2 years old *Camellia chrysantha* and 3 months old *Morinda officinalis* in nursery to the field. The results showed that the rare earth glutamate fertilizes micronutrient supplement is suitable for foliar application. The best dosage application is 200 ppm total rare earth oxides content, equivalent to 160g/ha.

The model of organic root fertilizer containing rare earth glutamate and foliar fertilizer containing rare earth lactate were built and tested for 10 years old *Camellia chrysantha* in BaChe, and about 5 years old *Morinda officinalis* in SocSon, 3 years old *Morinda officinalis* in Ba Che, 1.5 years old in Dong Hy, Thai Nguyen.

Table 2. Evaluation of changes in number of buds (flowers) and yield of dried flowers

| Formula  | Buds number /tree | Yeild of dried flowers (kg/tree) | Yeild of dried flowers (kg/500m <sup>2</sup> ) |
|----------|-------------------|----------------------------------|------------------------------------------------|
| CT1- ĐC  | 1050±58           | 1.060±0.12                       | 159.0±18.0                                     |
| CT2 - ĐH | 1128±62           | 1.182±0.15                       | 177.3±22.5                                     |

Table 3. Effect of rare earth fertilizers on growth and yield of *Morinda officinalis*

| Form<br>ula | Tree morphology                                                           | Root<br>diameter<br>(cm) | Number of<br>fruits for<br>seed<br>collection<br>/tree | Yield of<br>fresh<br>roots<br>(kg/tree) | Yield of fresh<br>roots<br>(kg/500m <sup>2</sup> ) |
|-------------|---------------------------------------------------------------------------|--------------------------|--------------------------------------------------------|-----------------------------------------|----------------------------------------------------|
| CT1-<br>ĐC  | many canopy, forms<br>large bush                                          | 1.43±0.43                | 15.4±6.71                                              | 2.55±0.35                               | 1530.0 ±63.5                                       |
| CT2-<br>ĐH  | many canopy , forms<br>large bush. Dark green,<br>thicker, foliage growth | 2.05±0.68                | 18.5±5.93                                              | 2.9±0.52                                | 1740.0±70.4                                        |

The results demonstrated a significant enhancement in the quality and productivity of the medical plants, such as: the yield of fresh root (*Morinda officinalis*) were increased by 13.7% in Ba Che, the *Morinda officinalis* were grown well compared the control sample in Soc Son and Dong Hy. The content of rutin in camellia flowers were increased by about 8%, and the content of Nystose in roots (*Morinda officinalis*) were increased by about 2% in Ba Che. Rare earth residues in leaves and flowers (*Camellia chrysantha*), and roots (*Morinda officinalis*) were not much different from the control sample.

Using of foliar fertilizers, root fertilizers containing rare earth microelements were improved efficiency and economic benefits on medicinal plants cultivation (*Camellia chrysantha*, *Morinda officinalis*), so it is recommended to medicinal plant growing areas should add rare earth micro organic fertilizers to the conventional cultivation methods.

## ASSESSMENT ABILITY TRIAZOLE FUNGICIDES-DEGRADATION OF AEROBIC BACTERIA STRAINS ISOLATED FROM THE AGRICULTURAL SOIL IN DA LAT

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### Project information:

- Project name: Luong Thi Tham
- Code: CS/22/01-01
- Managerial Level: Institute
- Duration: 12 months (Jan 2022 - Dec 2022)
- Contact email: luongtham0710917@gmail.com
- Published papers related to the project:

1. Luong Thi Tham, Nguyen Thi Hong Tham, Nguyen Tien Dat, Nguyen Viet Duc, Le Van Toan, Nguyen Le Hoai Bao, Nguyen Thuy Huong Trang, Assessment ability triazole fungicides-degradation of bacteria strains isolated in Da Lat, The 7th Conference on Nuclear Science and Technology for young researchers in the atomic energy, Ha Noi, Vietnam, 2022.
2. Luong Thi Tham, Nguyen Thi Hong Tham, Investigating the triazole fungicides decomposing ability of some bacterial strains isolated from agricultural soil in da lat, Vietnam national conference on biotechnology 2022, Dak Lak, Vietnam, 2022.
3. Luong Thi Tham, Nguyen Thi Hong Tham, Investigating the ability to decompose fungicides and plant growth-promoting of microbial strains isolated from vegetable soil in Da Lat, Vietnam national conference on biotechnology 2022, Dak Lak, Vietnam, 2022
4. Luong Thi Tham, Nguyen Tien Dat, Nguyen Thi Hong Tham, Nguyen Viet Duc, Le Van Toan, Nguyen Thuy Huong Trang, Nguyen Le Hoai Bao, Pham Thi Hong Trang, Ho Thanh Tam. Assessment ability triazole fungicides-degradation of bacteria strains isolated in Da Lat. DTU Journal of Science & Technology, Vol 55, 2022, (in Vietnamese).

Triazole fungicides are widely applied for various crops to control plant diseases. At present, over a quarter of the estimated global fungicides are triazole fungicides due to their high efficiencies. However, the triazole fungicides can migrate and accumulate in the soil as a source of persistent organic pollutants, because of their high stability, long chemical and photochemical half-lives. Da Lat, known as one of the leading high-tech agricultural development localities in Vietnam, but its famous agricultural zones with high quality vegetable and flower products are being polluted by the agro-chemical residues.

The abuse of pesticides for a long time in agriculture production has resulted in their accumulation in the soil, contaminating the soil and water resources, adversely affecting to the quality of agricultural products. Fortunately, it was found that the fungicides can be degraded by some soil bacteria and fungi, and their degradation capabilities are much affected by environmental factors such as pH, temperature, temperature, moisture, nutrient content... Therefore, fungicide degrading bacteria must be isolated, and their degrading capacities for specific fungicide should be evaluated in order to produce the microbial products for soil conditioner.

In this study, 100 µg/L of triazole (hexaconazole, propiconazole and difenoconazole) was supplemented as the sole carbon source into MSM broth medium for the growth of triazole degrading bacteria. The most effective degrading bacterial strains were isolated from the MSM agar supplemented with hexaconazole, propiconazole and difenoconazole at increasing concentrations (100, 200, 300, 400 and 500 µg/L) by screening with repetitive subculture. The triazole degrading capacity bacteria was estimated by the residues of hexaconazole, propiconazole and difenoconazole remaining in the culture by gas chromatography. The 16S rRNA gene sequencing method was applied to identify the isolated bacteria.

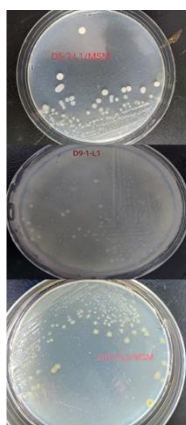


**Figure 1:** Colony morphology of 3 isolates on MSM agar

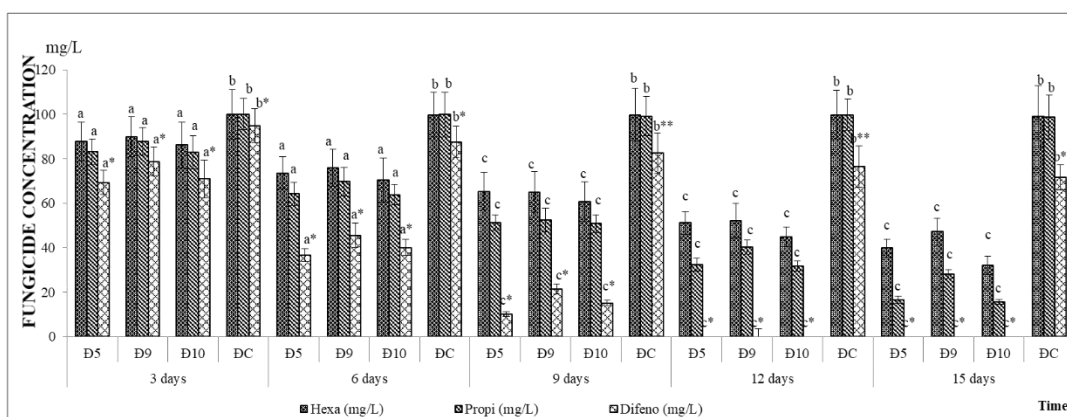


**Chart 1:** Evaluation of the ability to degrade Triazole fungicide active ingredients of 3 bacterial strains D5-2-L1, D9-1-L1 and D10-3-L2 in MSM+100 mg/L medium (Hexaconazole), Propiconazole and Difenoconazole), after 15 days of culture

As the results, 16 aerobic bacteria strains capable of decomposing triazole were isolated from 10 soil samples for vegetables and flowers production in Da Lat. Among them, there are 3 strains with symbols D5-2-L1, D9-1-L1 and D10-3-L2, showed the strongest growth ability on all media supplemented with hexaconazole, propiconazole and difenoconazole at various concentrations were identified (Figure 1). These three strains can degrade more than 50% of triazole (hexaconazole, propiconazole and difenoconazole) in the culture medium supplemented with triazole at 100 mg/L after 15 days (Chart 1). The sequencing results of the 16S rRNA gene of the identified triazole degrading bacteria showed the D5-2-L1, D9-1-L1 and D10-3-L2 belong to *Klebsiella* sp., *Citrobacter* sp., and *Pseudomonas aeruginosa*. This experiment provided further

evidence on the effect of the fungicide on plant growth. High doses of triazole significantly reduced the number of aerobic microorganisms in the soil. The isolated bacteria can eliminate or neutralize the adverse effects of these triazole fungicides on plants. Therefore, these 3 triazole degrading bacteria strains can be utilized to prepare the microbial fertilizers for soil condition due to their plant growth and triazole degrading capacities.

Based on our results, further studies should be done to clarify the impacts of isolated bacterial strains on the soil, as well as the yield and quality of agricultural products for preparation of the microbial fertilizers for soil condition and control the adverse effects of the pesticide residues in agricultural soils.

## PREPARATION OF NANOLIPOSOMES ENCAPSULATING NATURAL RADIOPROTECTANTS FOR SUPPORTING RADIOTHERAPY IN CANCER TREATMENT

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### Project information:

- **Project name:** Preparation of nanoliposomes encapsulating natural radioprotectants for supporting radiotherapy in cancer treatment
- **Code:** ĐTCB.11/21/VNCHN
- **Managerial Level:** Ministry
- **Duration:** 24 months (Jan 2021- Dec 2022)
- **Contact email:** jackminhhiep@yahoo.com
- **Published papers related to the project:**

1. Minh-Hiep Nguyen, Ngoc-Duy Pham, Quang-Tuan Che, Thi-Huynh-Nga Nguyen, Ngoc-Bich-Dao Vu, Thi-Ngoc-Mai Tran, Thanh-Kieu Trinh, Ngoc-Ai Trinh, Bao-Ngoc Pham, Van-Dong Le. Liposomal silibinin as a potential radioprotector for human lymphocytes in treating non-small-cell lung cancer. International Journal of Radiation Research, Vol 20(3), (2022), 521–529.

2. Nguyen Minh Hiep, Pham Ngoc Duy, Vu Ngoc Bich Dao, Tran Thanh Mai, Tran Thi Ngoc Mai, Nguyen Thi Huynh Nga. Investigation of the radioprotection for human lymphocytes and human fibroblasts of resveratrol-encapsulated liposomes. TNU Journal of Science and Technology, Vol 227, (2022), 137–145 (in Vietnamese).

Although there are outstanding methods for cancer treatment, radiotherapy (RT) continues to play an important role. In RT, cancer cells are destroyed by high-energy ionizing rays such as gamma rays, X-rays, electron beams, etc. However, RT also has adverse effects on human lymphocytes (resulting in an increased likelihood of infectious diseases) as well as human skin (affecting more than 80% of patients receiving RT and influencing more or less the quality of their lives). Therefore, the development of a novel formulation to alleviate the side effects of ionizing radiation on human lymphocytes and skin cells during RT will improve patient health as well as the practical effectiveness of RT.

Natural active compounds such as curcumin (CUR), silibinin (SIL), astaxanthin (AST),  $\alpha$ -tocopherol (TOC), quercetin (QUE) and resveratrol (RES) have been attracting attention to be used as natural radioprotector (NRPs) in recent years. However, most of these compounds exhibit poor water solubility, low penetration into cells/tissues, and relatively low stability under environmental conditions. Therefore, to overcome these problems, these NRPs have been encapsulated into liposomes (Lip), which is one of the most suitable nanocarrier systems for pharmaceutical application. In addition, it has been demonstrated that the encapsulation of NRPs into Lip could enhance their radioprotective ability compared to their native form, but before now no study has compared the radioprotective effects of the liposomal forms of CUR, SIL, AST, TOC, QUE and RES as well as their binary combined formulations. In addition, there has been no study to simultaneously evaluate their effects on cancer cells. These are the reasons why this study has been carried out.

In this study, rotary vacuum evaporator (IKA RV6, Germany), probe sonicator (Ultrasonic Liquid Processor VC 750, Sonics & Materials, USA), high-performance liquid chromatography (HPLC) LC-20AD (Shimadzu, Japan), fluorescence microscope (Axio Imager Z2, Carl Zeiss, Germany), light microscopy (Nikon Eclipse 80i, Nikon, Japan) were used. In addition, CUR (95% purity), SIL (98% purity), AST (97% purity), TOC (96% purity), QUE (95% purity), RES (99% purity), Anti-phospho-Histone H2A.X (Ser139) clone JBW301 antibody, and Alexa Flour 488 goat anti-mouse IgG antibody obtained from Sigma Aldrich (USA), and Phospholipon® 90G (Phosphatidylcholine) purchased from Lipoid GmbH (Germany) were also used. Moreover, lymphocytes collected from whole blood samples of healthy donor volunteers; human fibroblasts (HF cells) obtained from University of Science (VNUHCM), human liver cancer cells (HepG2 cells), human breast cancer cells (MCF-7 cells) and human lung cancer cells (A549 cells) gifted from International University (VNUHCM) and University of Medicine and Pharmacy (HCM city), respectively, were also used in this project.

All 6 Lip-NRPs (Lip-CUR, Lip-SIL, Lip-AST, Lip-TOC, Lip-QUE and Lip-RES) were prepared using a combined method of lipid-film hydration and sonication. The binary combined formulations was prepared by mixing two Lip-NRPs with the appropriate volume to reach to the defined concentration of each NRP in the combined formulation. The mean sizes, polydispersity indices (PDI) and zeta potentials of the 6 Lip-NRPs were measured with Zetasizer Nano ZS (Malvern, U.K.). The encapsulation efficiencies of the 6 Lip-NRPs and the amount of NRPs containing in liposomal dispersion were determined by high-performance liquid chromatography (HPLC). In addition, the free radical scavenging activities of the 6 NRPs (CUR, SIL, AST, TOC, QUE and RES) were evaluated by the DPPH method. Next, the radioprotective effects on lymphocytes and HF cells against ionizing radiation of 6 Lip-NRPs and their binary combined formulations were evaluated and compared using the trypan blue assay and the  $\gamma$ -H2AX assay to assess, respectively, the percentage of cell death and genotoxicity of the cells after irradiation (evaluated by the number of foci/cell). In addition, the effects of the optimal

Lip-NRP formulations on cancer cells (HepG2 cells, A549 cells and MCF-7 cells) were also evaluated using the same assays.

The results of the percentage of cell death and the number of foci/cell at the optimal NRP concentration of each Lip-NRP (having the highest radioprotection) are shown in **Table 1** which indicated that Lip-CUR, Lip-SIL, Lip-QUE and Lip-TOC gave the higher radioprotective effect for both of lymphocytes and HF cells than Lip-AST and Lip-RES. In addition, the results in **Table 1** and **Table 2** also imply the binary combined formulations of Lip-NRPs had a higher radioprotection than that of the corresponding single forms. Among the binary combined formulations, 10SIL/10TOC (the combination of Lip-SIL and Lip-TOC at a SIL concentration of 10 µg/mL and a TOC concentration of 10 µg/mL) and 7.5CUR/7.5SIL (the combination of Lip-CUR and Lip-SIL at a CUR concentration of 7.5 µg/mL and a SIL concentration of 7.5 µg/mL) showed the highest radioprotection for human lymphocytes and HF cells (**Table 3**). The experimental results (**Table 4**) indicated that 10SIL/10TOC formulation enhanced the effect of ionizing radiation on HepG2 cells and MCF-7 cells. On the contrary, 7.5CUR/7.5SIL formulation significantly radio-protected for all the 3 cancer cells.

In summary, 10SIL/10TOC formulation has a great potential application to be used as a radioprotection product for normal cells in radiotherapy for cancer treatment. Especially, based on the results, it is clearly to see that this formulation is suitable to be used in RT for the treatment of lung cancer and breast cancer. However, in future, it is necessary to further study the effects of 10SIL/10TOC formulation on different cancer cells as well as its radioprotection for normal cells which belong to the corresponding diseased organs in order to find out its ability to be applied in RT for treatment of each cancer type. In addition, the investigation of the oral-pharmacokinetics as well as the development of its commercial formulation are also required. Finally, the findings of this project indicated that this is a promising approach in radio-protecting for patients undergoing RT for cancer treatment thanks to the low production cost and high radioprotective effect for normal cells of Lip-NRP formulations.

Table 1. Radioprotection for (A) human lymphocytes and (B) HF cells of 6 Lip-NRPs at the optimal NRP concentration (n = 3).

| (A)                        |                              |                           | (B)                        |                              |                            |
|----------------------------|------------------------------|---------------------------|----------------------------|------------------------------|----------------------------|
|                            | Percentage of cell death (%) | Number of foci/cell       |                            | Percentage of cell death (%) | Number of foci/cell        |
| Control                    | 18.27 ± 0.96 <sup>a</sup>    | 7.72 ± 0.50 <sup>a</sup>  | Control                    | 23.23 ± 0.75 <sup>a</sup>    | 17.00 ± 0.83 <sup>a</sup>  |
| Lip-CUR<br>(CUR 7.5 µg/mL) | 7.30 ± 0.82 <sup>da</sup>    | 5.77 ± 0.61 <sup>e</sup>  | Lip-CUR<br>(CUR 10 µg/mL)  | 17.43 ± 0.43 <sup>b</sup>    | 11.80 ± 0.44 <sup>d</sup>  |
| Lip-SIL<br>(SIL 10 µg/mL)  | 5.75 ± 1.13 <sup>a</sup>     | 4.50 ± 0.65 <sup>da</sup> | Lip-SIL<br>(SIL 10 µg/mL)  | 8.37 ± 1.10 <sup>d</sup>     | 11.30 ± 0.70 <sup>da</sup> |
| Lip-AST<br>(AST 7.5 µg/mL) | 12.37 ± 0.39 <sup>b</sup>    | 5.37 ± 0.55 <sup>cd</sup> | Lip-AST<br>(AST 7.5 µg/mL) | 18.03 ± 0.89 <sup>b</sup>    | 13.43 ± 0.91 <sup>e</sup>  |
| Lip-TOC<br>(TOC 15 µg/mL)  | 10.03 ± 0.74 <sup>c</sup>    | 3.33 ± 0.45 <sup>f</sup>  | Lip-TOC<br>(TOC 20 µg/mL)  | 12.63 ± 0.36 <sup>c</sup>    | 10.29 ± 0.45 <sup>ef</sup> |
| Lip-QUE<br>(QUE 20 µg/mL)  | 7.95 ± 0.40 <sup>d</sup>     | 3.91 ± 0.41 <sup>ef</sup> | Lip-QUE<br>(QUE 15 µg/mL)  | 8.56 ± 0.57 <sup>d</sup>     | 9.73 ± 0.30 <sup>f</sup>   |
| Lip-RES<br>(RES 5 µg/mL)   | 12.60 ± 0.64 <sup>b</sup>    | 6.70 ± 0.46 <sup>b</sup>  | Lip-RES<br>(RES 5 µg/mL)   | 17.87 ± 0.43 <sup>b</sup>    | 15.50 ± 0.36 <sup>b</sup>  |

Table 2. Radioprotection for (A) human lymphocytes and (B) HF cells of the binary combined formulations of Lip-NRPs at the optimal NRP concentration (n = 3). Any two mean values followed by the same superscript letter in the same column represented two non-statistically different values according to One-way Anova with post hoc Duncan test in the SPSS software (p < 0.05).

| (A)           |                              |                           | (B)          |                              |                           |
|---------------|------------------------------|---------------------------|--------------|------------------------------|---------------------------|
|               | Percentage of cell death (%) | Number of foci/cell       |              | Percentage of cell death (%) | Number of foci/cell       |
| Control       | 18.16 ± 0.43 <sup>a</sup>    | 7.72 ± 0.50 <sup>a</sup>  | Control      | 22.68 ± 0.57 <sup>a</sup>    | 17.00 ± 0.83 <sup>a</sup> |
| 7.5CUR/15TOC  | 7.27 ± 0.15 <sup>b</sup>     | 2.73 ± 0.31 <sup>cd</sup> | 10CUR/20TOC  | 10.97 ± 0.68 <sup>b</sup>    | 8.80 ± 0.61 <sup>b</sup>  |
| 10SIL/10TOC   | 3.27 ± 0.35 <sup>d</sup>     | 4.13 ± 0.32 <sup>b</sup>  | 10SIL/10TOC  | 6.50 ± 0.70 <sup>a</sup>     | 9.83 ± 0.95 <sup>b</sup>  |
| 10QUE/15TOC   | 5.57 ± 0.83 <sup>c</sup>     | 2.17 ± 0.25 <sup>d</sup>  | 10QUE/20TOC  | 9.70 ± 0.72 <sup>c</sup>     | 6.90 ± 0.26 <sup>c</sup>  |
| 10QUE/7.5CUR  | 7.17 ± 0.35 <sup>b</sup>     | 3.07 ± 0.35 <sup>c</sup>  | 15QUE/5CUR   | 11.30 ± 0.40 <sup>b</sup>    | 9.47 ± 0.51 <sup>b</sup>  |
| 10SIL/15QUE   | 3.97 ± 0.21 <sup>d</sup>     | 3.27 ± 0.32 <sup>c</sup>  | 7.5SIL/10QUE | 8.63 ± 0.38 <sup>d</sup>     | 9.77 ± 0.25 <sup>b</sup>  |
| 7.5CUR/7.5SIL | 3.90 ± 0.30 <sup>d</sup>     | 2.83 ± 0.45 <sup>cd</sup> | 10CUR/10SIL  | 8.77 ± 0.35 <sup>cd</sup>    | 4.67 ± 0.32 <sup>d</sup>  |

Table 3. Radioprotection for human lymphocytes and HF cells of 2 optimal binary combined formulations of Lip-NRPs (n = 3).

|               |  | Cell type   | Percentage of cell death (%) | Number of foci/cell |
|---------------|--|-------------|------------------------------|---------------------|
| 10SIL/10TOC   |  | HF cells    | 6.50 ± 0.70                  | 9.83 ± 0.95         |
|               |  | Lymphocytes | 3.27 ± 0.35                  | 4.13 ± 0.32         |
| 7.5CUR/7.5SIL |  | HF cells    | 8.70 ± 0.62                  | 6.93 ± 0.45         |
|               |  | Lymphocytes | 3.90 ± 0.30                  | 2.83 ± 0.45         |

Table 4. Effects of 10SIL/10TOC and 7.5CUR/7.5SIL on (A) HepG2 cells, (B) A549 cells and (C) MCF-7 cells (n = 3). Any two mean values followed by the same superscript letter in the same column represented two non-statistically different values according to One-way Anova with post hoc Duncan test in the SPSS software (p < 0.05).

(A)

|               | Total percentage of cell death (%) | Percentage of cell death due to cytotoxicity (%) | Percentage of cell death due to irradiation (%) | The number of foci /cell after irradiation |
|---------------|------------------------------------|--------------------------------------------------|-------------------------------------------------|--------------------------------------------|
| Control       | 18.78 ± 0.65 <sup>b</sup>          | 0 <sup>c</sup>                                   | 18.78 ± 0.65 <sup>b</sup>                       | 11.14 ± 0.51 <sup>a</sup>                  |
| 10SIL/10TOC   | 29.49 ± 1.63 <sup>a</sup>          | 6.80 ± 0.52 <sup>b</sup>                         | 22.69 ± 1.12 <sup>a</sup>                       | 12.26 ± 0.46 <sup>a</sup>                  |
| 7.5CUR/7.5SIL | 28.51 ± 0.98 <sup>a</sup>          | 22.88 ± 1.03 <sup>a</sup>                        | 5.63 ± 0.84 <sup>c</sup>                        | 8.52 ± 0.82 <sup>b</sup>                   |

(B)

|               | Total percentage of cell death (%) | Percentage of cell death due to cytotoxicity (%) | Percentage of cell death due to irradiation (%) | The number of foci /cell after irradiation |
|---------------|------------------------------------|--------------------------------------------------|-------------------------------------------------|--------------------------------------------|
| Control       | 23.26 ± 0.99 <sup>c</sup>          | 0 <sup>c</sup>                                   | 23.26 ± 1.30 <sup>a</sup>                       | 8.15 ± 0.26 <sup>a</sup>                   |
| 10SIL/10TOC   | 26.76 ± 0.29 <sup>b</sup>          | 10.83 ± 0.68 <sup>b</sup>                        | 15.92 ± 0.46 <sup>b</sup>                       | 7.47 ± 0.39 <sup>b</sup>                   |
| 7.5CUR/7.5SIL | 31.85 ± 1.10 <sup>a</sup>          | 24.17 ± 0.74 <sup>a</sup>                        | 7.68 ± 0.50 <sup>c</sup>                        | 7.23 ± 0.16 <sup>b</sup>                   |

(C)

|               | Total percentage of cell death (%) | Percentage of cell death due to cytotoxicity (%) | Percentage of cell death due to irradiation (%) | The number of foci /cell after irradiation |
|---------------|------------------------------------|--------------------------------------------------|-------------------------------------------------|--------------------------------------------|
| Control       | 41.17 ± 2.59 <sup>b</sup>          | 0 <sup>c</sup>                                   | 41.17 ± 2.59 <sup>a</sup>                       | 10.06 ± 0.43 <sup>a</sup>                  |
| 10SIL/10TOC   | 50.85 ± 1.74 <sup>a</sup>          | 7.09 ± 0.32 <sup>b</sup>                         | 43.76 ± 1.75 <sup>a</sup>                       | 10.73 ± 0.47 <sup>a</sup>                  |
| 7.5CUR/7.5SIL | 53.33 ± 2.77 <sup>a</sup>          | 24.58 ± 1.91 <sup>a</sup>                        | 28.75 ± 1.96 <sup>b</sup>                       | 9.05 ± 0.28 <sup>b</sup>                   |

## **2.7. RADIATION SAFETY AND RADIOACTIVE WASTE MANAGEMENT**

## RESEARCH ON ESTABLISHING THE STANDARD DOSIMETRY FIELD FOR GAMMA AND X-RAY RADIATION AT SAFETY LEVELS ACCORDING TO ISO 4037 STANDARD IN THE CENTER FOR NUCLEAR TECHNOLOGIES

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### Project information:

- **Project name:** Research to establish standard dose fields for gamma radiation and X-rays at safe levels in accordance with ISO 4037 at the Center for Nuclear Technologies of Ho Chi Minh city

- **Code:** ĐTCB.14/20/TTHN

- **Managerial Level:** Ministry

- **Duration:** 24 months (Jan 2020 - Dec 2021)

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

1. Ong Quang Son et al., Adjustment of the initial filtration thickness for X-ray spectrum following ISO 4037, Vietnam Conference on Nuclear Science and Technology (VINANST-14)
2. Nguyen Hoang Long et al., Convention true value of gamma radiation field of <sup>137</sup>Cs source at the center for nuclear technologies, Vietnam Conference on Nuclear Science and Technology (VINANST-14)
3. Le Ngoc Thiem et al., Calibration of externally irradiated ionizing radiation dosimeters in Vietnam, Journal of Nuclear Science and Technology, Vol 69, 2022 (in Vietnamese)
4. Le Huu Loi et al., Establishment and quality assessment of X-ray narrow spectrum series according to ISO 4037:2019 at SSDL of Center for Nuclear Technologies, Nuclear Science and Technology (NST), Vietnam Atomic Energy Society (VAES) and Vietnam Atomic Energy Institute (VINATOM)

Ionization radiation is widely used in industry, agriculture, medicine, and many other related fields. Since then a network of Secondary Standard Dosimetry Laboratories (SSDLs) has been established in 1976. The ultimate aim is that these SSDLs should have the same qualities as radiation beams for calibrating the instrument. In this work, the establishment and quality assessment of the gamma standard field of Cs-137 source and X-ray narrow spectrum series (N-series) according to ISO 4037:2019 at SSDL of CNT has been done. The establishment of the Cs-137 gamma dose standard field and the N-40 to N-120 narrow

spectrum X-ray dose standard field is done based on the ISO 4037:2019 set of standards and the guiding documentation related to the SSDL of IAEA. Putting the new Standard Dosimetry Laboratory into operation and exploiting it effectively. Training laboratory staff with knowledge, qualifications, and professionalism to meet laboratory standards.

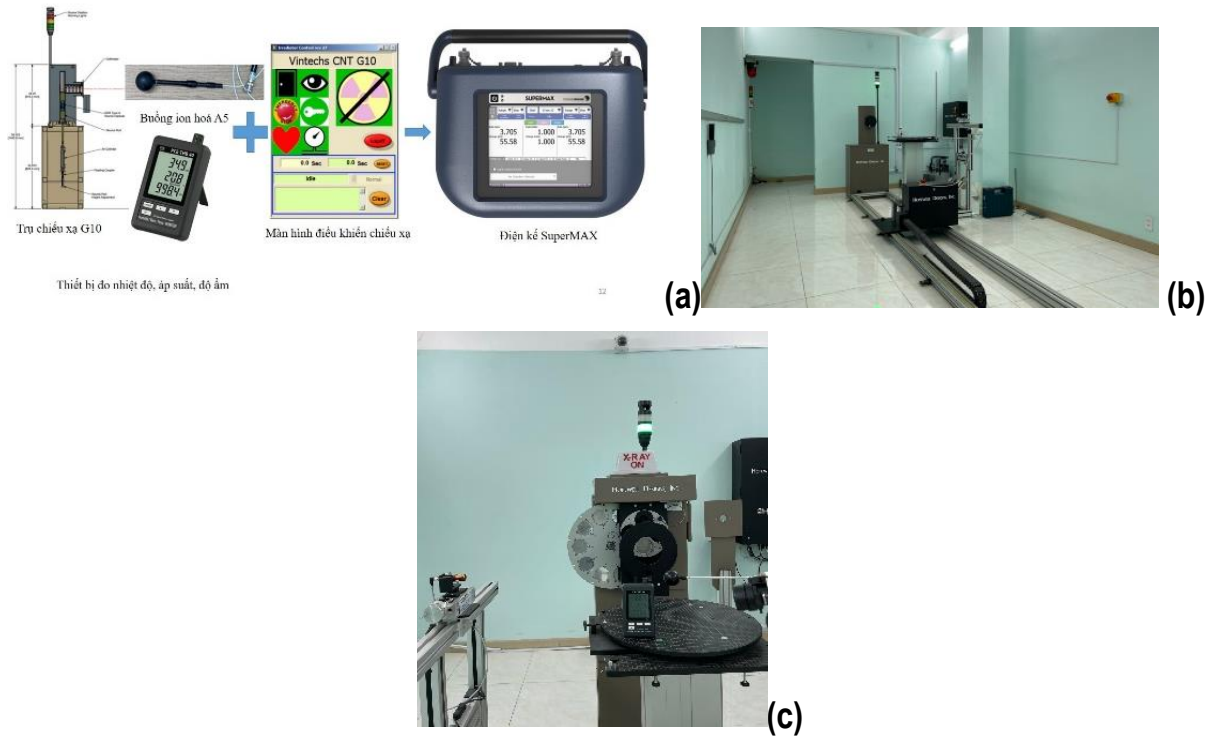


Figure. 1. Gamma standard field Cs-137 source and material (a, b) and X-ray system (c)

About Material and method, The standard gamma system source Cs-137 at CNT was used included: Gamma source: room size 6x4x3m, gamma source Cs-137 Type GSR-Cs-137/A (May 13, 2019, 0.998 TBq - 26,973 Ci activity), instrument linkage with the safety alarm system, A-5 ionization chamber, SuperMax electrometer, ... The reference X-ray system used included: room size 6x4x3m, X-ray generator, shielding post, high-voltage generator, cooling system, filters, laser positioner, Half-Value Stand, TK-30 reference ionization chamber. The X-ray tube model of the X-ray machine is Comet MXR 160/22, and the tube voltage regulation range is 7.5 - 160kV, with high stability, long continuous exposure time, long service life, and other advantages. About the method, experimental setup and evaluation of Cs-137 gamma source standard radiation field and N-40 to N-120 narrow-spectrum X-ray qualities were performed based on the ISO 4037-1, 2, 3:2019 series of standards, No.16 and "the evaluation guidelines Uncertainty for the IAEA Level 2 dosimetry laboratory" by the IAEA. For the Cs-137 source gamma system, measure and determine the air kerma rate (according to formula 1) at positions, then conduct a distance attenuation assessment, a distance radiative attenuation assessment, a radiation field homogeneity assessment, a scattering contribution assessment, and measurement uncertainty assessment. of air kerma rate (according to formula 3), environmental dose equivalent rate and individual dose equivalent rate (calculated according to formula 2) were performed and referenced according to ISO 4037:2019 to draw results. For X-ray systems, the process of establishing the standard field is done in 3 steps: Determine the

available filter thickness; Establish narrow spectrum qualities N-40 to N-120; Determine the uniformity of the radiation field, the contribution of the scattering component, and evaluate the measurement uncertainty of the air kerma. Measurements and evaluations were made at 2 distances, 100 cm, and 250 cm.

$$\dot{K}_a = k_{elec} \cdot N_K \cdot \frac{\overline{M_{raw}^{ref}} - \overline{M_{raw\_0}^{ref}}}{\tau} \cdot \frac{p_0}{p} \cdot \frac{273,15 + t^{\circ}C}{T_0} \quad (1)$$

$$\dot{H} = h_K \dot{K}_a \quad (2)$$

$$U = k \cdot \sqrt{\sum_{i=1}^n (c_i u_i)^2} \quad (3)$$

where,  $\dot{K}_a$  air kerma,  $k_{elec}$  electrometer calibration coefficient - SupperMAX,  $N_K$  ionization chamber standard coefficient,  $M_{raw}$  measured charge,  $\tau$  time for each measurement,  $p_0$  and  $t_0$  are the reference pressure temperature,  $p$ , and  $t$  temperature and pressure when measured experimentally,  $\dot{H}$  dose equivalence rate,  $h_K$  conversion factor,  $U$  measurement uncertainty,  $k$  is the coverage factor,  $c_i$  sensitivity,  $u_i$  component measurement uncertainty.

Through the process of measuring, calculating, and evaluating, The Cs-137 gamma dose standard field has been established at CNT, by ISO 4037:2019. The environmental dose equivalent rate and the individual dose equivalent rate are equal from 9.4 - 47183.2  $\mu\text{Sv/h}$  (Eq.2, with  $h_K=1.21$ ) in table 1. These environmental and individual dose equivalence values can be used as standard values for the calibration of gamma loggers for radiation safety and reference for personal dosimeters. Similarly, the narrow-spectrum N-40 to N-120 qualities of X-rays have been established in compliance with ISO 4037:2019, it can be used as a photon standard radiation field for calibrating survey meters and personal dosimeters in table 2.

Table 1. The conventional true value of the environmental dose equivalent rate, the individual dose equivalent rate of gamma standard field Cs-137 source in Center for Nuclear Technologies (01/12/2021)

| Qualities<br>(Gamma Cs-137<br>source) | Beam center<br>axis distance<br>(cm) | Conventional true value of the<br>environmental dose equivalent<br>rate $H^*(10)$ , the individual dose<br>equivalent rate $H_p(10)$ ( $\mu\text{Sv/h}$ ) <sup>(**)</sup> | Uncertainty of $H^*(10)$ ,<br>$H_p(10)$<br>$U(\%)$ ( $k=2$ )<br>( $U(\%) \leq 10\%$ , ISO 4037) |
|---------------------------------------|--------------------------------------|---------------------------------------------------------------------------------------------------------------------------------------------------------------------------|-------------------------------------------------------------------------------------------------|
| Using a lead<br>plate x 0             | 100                                  | 47183.2                                                                                                                                                                   | 5.65                                                                                            |
|                                       | 150                                  | 20789.6                                                                                                                                                                   | 5.65                                                                                            |
|                                       | 200                                  | 11664.9                                                                                                                                                                   | 5.65                                                                                            |
| ...                                   | ...                                  | ...                                                                                                                                                                       | ...                                                                                             |
| Using a lead<br>plate x 250           | 350                                  | 16.4                                                                                                                                                                      | 8.46                                                                                            |
|                                       | 400                                  | 12.4                                                                                                                                                                      | 9.05                                                                                            |
|                                       | 450                                  | 9.4                                                                                                                                                                       | 9.87                                                                                            |
| Using a lead<br>plate x 1000          | 100                                  | 52.8                                                                                                                                                                      | 6.00                                                                                            |
|                                       | 150                                  | 23.3                                                                                                                                                                      | 6.71                                                                                            |
|                                       | 200                                  | 13.1                                                                                                                                                                      | 9.47                                                                                            |

(\*\*) Calculated according to formula [2], with  $h=1.21$ , according to ISO 4037:2019 (environmental dose equivalent rate and personal dose equivalent rate have the same coefficient  $h$  as the Cs-137 gamma field).

*Table 2. The conventional true value of the environmental dose equivalent rate, the individual dose equivalent rate with narrow qualities*

| X-ray narrow-spectrum qualities | Conventional true value of the environmental dose equivalent rate $H^*(10)$ , the individual dose equivalent rate $H_p(10)$ (1mA) |                                |                                 |                                    |                                |                                 |
|---------------------------------|-----------------------------------------------------------------------------------------------------------------------------------|--------------------------------|---------------------------------|------------------------------------|--------------------------------|---------------------------------|
|                                 | Beam center axis distance 100 (cm)                                                                                                |                                |                                 | Beam center axis distance 250 (cm) |                                |                                 |
|                                 | $H^*(10)$ ( $\mu\text{Sv/h}$ )                                                                                                    | $H_p(10)$ ( $\mu\text{Sv/h}$ ) | U (%) ( $\leq 10\%$ , ISO 4037) | $H^*(10)$ ( $\mu\text{Sv/h}$ )     | $H_p(10)$ ( $\mu\text{Sv/h}$ ) | U (%) ( $\leq 10\%$ , ISO 4037) |
| N-40                            | 5510.5                                                                                                                            | 5687.5                         | 5.55                            | 883.4                              | 890.8                          | 5.56                            |
| N-60                            | 10562.1                                                                                                                           | 10992.0                        | 6.53                            | 1687.6                             | 1761.9                         | 6.54                            |
| N-80                            | 5434.3                                                                                                                            | 6459.7                         | 6.50                            | 859.1                              | 1021.2                         | 6.52                            |
| N-100                           | 2929.9                                                                                                                            | 3265.8                         | 6.48                            | 455.9                              | 501.2                          | 6.54                            |
| N-120                           | 3305.7                                                                                                                            | 3674.2                         | 6.45                            | 524.1                              | 569.2                          | 6.47                            |

With the initial success in completing this project, as well as soon putting into operation the gamma and X-ray standard dosimetry fields at the Center nuclear technologies, we hope to receive more investment in equipment. equipment to be able to complete the dosimetry system: Alpha, Beta, Gamma, X-ray, surface dose/dose titration, standard multifunctional radiometric devices, dosimetry for radiometric devices radiotherapy for medical radiation therapy.

## ESTABLISHMENT OF THE PHOTON REFERENCE FIELDS USING A MULTI-SOURCE GAMMA SYSTEM AND X-RAY GENERATOR

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### Project information:

- **Project name:** Establishment of the photon reference fields using a multi-source gamma system and X-ray generator
- **Code:** CS/22/04-02
- **Managerial Level:** Institute
- **Duration:** 12 months (Jan 2022 - Dec 2022)
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- **Published papers related to the project:**

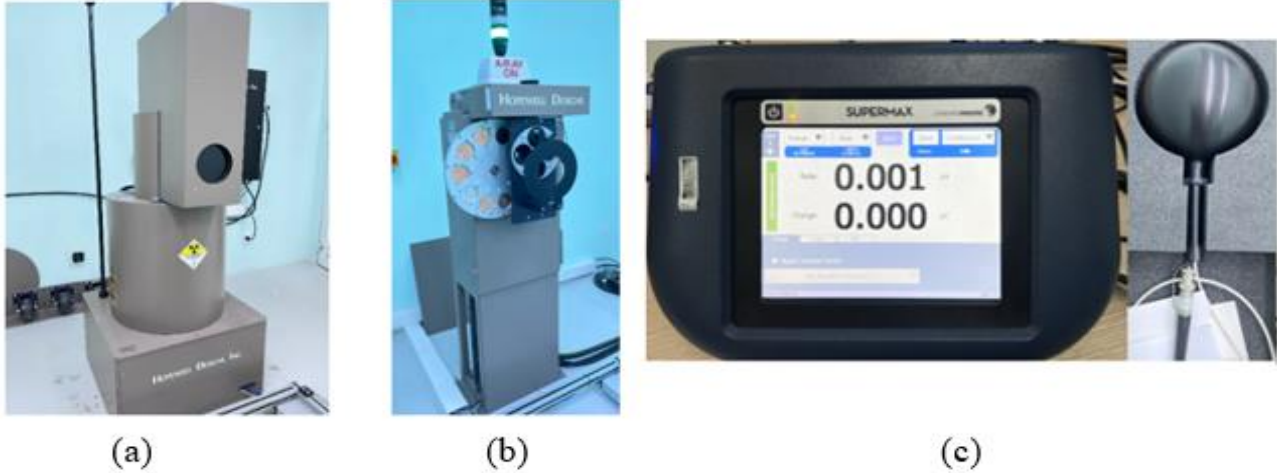
1. DANG Thi My Linh, NGUYEN Ngoc Quynh, BUI Duc Ky, DUONG Thi Nhung, "Characteristics of the reference X-ray narrow-spectrum series at SSDL of Institute for Nuclear Science and Technology", The 7th Vietnam Conference on Nuclear Science and Technology for Young Researchers.

2. DANG Thi My Linh, NGUYEN Ngoc Quynh, BUI Duc Ky, DUONG Thi Nhung, "Characteristics of the reference X-ray narrow-spectrum series at SSDL of Institute for Nuclear Science and Technology", Nuclear Science and Technology (NST).

The Institute for Nuclear Science and Technology (INST) is a member of the Vietnam Atomic Energy Institute (VINATOM), possesses a unique Secondary Standard Dosimetry Laboratory (SSDL) in the country on ionizing radiation dosimetry and calibration. This laboratory has been performed in the field of ionizing radiation dosimetry and calibration of photon measuring devices in order to ensure the reliability of the radiation measurements and safety assessment. As part of the project to upgrade the SSDL, the laboratory is equipped with a multi-source gamma system ( $^{137}\text{Cs}$  and  $^{60}\text{Co}$ ) and a new X-ray generator. To operate, it is very necessary to establish the photon reference fields according to international standards. The International Standard Organization (ISO) is published ISO 4037 which related to photon radiation (gamma and X-ray) for calibration of photon measuring devices in practical works. In this work, the characterization of the photon reference fields at the SSDL-INST was determined based on the ISO 4037 recommendations. The results show that the photon reference fields at the INST can be well applied in the practical calibration of photon measuring devices for radiation safety assessment.

In this work, the instruments used consist of: gamma calibration room with a multi-source gamma system (06 gamma source: 03  $^{137}\text{Cs}$  source with 1 Ci, 100 mCi, 10 mCi activity, 03  $^{60}\text{Co}$  source with 5 Ci, 100 mCi, 10 mCi) and X-ray calibration room with X-ray system (high

voltage from 0.1 to 160 kV, current from 0.1 to 45 mA). These calibration rooms are installed the instrument tables and rail systems which are used to move the calibrated devices following three axis (X,Y,Z) with the dimension 400 x 100 x 30 cm and has the ability to rotate 360°. Besides, the measuring instrument system includes an ion chamber and an electrometer. The ion chamber is the Exradin A4, with an active volume of 30 cm<sup>3</sup> and the electrometer is SuperMax, with two independent measurement channels (measuring range: 0.001 pC to 999.9 nC). The ion chamber and the electrometer are manufactured by the Standard Imaging Corporation and are calibrated in term of  $K_{air}$  at VSL (Dutch Metrology Institute).



(a) Multi-source gamma system; (b) X-ray generator; (c) Measuring instrument system  
Figure 1. Instruments used in this work.

In this study, the factors affecting the photon reference field such as the diameter of the field, the field uniformity, and the scattered radiation were determined. For X-ray reference field, the first step to be performed when producing X-ray qualities is to determine the inherent filtration of the X-ray tube. Then, the  $HVL_1$  and  $HVL_2$  for the X-ray narrow-spectrum series (N-40, N-60, N-80, N-100, N-120, N-150) were investigated and compared with the published values of the ISO-4037:2019 standard. The results show a good agreement for each specific X-ray beam quality.

The measuring instruments (ion chamber and electrometer) was used to determine the electric charges ( $R_0$ ) at the difference distances from 1m to 5m with difference gamma source ( $^{137}\text{Cs}$  và  $^{60}\text{Co}$ ) of the gamma reference field and the electric charges ( $R_0$ ) at a distance of 1m with X-ray beam qualities (N-40 to N-150). The electric charges were then corrected for the influence of temperature and pressure and normalized to the same duration time.

Based on the measured values of  $R_0$  in a time unit (nC/h), the  $K_{air}$  rates of X-ray beam qualities can be determined by the following equation (1):

$$K_{air} = R_0 \times N_K \times k_{T,P} \quad (1)$$

where,  $N_K$  is the calibration factor of the instruments at a specific X-ray beam quality (taken from the Exradin A4 calibration certificate of VSL);  $k_{T,P}$  is the correction factor for the influence of temperature and pressure.

From the  $\dot{K}_{air}$  obtained above, the photon ambient dose equivalent rates ( $H^*(10)$ ) and photon personal dose equivalent ( $H_p(10)$ ) can be calculated as follows:

$$H^*(10) = K_{air} \times C^*(10) \quad \left(\frac{Sv}{h}\right) \quad (2)$$

$$H_p(10) = K_{air} \times C_p(10) \quad \left(\frac{Sv}{h}\right) \quad (3)$$

where,  $C^*(10)$  and  $C_p(10)$  are respectively the conversion coefficients from  $\dot{K}_{air}$  to  $\dot{H}^*(10)$  and  $\dot{H}_p(10)$ .

For gamma reference field, the range of  $K_{air}$  rates of 1 Ci  $^{137}Cs$  source is from 135 to 2700  $\mu Gy/h$ , the range of  $K_{air}$  rates of 100 mCi and 10 mCi  $^{137}Cs$  sources are from 13 – 260  $\mu Gy/h$  and 3 – 7  $\mu Gy/h$ , respectively. The range of  $K_{air}$  rates of 5 Ci  $^{60}Co$  source is from 3000 - 48000  $\mu Gy/h$ , the range of  $K_{air}$  rates of 100 mCi and 10 mCi  $^{60}Co$  sources are from 50 - 800  $\mu Gy/h$  và 5 - 90  $\mu Gy/h$ , respectively. For X-ray reference field, the highest value of  $K_{air}$  rate is 14,08  $\frac{mGy}{h.mA}$  for N-150 beam quality and the lowest value of  $K_{air}$  rate is 1,80  $\frac{mGy}{h.mA}$  for N-100 beam quality. The results of  $K_{air}$ ,  $H^*(10)$ ,  $H_p(10)$  rates for X-ray reference field are also given in Table 1.

Table 1. Air kerma rates ( $K_{air}$ ), ambient dose equivalent rates ( $H^*(10)$ ) and personal dose equivalent ( $H_p(10)$ ) of X-ray beam quality.

| Radiation quality | High voltage (kV) | Mean energy (keV) | Total filtration (mm) |     |      | $K_{air}$<br>$\frac{mGy}{h.mA}$ | $H^*(10)$<br>$\frac{mSv}{h.mA}$ | $H_p(10)$<br>$\frac{mSv}{h.mA}$ |
|-------------------|-------------------|-------------------|-----------------------|-----|------|---------------------------------|---------------------------------|---------------------------------|
|                   |                   |                   | Al                    | Sn  | Cu   |                                 |                                 |                                 |
| N-40              | 40                | 33.3              | 4                     |     | 0.21 | 4.60                            | 5.43                            | 5.38                            |
| N-60              | 60                | 47.9              | 4                     |     | 0.6  | 6.92                            | 11.00                           | 11.42                           |
| N-80              | 80                | 65.2              | 4                     |     | 2.0  | 3.64                            | 6.30                            | 6.84                            |
| N-100             | 100               | 83.3              | 4                     |     | 5.0  | 1.80                            | 3.08                            | 3.38                            |
| N-120             | 120               | 100.0             | 4                     | 1.0 | 5.0  | 1.94                            | 3.18                            | 3.51                            |
| N-150             | 150               | 118.0             | 4                     | 2.5 |      | 14.08                           | 22.25                           | 24.36                           |

The obtained results show a good agreement with published recommendations of the International Standard Organization (ISO). This means the photon reference field at the Institute for Nuclear Science and Technology can be well applied in the practical calibration of X-ray measuring devices. In the future, the programs which to ensure the quality of calibration of gamma and X-ray measuring devices shall be researched and developed to be suitable with the requirements of ISO/IEC 17025:2017.

## 2.8. RADIATION TECHNOLOGY

## PRELIMINARY STUDY ON THE APPLICATION OF RADIATION TECHNOLOGY TO SYNTHESIZE CROSSLINKING BIODEGRADABLE FILM FROM THERMOPLASTIC STARCH (TPS) AND POLYBUTYLENE ADIPATE TEREPHTHALATE (PBAT)

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### Project information:

- **Project name:** Preliminary study on the application of radiation technology to synthesize crosslinking biodegradable film from thermoplastic starch (TPS) and polybutylene adipate terephthalate (PBAT)

- **Code:** CS/22/08-01

- **Managerial Level:** Institute

- **Duration:** 12 months (Jan 2022- Dec 2022)

- **Contact email:** tmthangbk@yahoo.com

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

1. Tran Manh Thang, Dam Thi Tam, Mai Duc Minh. "Research, synthesis of thermoplastic starch (TPS) from tapioca starch", The 7th Conference on Nuclear Science and Technology for young staff in the atomic energy industry, P. 40, October 2022. (in Vietnamese)

2. Tran Manh Thang, Tran Minh Quynh, Dam Thi Tam, Mai Duc Minh, Pham Duy Duong, Mai Van Vinh, Tran Xuan An. "Effect of gamma irradiation on the degree of crosslinking of TPS/PBAT biodegradable polymer films from thermoplastic starch (TPS) and polybutylene adipate terephthalate (PBAT)", Journal of Science and Technology - Hanoi University of Industry. Is sending (in Vietnamese)

Plastic waste is the source of pollution to natural habitats like terrestrial, water, and marine environments. Vietnam ranks 4th in the list of 20 countries with the largest amount of plastic waste. The Vietnamese government is also striving to use 100% environmentally friendly bags and packaging materials to replace traditional polymer bags by 2025. However, the cost of bags made from 100% biodegradable plastic is high, so it is necessary to find cheap and readily available materials in Vietnam to blend with biodegradable plastics while its quality is still assurance for the consumers. Cassava is a food crop that was planted in many regions, especially in the midland and mountainous areas of the country so *tapioca* starch materials are cheap and biodegradable. However, it is necessary to modify starch into thermoplastic starch (TPS) before blending it with other biodegradable polymers. Polybutylene adipate terephthalate (PBAT) is capable of biodegradation into CO<sub>2</sub> and H<sub>2</sub>O, thus limiting pollution and being environmentally friendly. PBAT has a wide range of melting points, low modulus of elasticity, and low hardness, but high flexibility and toughness. Therefore, PBAT can be blended with TPS to improve the properties of TPS films thus created new materials that are still biodegradable, helping to reduce environmental pollution. Application of radiation

technology to crosslinking polymer films by gamma-rays is an innovative method; the crosslinking process by radiation technology (gamma-rays generate free radicals and add a crosslinking agent such as TAIC) can be processed at room temperature, a simple technological process, easy to proceed on a large scale with high reliability and controllable product quality; No catalysts, antioxidants, and stabilizers are used so radiation technology has many advantages such as saving energy, space, and chemicals.

This research aims to synthesize a new biodegradable polymer by creating TPS and then blending it with PBAT (TAIC crosslinking agent) and then irradiation by gamma-rays, with the purpose of reducing plastic waste.

TPS/PBAT polymer films were synthesized through several stages and TPS/PBAT has the components as shown in Table 1. Firstly, modify starch into thermoplastic starch by blending cassava starch (Phuc Thinh Joint Stock Company, Thanh Hoa, Vietnam) with plasticizers including glycerol (Merck, Germany), ethylene glycol (Fisher), and tween 80 surfactants (Daejung, Korea) for 60 minutes. The mixture was incubated for 24 h in an airtight condition to avoid the atmospheric air. After incubating, the mixture was put in a heating device at about 155°C - 170°C and mixed well for 15 to 30 minutes. The formed TPS is dried at 80 °C for 3-4 hours. TPS properties were analyzed by infrared spectroscopy (FT-IR); The results showed that both starch and thermoplastic starch have characteristic peaks of starch (the absorption peak at 3367 cm<sup>-1</sup> corresponds to the stretching vibration of the –OH group). The peaks were shown that the plasticizers added to starch to make thermoplastic starch did not change the structure of the starch because glycerol and ethylene glycol are substances that have only -OH radicals, but the absorption peak at 3367 cm<sup>-1</sup> of the sample has plasticizer is stronger. Therefore, the plasticization process only causes the starch to swell to easily mix. In the manufacture of thermoplastic starch, the plasticizing process can be carried out with a sufficient amount of plasticizer because if the amount of plasticizer is too small, it is not enough to plasticize the mixture, causing cracking, leading to a decrease in the tensile strength of the material. Thermal gravimetric analysis (TGA) applied to the samples with Glycerol content of about 25% showed that the plasticizer was well blended with the cassava starch to form the homogeneous materials and lost 99.99% of its mass at 338.88°C. This result is consistent with those of the previous studies in which Glycerol plasticizer only accounts for about 25-30%.

Table 1: The composition of TPS/PBAT films

| Composition  | Starch | Glycerol | Ethylene Glycol | TWEEN 80 | PBAT | TAIC |
|--------------|--------|----------|-----------------|----------|------|------|
| Weight (gam) | 1000   | 400      | 200             | 20       | 1000 | 60   |

The TPS was then premixed with the biodegradable polymer (PBAT) and the cross-linking agent Triallyl Isocyanurate (TAIC from Merck) to make TPS/PBAT polymer (the mixture is mixed by the twin screw extruder machine with corresponding temperatures: 140-160-160-165-165-165-165-170-170-170°C; and extrusion speed 200 rpm. The TPS/PBAT polymer is cooled and granulated to form granules. TPS/PBAT polymer beads, after fabrication, were dried at 80°C for 4 hours, then film formed by the film forming machine (labtech) at a temperature from 140°C to 170°C, the speed is about 70 rpm to form the film. SEM images of the TPS/PBAT film show that TPS blends well with PBAT.

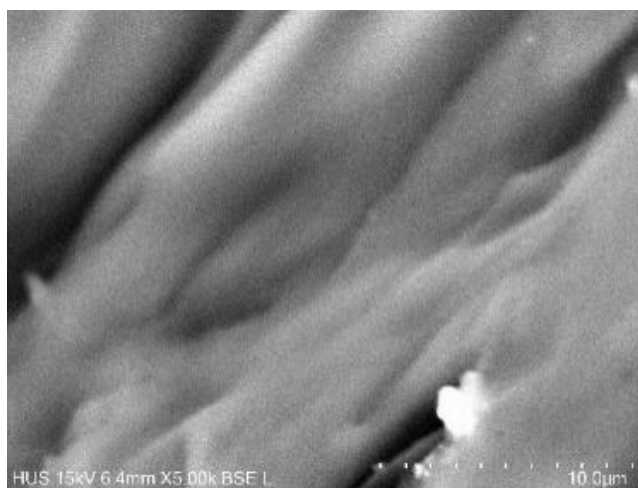


*Figure 1. TPS/PBAT polymer film observed by SEM*

The films (20 cm x 10 cm x 0.7 cm) were arranged in PE bags and irradiated at doses of 10, 20, 40, 50, 60, and 100 kGy. The sample placement in the irradiation chamber was determined according to the Pascal program so that the material received almost uniform absorbed doses over the entire sample volume. Corresponding to the expected irradiation dose, the required irradiation time was determined to achieve the desired irradiation dose. At the end of irradiation, the dosimeters were stored at room temperature, protected from direct light and the absorbed dose was determined.

The gel fraction was 22.5%, 47.38%, 5.05%, 60.30%, 64.81%, 72.63%, and 80.20% with the doses of 0, 10, 20, 40, 50, 60 and 100 kGy respectively. It can be seen that the unirradiated sample was only Gelatinized, so a partial cross-linking occurred; The gel fraction increased with increasing dose from 10 kGy to 100 kGy. This shows that PBAT polymer and starch may have cross-linked with each other. The tensile strength test of the TPS/PBAT film showed that the tensile strength of the unirradiated sample reached 7.11 MPa and was highest at the irradiation dose of 100 kGy (11.15 kGy). Determination of the biodegradability of the crosslinked and non-crosslinked TPS/PBAT film by Alpha-amylase showed that after the first week the samples were irradiated at high doses, the degradation ability was hard (At 100 kGy, irradiation samples was a loss of 35.58% weight), showing that the TPS/PBAT polymer film is cross-linked, so it is harder for Alpha-amylase to decompose the film. However, after 2 weeks, all samples before and after irradiation had the same mass loss rate (approximately 54%). It shows that TPS/PBAT polymer film is decomposed in Alpha-amylase enzyme.

In conclusion, thermoplastic starch and TPS/PBAT polymer films were made at Hanoi Irradiation Center. The plasticizers used in the manufacture of TPS did not change the structure of the starch, but made the starch swell and made it easier to blend (Glycerol accounted for 25 wt% of the sample mass and Ethylene glycol accounted for 12.5 wt%). The TPS blended well with the PBAT polymer resulting in homogenizer. Good crosslinking process of TPS/PBAT polymer films at exposure doses of 50, 60, and 100 kGy with gel fraction of 64,81%, 72,63% và 80,20% respectively. The films were decomposed in the Alpha-amylase enzyme (loss of 54 % weight after 2 weeks). TPS/PBAT films will be investigated to be applied in daily life to reduce current environmental pollution.

## SYNTHESIS OF Cu/TiO<sub>2</sub> NANOCOMPOSITE MATERIAL BY ELECTRON BEAM IRRADIATION FOR PHOTO-DEGRADATION OF ORGANIC SUBSTANCES IN LEACHATE

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### Project information:

- **Project name:** Synthesis of Cu/TiO<sub>2</sub> nanocomposite material by electron beam irradiation for photo-degradation of organic substances in leachate.

- **Code:** CS/22/07-01

- **Managerial Level:** Institute

- **Duration:** 12 months (Jan 2022 – Dec 2022)

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

1. Nguyen Chi Thuan, Nguyen Thi Kim Lan, Le Anh Quoc, Dang Van Phu, Nguyen Ngoc Duy, "Synthesis of Cu/TiO<sub>2</sub> nanocomposite material by electron beam irradiation for photo-degradation of organic substances in leachate", the 7th National Conference for Young Researchers on Nuclear Science and Technology, Ha Noi, 2022

Nowadays, pollution is an environmental concern for people throughout the world. The treatment of organic substances in landfill leachate is a complex problem for scientists because the organic substances contented in landfill leachate are classified as high. Most of the organic substances in leachate cause color and odor, which is also the cause of high COD (Chemical Oxygen Demand) and BOD (Biochemical Oxygen Demand) content (COD > 2000 mg/L, BOD > 1200 mg/L). COD is a test that measures the amount of oxygen required to chemically oxidize the organic and inorganic material; BOD represents the amount of oxygen consumed by bacteria and other microorganisms while decomposing organic matter under aerobic. Removing of organic substances based on the COD and BOD of leachate is a prerequisite before leachate is discharged into natural water.

Photocatalyst is an expected and interesting solution, allowing complex organic molecules to be processed under light irradiation without providing other chemicals. When the catalyst is excited by light of the appropriate wavelength, the valence electrons will move from the valence band to the conduction band, creating valence band holes. Photo-generated electrons and holes create potent oxidizing agents  $\cdot\text{OH}$ ,  $\cdot\text{O}_2\ldots$  were active subunits that readily participate in reactions with organic substances and colorants to produce CO<sub>2</sub> and H<sub>2</sub>O.

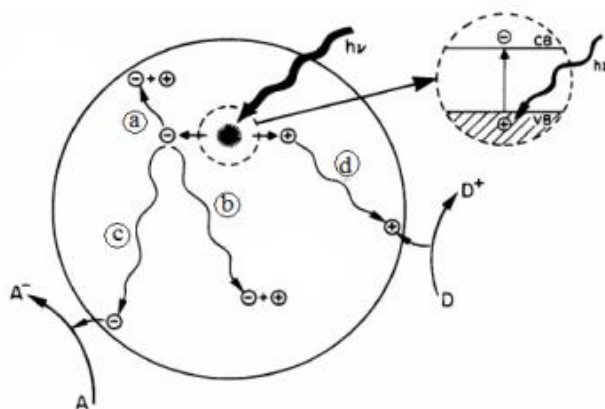


Figure 1. Schematic diagram of photo-excitation and electron transfer process

TiO<sub>2</sub> is considered the most effective photocatalyst to decompose organic substances due to physic-chemical stability, high catalytic activity, low cost, environmental safety, ease of production, and catalysis of many decompositions types of organic pollutants in water. Besides the high availability, the limitation of TiO<sub>2</sub> is high band gap energy ( $E_g > 3.2$  eV) and excitation only by ultraviolet (UV) light. Most of the studies to extend the light sensitivity of TiO<sub>2</sub> are done by doping metals, metal oxides or inorganic substances, etc. onto TiO<sub>2</sub>. Among the selected metals doped to TiO<sub>2</sub>, copper (Cu) has attracted a lot of attention from scientists for its ability to bind on TiO<sub>2</sub> crystal lattice as well as the economy of Cu at low cost and easy to find. The presence of Cu<sup>2+</sup> facilitates the generation of intermediate energy levels during the transition between the valence and conduction bands, captures electrons caused by light excitation, and prevents the recombination of electrons in the rapid combination of electron-hole pairs.

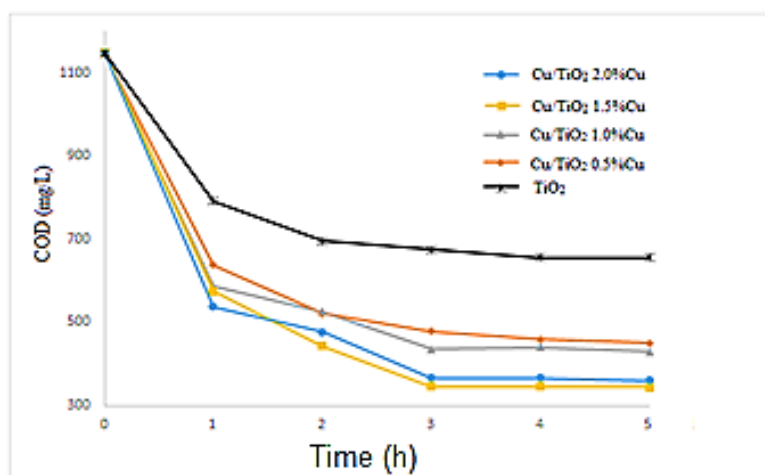
Cu/TiO<sub>2</sub> nanocomposite photocatalyst prepared by electron beam irradiation was investigated in the dose range of 20-80 kGy. In particular, 5.0 g of TiO<sub>2</sub> was dispersed in the mixtures of 80 ml of CuSO<sub>4</sub> solution and 20 ml of 96° alcohol, in which the desired copper content would be from 0.5 to 2.0% (w/w). The mixtures were put into PE zipper bags and purged oxygen by N<sub>2</sub> for 5-minute anti-oxidation before irradiation. Then, the samples were irradiated by EB of UELR-10-15S2 linear accelerator, 10.0 MeV, at the Research and Development Center for Radiation Technology (VINAGAMMA). Finally, the obtained products were filtered, dried at 50 °C for 24 hours, then ground to obtain nanocomposite Cu/TiO<sub>2</sub> powder (Fig. 2).



Figure 2.  $\text{TiO}_2$  and  $\text{Cu/TiO}_2$  nanocomposite with different Cu content

$\text{Cu/TiO}_2$  nanocomposite material was characterized by Ultraviolet-Visible spectroscopy (UV-Vis), transmission electron microscopy (TEM), X-ray diffraction (XRD), and Brunauer-Emmett-Teller measurement (BET). The size of Cu particles in  $\text{Cu/TiO}_2$  nanocomposite is in the range of 20-30 nm. The band gap energy of  $\text{Cu/TiO}_2$  nanocomposite was in the range of 2.9-2.2 eV, that reduced in comparison with that of  $\text{TiO}_2$  (3.2 eV). Cu nanoparticles doped to  $\text{TiO}_2$  increased the light absorption capacity of the material, and the light absorption spectrum expanded from the ultraviolet region to the visible region.

The photocatalytic activity of  $\text{Cu/TiO}_2$  nanocomposites used to decompose organic substances in water was studied by changing of COD and BOD concentrations in leachate. The results of COD and BOD concentrations show that the decomposition of organic substances of  $\text{Cu/TiO}_2$  nanocomposites is higher than that of  $\text{TiO}_2$ . The photocatalytic efficiency of  $\text{Cu/TiO}_2$  nanocomposites depends on the content of Cu nano in the material. In the ratio of 0.2 g nanocomposite  $\text{Cu/TiO}_2$  in 100 ml of leachate, the catalyst sample with 1.5% Cu concentration gave optimal results. The values of COD and  $\text{BOD}_5$  removal efficiency were 73.3% and 51.4%, respectively (Fig. 3). This shows that the  $\text{Cu/TiO}_2$  nanocomposites photocatalyst materials with suitable Cu concentration not only effectively absorbed light but also increased the separation efficiency pairs of  $\text{e}^-$  and  $\text{h}^+$  leading to photocatalytic efficiency significant increase.



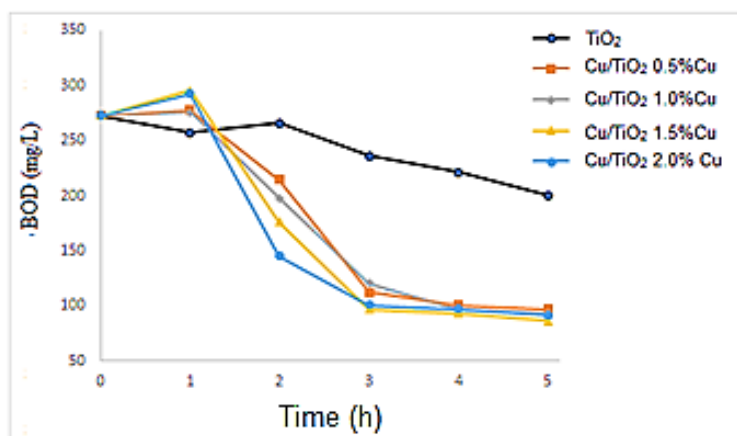


Figure 3. Change of COD and BOD of leachate treated by Cu/TiO<sub>2</sub> nanocomposite

In this study, the experiment of Cu nano/TiO<sub>2</sub> doped to the porous material was also carried out by mixing the fabricated nanocomposite with finely ground rice husk ash and alcohol. The mixtures were shaped into the round ball, allowed to dry naturally and then calcined at 1000°C to form Cu nano/TiO<sub>2</sub>/silica gel materials. The results of organic substances treatment in the leachate by Cu nano/TiO<sub>2</sub>/silica gel materials were the same as those by Cu/TiO<sub>2</sub> nanocomposite powders. After 5 times of reusability testing, the COD and BOD<sub>5</sub> removal efficiency of leachate of Cu/TiO<sub>2</sub> nanocomposite doped to silica gel reached 64.1% and 44.4%. Doping Cu/TiO<sub>2</sub> nanocomposites to silica gel for the easier recovery of the catalyst, in order to extend the life of the material and save the costs.

Base on the results of the study, Cu/TiO<sub>2</sub> nanocomposite materials was used as photocatalysts fabricated by electron beam irradiation with the following advantages: reaction conditions at room temperature of 30°C, uniform reducing agent in the reaction system, and the product of high purity. Also, these results are the premise for the application of organic matter treatment in wastewater under visible light conditions, thereby contributing to the reduction of environmental pollution.

## STUDY ON THE PROCEDURES FOR PHYTOSANITARY IRRADIATION LONGAN FRUIT, MANGO, DRAGON FRUIT ON ELECTRON BEAM ACCELERATOR UELR-10-15S2

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1. Nguyen Thi Ly, Cao Van Chung, Chu Nhut Khanh, Pham Thi Thu Hong, Doan Binh, Le Quang Thanh, Vo Anh Tuan, Nguyen Duy Ngoc, Ngo Tuong Vy, Phan Thi Thu Hien, Ta Ngoc Tu Quynh, Tcheng Hoang Nhu Hao, Nguyen Thuy Uyen, Tran Thi Thu Thuy, "Quarantine treatment of hoa loc mango by electron beam irradiation", Nuclear Science and Technology, Vol.11, No. 3 (2021), pp. 34-43.

2. Nguyen Thi Ly, Cao Van Chung, Chu Nhut Khanh, Pham Thi Thu Hong, Doan Binh, Le Quang Thanh, Vo Anh Tuan, Nguyen Duy Ngoc, Ngo Tuong Vy, Phan Thi Thu Hien, Ta Ngoc Tu Quynh, Tcheng Hoang Nhu Hao, "Effects of Electron beam irradiation on Dose uniformity ratio and quality of Hoa Loc mango", The Vietnam conference on Nuclear science and Technology 14th (09-10/12/2021, Da Lat-Lam Dong)

3. Chu Nhut Khanh, Nguyen Thi Ly, Cao Van Chung, Pham Thi Thu Hong, Doan Binh, Tran Hoa Truc, Nguyen Tran Diem Ha, "study on the effect of pretreatment methods combined with low-dose electron beam irradiation on the quality of exporting Edor longan fruit", The 7th Conference on Nuclear Science and Technology for Young Researchers (06-07/10/2022, Ha Noi).

Globalization has allowed consumers to choose and use a wide range of fresh fruits, even those that are unavailable in local areas. However, the drawback of this widespread commercialization is the increased risk of the regional spread of dangerous pests and diseases, leading to significant losses for the agricultural industry and the natural environment. This concern is the reason why many nations have mandated phytosanitary checks for fresh fruits before they are imported. For phytosanitary treatment, a variety of techniques are used, including irradiation, hot water dipping, cold heat treatment, and fumigation, each of which has advantages and limitations of its own and whatever approach is adopted, it must have a 99.99% quarantine efficiency [1]. Irradiation is a modern method with many outstanding advantages such as allowing processing of prepackaged fruits. In addition, this technique causes no chemical residues and minor environmental effects. The majority of fresh fruits are resistant to quarantine irradiation (1 kGy). Recently, using an accelerator for irradiation treatment has been developed and electron beam irradiation (EB) has been proven as a potential intervention to treat fresh products, especially plant origin products [2, 3]. EB can easily penetrate to a product at a limited depth depending on the density and product characteristics and its direction. Therefore, the absorbed dose at each point in a product exposed to electrons is affected by the density, shape and thickness of irradiated object because electrons are gradually attenuated and scattered when passing through material.

Unlike processed products, the complex shaped fruits produced large differences in density within the fruit boxes and irradiation containers, thus, different fruits receive different absorbed doses during the same irradiation process. It is very important to ensure that all portions of the irradiated product received the minimum dose required for radiation quarantine treatment. Additionally, dose uniformity ratio ( $DUR = D_{max}/D_{min}$ ) was within limitation, and acceptable processing efficiencies. In fact, a vast majority of the food items receive greater absorbed doses than the required minimum doses [4]. Consequently, the color, texture, flavor, and even nutritional compositions of fresh produce may be deteriorated if the product was exposed to EB with an excessive dose. Thus, the maximum absorbed dose must be under limitation of 1000 Gy as requirements of FDA, and the dose uniformity ratio should not be higher than 2.5 as APHIS/USDA recommendation [5]. In this study, fruits with heterogeneous sizes and shapes such as mango and dragon fruit were further studied besides the longan to provide a suitable treatment process for each type of fruit to meet exported requirements to tough markets like Australia.

The samples of Hoa Loc mango, Edor longan and dragon fruit were purchased from Chanh Thu Export and Import Fruit Company, located in Nhon Phu Hamlet, Hoa Nghia Commune, Cho Lach District, Ben Tre Province and from Hoa Loc Cooperative, located in Hoa Hung Commune, Cai Be District, Tien Giang Province. The fruits which were collected from the garden have the planting area code, free from external diseases, characteristic shape and color, and must meet export standards. The dragon fruits had thickness from 7.2 to 8.5 cm and weight from 318,7g to 500g, except for one carton box containing 9 fruits with the thickness and weight up to 9,0 cm and 627,8g. The Hoa Loc mangoes had thickness from 7.2 to 8.5 cm and weight from 379 to 672g. The Edor longan fruits had an average diameter of 2.4 cm; 70-80 fruits/kg. The samples were packed in 4.5 kg/ carton box for dragon fruits, 5 kg/ carton box for mango and longan fruits. The carton box dimensions of 42 x 31.5 x 12 cm and 48 x 31.5 x 12

(cm) for dragon fruit packed 9-11 fruits/carton box and 12 fruits/carton box, respectively to ensure that the fruits were horizontal and parallel to the conveyor surface. The carton box dimensions of 42 x 31.5 x 12 cm for the mango and the basket dimensions of 43 x 36 x 11 (cm) for the longan. The samples were irradiated by electron beam accelerator UELR-10-15S2 at Vinagamma with the generic dose of 0,4 kGy (for longan fruits, dragon fruits with 10-12 fruits/ carton box, mango with 10-11 fruits/ carton box), 0,5 kGy for mango with 9 fruits/ carton box, and 0,65 kGy for mango 8 fruits/ carton box. Mangoes with 8-9 fruits/carton box were additional POM plastic (holer dimention of 10x76 and 72x58 (mm)) outside the carton box. To measure the absorbed doses, B3 WINdose dosimeters and alanine dosimeters were used. The quality of the samples was tested by assessment of organoleptic value during storage at room temperature (25-26°C) after the assumed period of transport by sea (23 days, T° = 5-8°C; RH = 85-90%) and by air (3 days, T° = 10-15°C). 5-point scale was used where, 1= very poor, 2 = poor, 3 = fair, 4 = good and 5 = excellent). Scores from 2.5 to 5 were considered acceptable [6].

The dose distributions in Hoa Loc carton box are presented in Table 1. The results showed that the dose uniformity ratios (DURs) with additional POM plastic (8 and 9 fruits/carton box) or non-additional POM plastic (10 and 11 fruits/carton box) are all within allowable limits ( $\leq 2,5$ ). The Dmin values were obtained in carton box packed 8, 9, 10 and 11 fruits are 0.415; 0.415; 0.433 and 0.420 kGy, respectively. While the Dmax values are 0.969; 1,021; 1,004; 1,004 kGy, respectively and the DURs are 2,335; 2,461; 2,322; 2,391, respectively. The result was similar with the results of Moreno et al. (2006) reported that the obtained DUR value after irradiation was 2,4 when treated Tommy mango by 10 MeV electron beam irradiation [2]. Reference dose values have also been determined per carton box and compared with alanine dosimeters. The results showed that the difference between the two types of dosimeters was not significant. Thus, Hoa Loc mango with a thickness of less than 8.5 cm can be irradiated for quarantine purpose on the electron beam accelerator UELR-10-15S2 and can control the dose of Dmin, Dmax in the carton through the reference dose projection and coefficients Rmin and Rmax in Table 1.

Table 1. Dose uniformity in the carton box containing the Hoa Loc mango and in the largest and smallest fruits of the carton box

| Type of Dosimeters | Additional POM plastic |         |                     |         | Non additional POM plastic |         |                      |         |
|--------------------|------------------------|---------|---------------------|---------|----------------------------|---------|----------------------|---------|
|                    | 8 fruits/carton box    |         | 9 fruits/carton box |         | 10 fruits/carton box       |         | 11 fruits/carton box |         |
|                    | d = 8.4                | d = 8.0 | d = 8.2             | d = 7.3 | d = 8.0                    | d = 7.3 | d = 7.8              | d = 7.2 |
| Alanine            | -                      | -       | -                   | -       | 2,491                      | -       | 2,467                | -       |
| B3 time 1          | 2,160                  | 2,280   | 2,196               | 2,402   | 2,490                      | 2,196   | 2,402                | 2,402   |
| B3 time 2          | 2,280                  | 2,363   | 2,084               | 2,280   | 2,196                      | 2,196   | 2,402                | 2,402   |
| B3 time 3          | 2,280                  | 2,084   | 1,915               | 2,196   | 2,280                      | 2,160   | 2,280                | 2,402   |
| Dmax average       | 0,969±0,000            |         | 1,021±0,000         |         | 1,004±0,030                |         | 1,004±0,030          |         |

| Type of Dosimeters     | Additional POM plastic |         |                     |         | Non additional POM plastic |         |                      |         |
|------------------------|------------------------|---------|---------------------|---------|----------------------------|---------|----------------------|---------|
|                        | 8 fruits/carton box    |         | 9 fruits/carton box |         | 10 fruits/carton box       |         | 11 fruits/carton box |         |
|                        | d = 8.4                | d = 8.0 | d = 8.2             | d = 7.3 | d = 8.0                    | d = 7.3 | d = 7.8              | d = 7.2 |
| Dmin average           | 0,415±0,009            |         | 0,415±0,009         |         | 0,433±0,028                |         | 0,420±0,009          |         |
| DUR carton box average | 2,335±0,065            |         | 2,461±0,051         |         | 2,322±0,151                |         | 2,391±0,105          |         |
| Dref average (B3)      | 1,127±0,000            |         | 0,772 ± 0,000       |         | 0,591±0,000                |         | 0,619±0,022          |         |
| Dref (Alanine)         | 0,998                  |         | 0,722               |         | 0,548                      |         | -                    |         |
| Rmin (Dref/Dmin)       | 2,716                  |         | 1,860               |         | 1,365                      |         | 1,474                |         |
| Rmax (Dref/Dmax)       | 1,163                  |         | 0,756               |         | 0,589                      |         | 0,617                |         |

Table 2 shows that both types of packing method had equivalent Dmax and Dmin values across all three replicates (dumping and bagging). The average reference dosimeter measured with a B3 dosimeter 15 cm from the top of the basket was 0.634 kGy for dumping and 0.534 kGy for drawstring bags, whereas it was 0.588 kGy and 0.531 kGy measured with an Alanine dosimeter. The Rmin coefficient for controlling Dmin dose is 1.4 for dumping and 1.18 for bagging. The Rmax coefficient for controlling the dose of Dmax is 0.67 (dumping) and 0.56 (bagging) (Table 1). Controlling the dose of Dmax and Dmin in the exporting longan basket through Rmax and Rmin values is critical, both to reduce the number of dosimeters used and to avoid re-infection.

Table 2: The dose uniformity in the exporting longan basket for two types of packing

| Type of Dosimeters | DUR           |       |      |              |       |      |
|--------------------|---------------|-------|------|--------------|-------|------|
|                    | Dumping       |       |      | Bagging      |       |      |
|                    | Dmax          | Dmin  | DUR  | Dmax         | Dmin  | DUR  |
| B3 time 1          | 0,969         | 0,465 | 2,08 | 0,969        | 0,465 | 2,08 |
| B3 time 2          | 0,969         | 0,465 | 2,08 | 0,918        | 0,425 | 1,97 |
| B3 time 3          | 0,918         | 0,425 | 2,16 | 0,969        | 0,465 | 2,08 |
| Dref average (B3)  | 0,634 ± 0,069 |       |      | 0,534 ± 0,03 |       |      |
| Dref (Alanine)     | 0,588         |       |      | 0,531        |       |      |
| Rmin (Dref/Dmin)   | 1,40          |       |      | 1,18         |       |      |
| Rmax (Dref/Dmax)   | 0,67          |       |      | 0,56         |       |      |

Table 3: Dose absorbance in carton box containing Dragon fruit and in fruit with the largest siz

| Packing | Fruit thickness (cm) | Position of Dosimeters | Alanine | B3 time 1 | B3 time 2 | B3 time 3 | Dmax average | Dmin average | DUR carton box average | Dref average (B3) | Rmin (Dref/Dmin) | Rmax (Dref/Dmax) |
|---------|----------------------|------------------------|---------|-----------|-----------|-----------|--------------|--------------|------------------------|-------------------|------------------|------------------|
| 9       | 9.0                  | Surface                | 0,521   | 0,548     | 0,548     | 0,591     | 1,021±0,000  | 0,230±0,019  | 4,461±0,388            | 0,695±0,053       | 3,022            | 0,681            |
|         |                      | Center                 | 0,196   | 0,241     | 0,208     | 0,241     |              |              |                        |                   |                  |                  |
|         |                      | Top                    | -       | 0,820     | 0,772     | 0,772     |              |              |                        |                   |                  |                  |
|         | 8.3                  | Surface                | -       | 0,548     | 0,591     | 0,591     |              |              |                        |                   |                  |                  |
|         |                      | Center                 | -       | 0,410     | 0,410     | 0,465     |              |              |                        |                   |                  |                  |
|         |                      | Top                    | 0,964   | 1,021     | 0,969     | 0,969     |              |              |                        |                   |                  |                  |
| 10      | 8.5                  | Surface                | 0,430   | 0,465     | 0,425     | 0,465     | 0,986±0,030  | 0,410±0,000  | 2,406±0,073            | 0,493±0,069       | 1,202            | 0,500            |
|         |                      | Center                 | -       | 0,410     | 0,425     | 0,410     |              |              |                        |                   |                  |                  |
|         |                      | Top                    | 0,726   | 0,772     | 0,725     | 0,772     |              |              |                        |                   |                  |                  |
|         | 7.9                  | Surface                | 0,429   | 0,465     | 0,425     | 0,465     |              |              |                        |                   |                  |                  |
|         |                      | Center                 | -       | 0,410     | 0,410     | 0,465     |              |              |                        |                   |                  |                  |
|         |                      | Top                    | 0,723   | 0,772     | 0,772     | 0,725     |              |              |                        |                   |                  |                  |
| 11      | 8.2                  | Surface                | 0,411   | 0,410     | 0,410     | 0,425     | 1,021±0,000  | 0,410±0,000  | 2,490±0,000            | 0,562±0,025       | 1,371            | 0,550            |
|         |                      | Center                 | -       | 0,465     | 0,410     | 0,410     |              |              |                        |                   |                  |                  |
|         |                      | Top                    | 0,694   | 0,772     | 0,725     | 0,725     |              |              |                        |                   |                  |                  |
|         | 7.9                  | Surface                | 0,430   | 0,465     | 0,425     | 0,465     |              |              |                        |                   |                  |                  |
|         |                      | Center                 | -       | 0,465     | 0,410     | 0,465     |              |              |                        |                   |                  |                  |
|         |                      | Top                    | 0,722   | 0,772     | 0,725     | 0,772     |              |              |                        |                   |                  |                  |
| 12      | 8.1                  | Surface                | 0,528   | 0,591     | 0,548     | 0,548     | 0,986±0,030  | 0,415±0,009  | 2,376±0,022            | 0,562±0,025       | 1,354            | 0,570            |
|         |                      | Center                 | 0,442   | 0,465     | 0,425     | 0,465     |              |              |                        |                   |                  |                  |
|         |                      | Top                    | 0,467   | 0,548     | 0,465     | 0,465     |              |              |                        |                   |                  |                  |
|         | 7.4                  | Surface                | -       | 0,969     | 0,918     | 0,918     |              |              |                        |                   |                  |                  |
|         |                      | Center                 | 0,504   | 0,548     | 0,548     | 0,591     |              |              |                        |                   |                  |                  |
|         |                      | Top                    | 0,378   | 0,425     | 0,410     | 0,410     |              |              |                        |                   |                  |                  |

Dose distribution was also carried out in a carton box containing dragon fruit. Table 3 results show that the minimum dose absorption was located in the center of the dragon fruit for boxes of 9, 10 and 11 fruits. The minimum absorbed dose was located on the underside of a box of 12 fruits/box. The absorbed dose measured by the B3 dosimeters was higher than that measured by the Alanine dosimeters, but the difference was insignificant. This result also confirms that the carton dimensions of 42 x 31.5 x 12 cm and 48 x 31.5 x 12 (cm) were suitable for irradiating dragon fruit packed 9, 10, 11, 11 fruits/carton box and 12 fruits/carton box on electron beam accelerator UELR-10-15S2 with a dose of 0.4 kGy. Routine dose was also established to control the Dmin and Dmax doses in the product container (Table 3).

The effect of EB irradiation on the overall acceptability quality of longan, mango, dragon fruit on electron beam accelerator was studied. The results in Table 4 show that the overall acceptability quality of three types of fruits was very good on day 0, but that scores gradually decreased over storage time in all treatments and in all three types of fruit. All irradiated treatments had non-significant differences in scores at the same time of storage. When mango was stored at room temperature, the control treatment was accepted for 12 days. Meanwhile, until the 15th day of storage, the irradiation treatments were still acceptable. Although there was a decreasing trend in all treatments during storage time, the Edor longan fruits were still well appreciated after 18 days of storage (by sea). After electron beam irradiation treatment, the dragon fruit can be stored for 13 days under assumed commercial conditions by air route (10 - 15°C/3 days; then stored at room temperature 25 - 26°C).

Table 4. Effect of electron beam irradiation on overall acceptability quality of three type of fruits during storage time at room temperature.

| Overall acceptability quality of Hoa Loc mango (assumed commercial conditions by air) |                           |                            |                            |                           |                            |
|---------------------------------------------------------------------------------------|---------------------------|----------------------------|----------------------------|---------------------------|----------------------------|
|                                                                                       | Day 0                     | Day 5                      | Day 12                     | Day 15                    | Day 21                     |
| Control                                                                               | 4,85 ± 0,38 <sup>Ax</sup> | 4,54 ± 0,52 <sup>Ax</sup>  | 3,38 ± 0,77 <sup>Az</sup>  | 2,15 ± 0,38 <sup>At</sup> | -                          |
| 8                                                                                     | 4,85 ± 0,38 <sup>Ax</sup> | 4,38 ± 0,51 <sup>Ay</sup>  | 3,46 ± 0,52 <sup>At</sup>  | 2,77 ± 0,44 <sup>Bu</sup> | 1,85 ± 0,38 <sup>Av</sup>  |
| 9                                                                                     | 4,77 ± 0,44 <sup>Ax</sup> | 4,46 ± 0,52 <sup>Ax</sup>  | 3,54 ± 0,52 <sup>Ay</sup>  | 2,69 ± 0,48 <sup>Bz</sup> | 2,23 ± 0,44 <sup>Bt</sup>  |
| 10                                                                                    | 4,77 ± 0,44 <sup>Ax</sup> | 4,23 ± 0,44 <sup>Ay</sup>  | 3,31 ± 0,48 <sup>Az</sup>  | 2,62 ± 0,51 <sup>Bt</sup> | 1,85 ± 0,38 <sup>Au</sup>  |
| 11                                                                                    | 4,69 ± 0,48 <sup>Ax</sup> | 4,31 ± 0,48 <sup>Ay</sup>  | 3,46 ± 0,52 <sup>Az</sup>  | 2,69 ± 0,48 <sup>Bt</sup> | 2,15 ± 0,38 <sup>ABu</sup> |
| Overall acceptability quality of Edor longan (assumed commercial conditions by sea)   |                           |                            |                            |                           |                            |
|                                                                                       | Day 1                     | Day 4                      | Day 10                     | Day 18                    | Day 22                     |
| SO <sub>2</sub> (Control)                                                             | 4,86 ± 0,36 <sup>Ax</sup> | 3,93 ± 0,73 <sup>Ay</sup>  | 3,50 ± 0,85 <sup>Ay</sup>  | 2,50 ± 0,52 <sup>Az</sup> | 1,71 ± 0,47 <sup>At</sup>  |
| SO <sub>2</sub> + Irra. (Bagging)                                                     | 4,64 ± 0,50 <sup>Ax</sup> | 4,29 ± 0,73 <sup>Axy</sup> | 3,93 ± 0,83 <sup>Ay</sup>  | 2,86 ± 0,36 <sup>Az</sup> | 2,07 ± 0,62 <sup>At</sup>  |
| SO <sub>2</sub> + Irra. (Dumping)                                                     | 4,57 ± 0,51 <sup>Ax</sup> | 4,00 ± 0,39 <sup>Ay</sup>  | 3,57 ± 0,85 <sup>Ayz</sup> | 2,71 ± 0,47 <sup>At</sup> | 1,93 ± 0,73 <sup>Au</sup>  |

| Overall acceptability quality of Hoa Loc mango (assumed commercial conditions by air) |                            |                           |                            |                           |                            |
|---------------------------------------------------------------------------------------|----------------------------|---------------------------|----------------------------|---------------------------|----------------------------|
|                                                                                       | Day 0                      | Day 5                     | Day 12                     | Day 15                    | Day 21                     |
| Control                                                                               | 4,21 ± 0,58 <sup>ABx</sup> | 4,03 ± 0,51 <sup>Ax</sup> | 3,86 ± 0,77 <sup>Ax</sup>  | 3,07 ± 1,14 <sup>Ay</sup> | 2,07 ± 0,62 <sup>Az</sup>  |
| 10                                                                                    | 4,64 ± 0,50 <sup>Ax</sup>  | 4,00 ± 0,68 <sup>Ay</sup> | 2,79 ± 0,89 <sup>Bz</sup>  | 2,50 ± 0,52 <sup>Az</sup> | 2,00 ± 0,68 <sup>At</sup>  |
| 11                                                                                    | 4,36 ± 0,50 <sup>ABx</sup> | 4,26 ± 0,84 <sup>Ax</sup> | 3,21 ± 0,97 <sup>ABy</sup> | 2,57 ± 0,85 <sup>Az</sup> | 1,79 ± 0,43 <sup>ABt</sup> |
| 12                                                                                    | 4,07 ± 0,73 <sup>Bx</sup>  | 3,43 ± 0,51 <sup>By</sup> | 2,64 ± 0,74 <sup>Bz</sup>  | 2,50 ± 0,52 <sup>Az</sup> | 1,50 ± 0,52 <sup>Bt</sup>  |

\*The values in the table represent the mean ± standard deviation.

\*Values with different letters (A-B) represent statistically significant differences ( $p < 0.05$ ) by column (treatment).

\*Values with different letters (x-u) represent statistically significant differences ( $p < 0.05$ ) by row (day).

Based on our results, it can be confirmed that the electron beam irradiation of longan, mango, dragon fruit by EB accelerator can be applied for quarantine treatment of fresh fruits. The Hoa Loc mangoes packed with additional POM plastic plates in the boxes for 8 and 9 fruits were irradiated at 0.65 and 0.5 kGy showed the absorbed doses and dose uniformity within the allowable threshold for export. Their sensory quality and overall acceptability met the consumer's requirements after 15 days of storage at room temperature of 25 - 26°C. Similar results were obtained with the boxes of 10 and 11 fruits irradiated at 0.4 kGy. The Edor longans in both packaging specifications can be also radiation quarantined by the electron beam accelerator and their sensory quality can be acceptable by consumers after 18 days of storage at 25 - 26°C. Boxes of 10, 11 and 12 dragon fruits are suitable for irradiation quarantine with the minimum dose not less than 0.4 kGy, and their sensory quality and overall acceptability met the consumer's requirements after 13 days of storage at 25-26°C. These results facilitate to establish the procedures of radiation quarantine treatment using UELR-10-15S2 accelerator for exportation of fresh fruits to the US and Australia.

## REFERENCE

- [1]. Torres-Rivera, Z. and Hallman, G. J. 2007. Low-dose irradiation phytosanitary treatment against Mediterranean fruit fly (Diptera: Tephritidae), *Florida Entomologist*, 90, 343–346. doi:10.1653/0015-4040(2007)90 [343: LIPTAM] 2.0.CO;2.
- [2]. Moreno M., Castell-Perez M. E., Gomes C., Da Silva P. F. and Moreira R.G., The effects of electron beam irradiation on physical, textural, and microstructural properties of “Tommy Atkins” mangoes (*Mangifera indica* L.), *Journal of Food Science*, 71(2), pp. 80–86, 2006.
- [3]. Moreno M.A., Castell-Perez M. E., Gomes C., Da Silva P. F. and Moreira R.G., “Quality of electron beam irradiation of blueberries (*Vaccinium corymbosum* L.) at medium dose levels (1.0-3.2 kGy)”, *Food Science and Technology*, 40(7), pp. 1123–1132, 2007.

- [4]. Hallman G. J. and Martinez L. R., “Ionizing irradiation quarantine treatment against Mexican fruit fly (Diptera: Tephritidae) in citrus fruits”, *Postharvest Biology and Technology*, 23: 71Ð77, 2001.
- [5]. FDA (U.S. Food and Drug Administration)., “Irradiation in the production, processing, and handling of food”, *Federal Register*, 51(75), pp. 13375–13399, 1986.
- [6]. Abu-Tarboush, H., Al-Kahtani, H., Atia, M., Abou-Arab, A., Bajaber, A., & Mojaddidi, M. (1997). Sensory and microbial quality of chicken as affected by irradiation and postirradiation storage at 4.0. *Journal of Food Protection*, 60(7), 761-770. <https://doi.org/10.4315/0362-028X-60.7.761>

## **2.9. RADIOCHEMISTRY AND MATERIALS SCIENCE**

## STUDY ON IMPROVEMENT OF THE EFFICIENCY OF VINACOMIN WASTEWATER TREATMENT WITH ACTIVE LIME MILK

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### Project information:

- **Project name:** Study on improvement of the efficiency of Vinacomin wastewater treatment with active lime milk

- **Code:** DTCB.11/20/VCNXH

- **Managerial Level:** Ministry

- **Duration:** 33 months (Jan 2020- Dec 2021, extend to Sep. 2022)

- **Contact email:** hoangvanduc11@gmail.com

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

1. Hoang Van Duc, Nguyen Van Tung, Tran Ngoc Ha, Hoang Thi Tuyen, Hoang Nhuan (2022) "Removal of manganese and iron from coal mining wastewater by activated lime milk at scale of 50 liters/batch", Internauke, Sci.J., No9(232).

2. Useful solution "Process of treating industrial wastewater containing iron and manganese using activated lime milk", National Office of Intellectual Property of Viet Nam (2022), code, 2-2022-00182, date 10-05-2022.

3. Hoang Van Duc, Nguyen Van Tung, Vu Thi Phuoc, Hoang Thi Tuyen, Tran Ngoc Ha, Hoang Nhuan (2022) "Research on Evaluating the ability to treat Fe and Mn in wastewater solution during coal mining using activated lime milk", Journal of Chemistry and Application, 2<sup>(61)</sup>/6-2022.

4. Ngo Tra My, Vu Thi Phuoc, Hoang Van Duc (2020), "Study on treatment ability of Mn and Fe in wastewater of coal underground mining by activated lime milk", Proceeding of the 6th Conference on Nuclear Science and Technology for Young Researchers, VINATOM, Ha Noi, Vietnam.

5. Hoang Van Duc, Tran Ngoc Ha, Nguyen Thi Thuc Phuong, Hoang Thi Tuyen, Hoang Nhuan (2021) "Removal of manganese and iron from coal mining wastewater using activated lime milk", Proceeding of the 14th Conference on Nuclear Science and Technology, VINATOM, Da Lat, Vietnam.

In the current mining operations, every year coal mining activities generate more than 100 million m<sup>3</sup> of wastewater containing iron and manganese. Iron and manganese contents, fluctuating seasonally, can be up to 500 ppm and 20 ppm, respectively.

The general principle of the underground wastewater treatment process is to use alkaline chemical agents (lime, caustic soda, etc..) to neutralize the acidity, creating a favorable environment for oxidation of heavy metals Fe, Mn. Then use coagulants and flocculants (PAC, PAM) to increase the ability to agglomerate and separate the suspended particles available in the wastewater along with the particles generated when neutralizing to remove impurities in the wastewater

There are many research works, in Vietnam, on wastewater treatment containing Fe, Mn, especially Mn. However, in most of the proposed processes, neutralization (using lime or NaOH chemicals) and aeration are carried out simultaneously. The weaknesses of these processes are: the amount of chemicals consumed is large, the generated sludge is a lot and has poor filterability, the process is complicated, and the treatment cost is high due to the low efficiency manganese filter sand system.

In this Project the technological process has been researched and proposed (in which neutralization is performed first using activated lime milk instead of lime powder or NaOH, and then oxidation Fe, Mn by aeration) as shown in Figure 1:

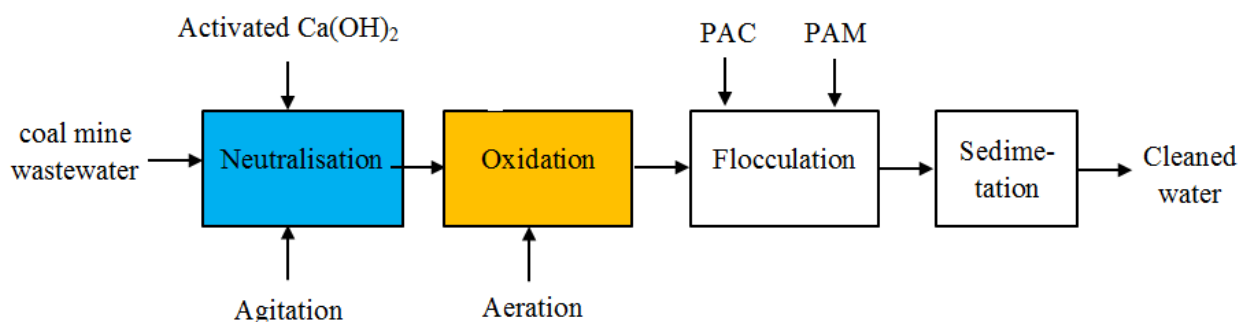


Figure 1. Flow chart of Fe, Mn treatment technology.

Activated lime milk was produced with the following specifications:

**Table 1:** Properties of produced activated lime milk

| No. | Properties                       | Active lime milk solution |
|-----|----------------------------------|---------------------------|
| 1   | Appearance                       | White mud                 |
| 2   | Average elementary particle size | 7 $\mu\text{m}$           |
| 3   | $\text{Ca(OH)}_2$ concentration  | 28%                       |
| 4   | Specific conductivity            | 7729 $\mu\text{S/cm}$     |
| 5   | Purity of $\text{Ca(OH)}_2$      | $\geq 98,5\%$             |
| 6   | Viscosity                        | 202 cP                    |
| 7   | Recovery                         | 92,3 %                    |

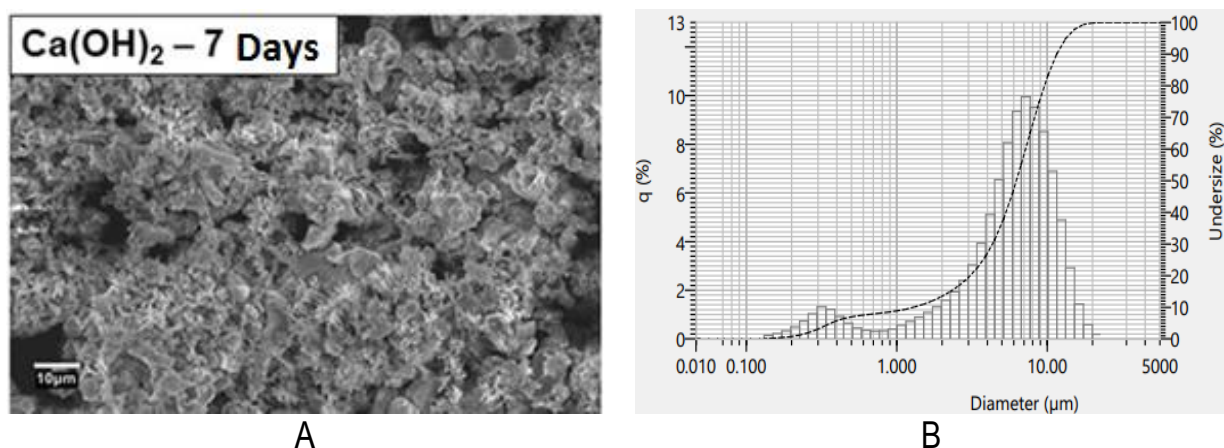


Figure 2. A) SEM image of lime milk product after 7 day-storage time; B) Particle size distribution of lime milk product after 7 day-storage time.

The main equipment, based on that the experiments were carried out, in this project is an batch wastewater treatment device with volume of 50 liter (Cylinder; 304 stainless steel material; height of 500 mm, diameter of 400 mm; Stirring speed of 0-2000 rpm). Wastewater samples were collected at Nui Nhen mining area (Fe: 84.3 ppm, Mn: 5.55 ppm, pH: 2.54).

The results of wastewater treatment process at Nui Nhen mine with activated lime milk (compared with lime powder), following to the technological process diagram in Figure 1, were shown in Table 2.

Table 2: Summary of Fe and Mn treatment results in Nui Spider mine wastewater with activated lime milk and lime powder at scale of 50 liters/batch.

|                                 |    | Use activated lime milk |                         |                   | Use lime powder |                         |                   | QCVN40/2011<br>column B |
|---------------------------------|----|-------------------------|-------------------------|-------------------|-----------------|-------------------------|-------------------|-------------------------|
|                                 |    | Initial                 | After<br>neutralization | After<br>aeration | Initial         | After<br>neutralization | After<br>aeration |                         |
| Metal<br>concentration<br>(ppm) | Fe | <b>84,03</b>            | 0,64                    | 0,12              | 84,03           | 5,36                    | 0,73              | 5,00                    |
|                                 | Mn | <b>5,55</b>             | 1,05                    | <b>0,51</b>       | 5,55            | 1,43                    | <b>1,22</b>       | 1,00                    |
| pH                              |    | <b>2,54</b>             | 8,11                    | 8,04              | 2,54            | 8,12                    | 8,07              |                         |
| Lime amount (g)                 |    | 6,47                    |                         |                   | 10,53           |                         |                   |                         |
| Waste sludge<br>generated (g)   |    | 16,28                   |                         |                   | 21,18           |                         |                   |                         |

With the process of simultaneous treatment of Fe and Mn in wastewater carried out by the method of neutralization first and then oxidizing aeration, the results in Table 2 shown that the use of activated lime milk is better than the use of lime powder. The Fe/Mn ratio in the studied ranges, the larger the value, the higher the treatment efficiency, and the required neutralizing pH ranges from 8 to 9. The treatment process of Nui Nhen coal mining wastewater showed that: when neutralized with lime milk at pH = 8, the Fe and Mn contents after treatment decreased from 84.03 ppm and 5.55 ppm to 0.12 ppm and 0.51 ppm respectively, meeting wastewater quality requirements according to QCVN40/2011 column

B. The use of lime milk helps to reduce the amount of consumed chemicals (40%) and the amount of sludge generated (25%) compared to using powdered lime. Thus, the use of activated lime milk to simultaneously treat Fe and Mn in coal mining wastewater gives high efficiency.

## STUDY ON THE SYNTHESIS OF A SENSOR MATERIAL BASED ON THE ZIRCONIUM/EUROPIUM OXIDES FOR THE APPLICATION IN DETECTING ETHANOL VAPOR

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### Project information:

- **Project name:** Study on the synthesis of a sensor material based on the zirconium/europium oxides for the application in detecting ethanol vapor
- **Code:** CS/22/03-02
- **Managerial Level:** Institute
- **Duration:** 12 months (Jan 2022- Dec 2022)
- **Contact email:** buictr@gmail.com
- **Published papers related to the project:**

1. Ngo Quang Huy, Nguyen Dinh Viet, Nguyen Thanh Thuy, Luu Xuan Dinh, Bui Cong Trinh. "Study on the synthesis of a sensor material based on the oxides zirconium/europium". J. Internauka, 39(262). 2022. DOI: 10.32743/26870142.2022.39.262.346131;

2. Nguyen Dinh Viet, Ngo Quang Huy, Nguyen Thanh Thuy, Luu Xuan Dinh, Bui Cong Trinh. "Study of nano oxide zirconium/europium sensor material synthesis", reported in the 7th Conference of Nuclear Science and Technology for young researcher, 6-7, Oct. 2022, Hanoi, Vietnam.

In recent years, the vapor detection of organic compounds based on the phenomenon of photocatalysts has played an important role in many fields, such as environmental monitoring, medical diagnosis, national security, etc. The photocatalytic phenomenon occurs when a heterogeneous catalytic reaction occurs on the surface of the solid catalyst and is accompanied by the emission.

With the goal of providing the basic parameters for the synthesis of sensor materials on the zirconium/europium nano-oxide base, the synthesis process consists of two stages: the precipitation of these elements as the hydroxides and their calcination to form the oxide mixture.

In the hydroxide precipitation stage, the investigation of factors affecting the synthesis process resulted in the following optimal specifications: molar ratio of Eu - 5%, pH - 7, stirring speed - 200 rpm, reaction time - 2 hours. At this condition, the synthesis yield is greater than 96% and the hydroxide phases are evenly distributed.

At the calcination stage of hydroxide precipitates the investigation of the calcination temperature is shown in Table 1.

Table 1. Specific surface areas of samples after calcination at different temperatures

| T, °C                                | 400    | 500    | 600    | 700    |
|--------------------------------------|--------|--------|--------|--------|
| S, m <sup>2</sup> /g                 | 50,62  | 62,46  | 84,15  | 83,93  |
| Capillary volume, cm <sup>3</sup> /g | 0,0135 | 0,0247 | 0,0859 | 0,0816 |
| Capillary size, nm                   | 2,125  | 2,897  | 4,216  | 4,056  |
| Particle size, nm                    | 800    | 68     | 30     | 32     |

Table 1 showed that, at low temperatures (below 500°C), the dehydration occurred incompletely. At 600 and 700°C, the specific surface area reached the maximum values and the base particle size reached 30-32 nm, the large capillary volume ... These parameters would facilitate the catalytic effect of the material. Therefore, the optimum temperature was selected to be 600°C, and the heating time was 2 hours. In addition, the sample after calcination at this optimal condition achieved the definite phase composition as shown in Figure 1.

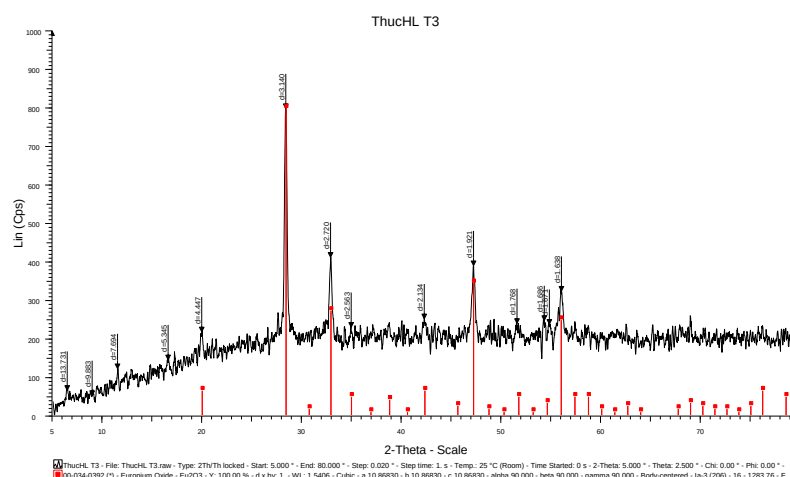


Figure 1. XRD spectrum of the sample at 600°C

At 600°C the cubic phase (corresponding to  $\text{Eu}_2\text{O}_3$ ) appeared.

The powder sample was synthesized with the above optimal parameters and evaluated for its ability to convert ethanol vapor into ethanal. The conversion results are shown in Table 2.

Table 2. Contents of ethanol and ethanol in steam after reaction

| T, °C | Content of $\text{C}_2\text{H}_5\text{OH}$ , g/L | Content of $\text{C}_2\text{H}_4\text{O}$ , g/L |
|-------|--------------------------------------------------|-------------------------------------------------|
| 100   | 0.55                                             | 0                                               |
| 150   | 0.45                                             | 0.11                                            |
| 200   | 0.40                                             | 0.16                                            |
| 250   | 0.46                                             | 0.10                                            |
| 300   | 0.48                                             | 0.09                                            |

Thus, it is obvious that the concentration of ethanal rose and reached a maximum of 0.16 g/L as the temperature rose from 100 to 200°C. Due to the lower gas phase adsorption onto the material's solid surface at temperatures above 200°C, the product content was reduced.

Additionally, the GFN2-xTB method of theoretical calculation has demonstrated that the energy released during the conversion of ethanol to ethanal on the material's surface was 196.77 kJ. mol<sup>-1</sup>, which was significantly more than the energy needed to excite Eu<sub>2</sub>O<sub>3</sub> to an excited state (69.16 kJ. Mol<sup>-1</sup>).

Within the framework of the Project, the optimal parameters for the synthesis of zirconium/europium oxide nanomaterials were obtained and met the requirements of the registered contents. The experimental and theoretical analysis processes reveal that the substance is capable of converting ethanol vapor into ethanal vapor as well as generating emissions. The sensors that measure the amount of alcohol vapor in the air or breath can be made from the synthesized materials.

## STUDY ON THE PROCESS FOR PRODUCTION OF METALLIC ZINC POWDER FROM ZINC OXIDE WITH HIGH CHLORIDE CONTENTS BY ELECTROLYSIS IN ALKALINE SOLUTION

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### **Project information:**

- **Project name:** Study on the process for production of metallic zinc powder from zinc oxide with high chloride contents by electrolysis in alkaline solution
- **Code:** ĐTCB.06/21/VCNXH
- **Managerial Level:** Ministry
- **Duration:** Jan 2021 – Dec 2022 (extended to Jun 2023)
- **Contact e-mail:** tranvuong87@gmail.com
- **Published papers related to the project**

1. Tran Ngoc Vuong, Pham Minh Tuan, Vu Duy Hung, Nguyen Dinh Dang, Nguyen Tien Tung “A process for leaching of zinc in alkaline medium and purifying of the leach solution” Proceedings of the 14th Vietnam Conference on Nuclear Science and Technology, Da Lat, Vietnam, 2021, p234.(in Vietnamese)
2. Tran Ngoc Vuong, Pham Minh Tuan, Vu Duy Hung, Nguyen Dinh Dang, Nguyen Tien Tung “Dechlorination of a raw zinc oxide with high content of chlorides derived from electric arc furnace dust” Vietnam Journal of Science and Technology (accepted).(in Vietnamese)
3. Tran Ngoc Vuong, Pham Minh Tuan, Vu Duy Hung, Nguyen Dinh Dang, Nguyen Tien Tung “Study on remove pb from electrolyte solution for production of zinc powder metal by alkaline electrochemical method” Journal of Chemistry and Application (in Vietnamese) (accepted).
4. Tran Ngoc Vuong, Pham Minh Tuan, Vu Duy Hung, Nguyen Dinh Dang, Nguyen Tien Tung “Technology for producing zinc powder metal by electronic methods in alkaline medium” Proceedings of the 15th Vietnam Conference on Nuclear Science and Technology, Nha Trang, Vietnam, 2023 (in Vietnamese)

Zinc electrolysis in alkaline solution has been attracting the attention of scientists in recent decades to find an alternative technological solution to the conventional method of electrolysis in sulfuric acid solution. The advantage of zinc electrolysis in alkaline solution is that the electricity cost is about 23% lower. Moreover the raw materials with high content of Pb, Fe, and Cl such as the zinc oxide recovered from the recycling of steelmaking arc furnace dust by pyrometallurgy that cannot be used by the conventional method but can be

used for zinc electrolysis in alkaline solution. In addition, zinc electrolysis in an alkaline solution can directly produce metallic zinc powder.

Metallic zinc powder is in great demand and is applied in many industrial fields such as the anti-corrosion coating industry for marine ships, as a chemical technology reducing agent to remove metal cations from solution. In addition, metallic zinc powder is also used in many other fields such as explosives, fireworks, in zinc plating technology, in technology of catalysts, etc.,

This research focused on the technological parameters for each stage: raw material processing, zinc dissociation with NaOH, separation of impurities in the leach liquor, zinc electrolysis, product drying, in which electrolysis is the most important stage to zinc recovery and to the quality of final product (metallic zinc powder).

The factors affecting the electrolysis process such as zinc concentration, NaOH concentration in the electrolyte solution, electrolysis temperature, current density have been carefully studied on the basis of zinc content analysis results, particle size of the obtained zinc powder and electrolytic current efficiency.

The reduction of  $\text{Zn}^{2+}$  concentration leads to a smaller particle size which is beneficial for the production of metallic zinc powder but when the  $\text{Zn}^{2+}$  concentration is too low, it will facilitate hydrogen generation and adversely affect the electrolysis current efficiency. When the concentration of NaOH increases, the size of the zinc particles is smaller, but the electricity cost is higher, and the metallic zinc powder is dissolved more into the electrolyte solution. The optimum range of current density was determined at which the formation of metallic zinc powder with small particle size and low energy loss. In the process of electrolysis, when the temperature is increased, the amount of metal zinc formed will be redissolved into the solution, so it is necessary to control the appropriate electrolysis temperature.

From the above studies, a set of experimental electrolysis equipment has been designed and installed and a technological process of zinc electrolysis in alkaline solution to prepare metallic zinc powder from zinc oxide with high chloride content has been designed.

Schematic diagram of electrolysis technology for preparation of metallic zinc powder in alkaline solution is presented in Figure 1.

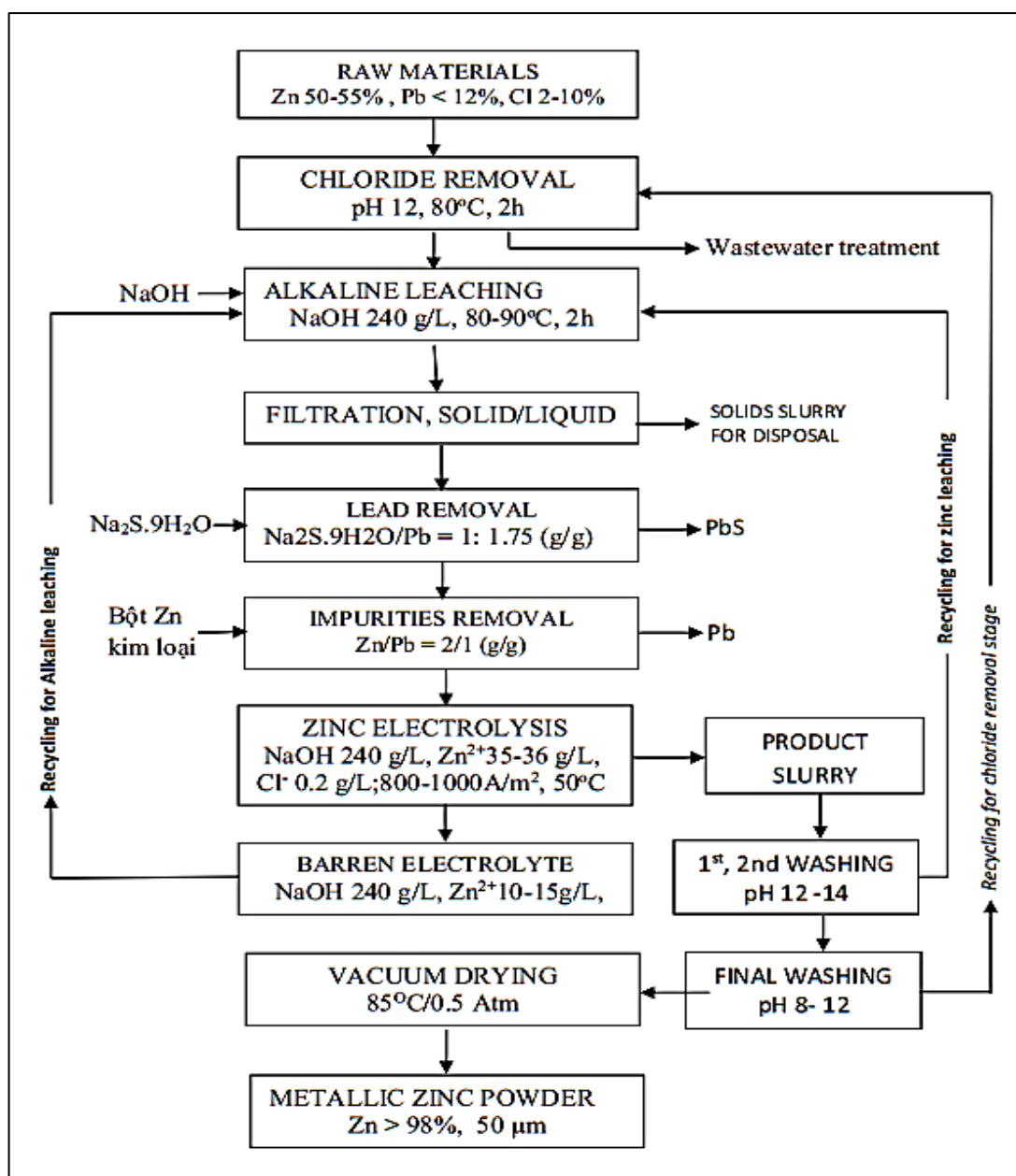


Figure.1. Technological process diagram for the production of metallic zinc powder by electrolysis in alkaline solution

The starting material with main compositions of Zn 53%, Pb 12%, Fe 2.1%, Cl 5.2% was treated to remove chloride by NaOH solution by stirring, solid/liquid ratio 1/10, pH 12, 80°C in 2 hours. The raw materials after chloride removal stage contented 0.2 - 0.5% Cl were dissolved by NaOH solution 240g/L, 80-90°C in 2 hours then filtered to separate solid/liquid. The leach liquor was purified from impurities (Zn content 35-40 g/L, Pb < 10mg/L, other impurities below detection limit) by using sodium sulfide and metallic zinc powder then lead to electrolysis.

The electrolysis process is carried out at a current density of 800-1000A/m<sup>2</sup>, the temperature is below 50°C until the zinc concentration in the solution is 8-10g/L. The metallic zinc powder was separated from the electrode and electrolyte solution, filtered and washed several times with water, the wash water with pH > 12 is recirculated in the zinc leaching, the wash water with pH 8-12 is reused to remove chloride in raw materials, the washing process ends when the final rinse water pH is below 8. The product is filtered and dried in a vacuum dryer at 85°C, 0.5atm.

Electrolysis equipment set includes 03 electrolysis cells connected in series by overflow pipeline system, 05 electrodes (02 cathodes and 03 anodes) on each cell, 12V-100A rectifier power supply and metering pump circulating 18 L/h.

Electrolysis cell: Size 250mm long, 250mm wide, 300mm high, made of 10mm thick polypropylene (PP) material.

Electrode: Stainless steel (SUS 304) for both anode and cathode, 250mm length, 150mm wide, working area: 150mmx150mm.

Rectifier power supply: 12V – 100A.

Product quality of prepared zinc metal powder: Zn 98.36%, Cd 0.001%, Pb 0.06%, median size 43µm (*unmilled sample*).

In conclusion, a process for manufacturing metallic zinc powder from zinc oxide with high content of chloride (Zn 53%, Pb 12%, Fe 2.1%, Cl 5.2%) by electrolysis in NaOH solution has been studied.

The preliminary treatment of raw materials for chlorides removal has been thoroughly studied. Chloride impurities in zinc-containing materials were removed at pH 12 by using NaOH solution, solid/liquid ratio = 1/10, temperature 80°C, time 120 minutes. Chloride content in the materials after treatment is 0.2-0.5% chloride removal efficiency reached 96%.

The process of dissolving zinc by NaOH was carried out with solid/liquid ratio = 1/15, NaOH 240 g/L, dissolving time 90 minutes, temperature 90°C. The solution after dissolution has a Zn<sup>2+</sup> content of 35-40 g/L, and the leaching efficiency is 97.5-98%. The leach liquor was purified by precipitation with sodium sulfide agent, reaction time 90 mins., mass ratio Na<sub>2</sub>S.9H<sub>2</sub>O/Pb = 1.8. Lead removal efficiency reached 99.7%, the Pb content in purified solution is < 10mg/l, Cd and Cu below the detection limit.

The influence of some impurities such as Pb<sup>2+</sup>, Cl<sup>-</sup>, F<sup>-</sup> has been studied on the electrolysis of metallic zinc powder. The allowable content of Pb<sup>2+</sup> is less than 50mg/L, while Cl<sup>-</sup> and F<sup>-</sup> with concentrations up to 5g/L do not affect the electrolysis process. Some others anion impurities such as CO<sub>3</sub><sup>2-</sup>, SO<sub>4</sub><sup>2-</sup> and SiO<sub>3</sub><sup>2-</sup> have negligible influence on the electrolysis.

The technological parameters of washing and drying zinc metal powder product were studied, the pH in the final washing reached 7-8, the amount of washing water consumed 10L/kg of product.

Technological parameters for producing of metallic zinc powder by electrolysis in alkaline solution: concentration of  $Zn^{2+}$ , free NaOH in the electrolyte are 35-40g/L, 180-200g/L respectively, current density 800-1000A/m<sup>2</sup>, the electrolysis temperature is less than 50°C. Current efficiency reaches 95%, the consumption of electricity for electrolysis is 2.7-3.2kWh/kg of product. The zinc recovery efficiency was over 98%, the obtained product met the requirements: total zinc content 98%, Pb, Cd content < 0.1%, particle size less than 50 µm.

A continuous electrolysis system of 03 electrolysis cells, working capacity of 3x15 liters, 300g zinc powder per hour, electrodes made of SUS304 (both anode and cathode) 250x150x2mm, circulating pump of 18L/h has been designed, manufactured and put into service for the research. The electrolysis system has been working stably.

The results of this research can be upgraded on a larger scale.

## STUDY ON SYNTHESIS OF COMPOSITE MATERIAL BY USING ACTIVATED CARBON AND METALLIC FERRITE FOR APPLICATION IN MANUFACTURING GENERATOR

<sup>99</sup>Mo/<sup>99m</sup>Tc

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### Project information:

- Project name: STUDY ON SYNTHESIS OF COMPOSITE MATERIALS BY USING ACTIVATED CARBON AND METALLIC FERRITE FOR APPLICATION IN MANUFACTURING GENERATOR <sup>99</sup>Mo/<sup>99m</sup>Tc

- Code: ĐTCB 13/21/VNCHN

- Managerial Level: Ministry

- Duration: 12 months (Jan 2021- Dec 2022)

- Contact email: ntbinhdv@gmail.com

- Published papers related to the project:

1. Nguyen Thanh Binh, Nguyen Nho Dung, Nguyen Mau Thanh, Dao Ngoc Nhiem, Doan Manh Dung, Le Lam Son, Nguyen Duc Vu Quyen, Tran Ngoc Tuyen, Nguyen Hoang Tuan, and Dinh Quang Khieu. Electrochemical determination of methylparaben with manganese ferrite/activated carbon-modified electrode. Journal of Materials Science: Materials in Electronics, Vol 33, pages20884–20899 (2022), (ISI Q2, IF = 2,779)

2. Nguyen Thanh Binh, Dang Ho Hong Quang, Nguyen Nho Dung, Nguyen Mau Thanh. Study on synthesis of activated carbon materials from rice husk ash doped with ZIF-11 orientation in electrochemical analysis. Journal of Chemistry, Physics and Biology. ISSN (0868-3224), Vol 27, No 2/2022. (In Vietnamese)

3. Nguyen Thanh Binh, Nguyen Nho Dung, Nguyen Giang Nam, Nguyen Mau Thanh. Synthesis of activated carbon from rice husk ash doped ZIF-11 and application of lead analysis by soluble vol-ampere method. Proceedings of the national conference for young scientists 2021. Hue university publishing house. Book No. NC/263-2021. (in Vietnamese)

Nowadays, <sup>99m</sup>Tc is vitally needed and makes up more than 80% of nuclear imaging diagnostic applications. The production of <sup>99m</sup>Tc from <sup>99</sup>Mo as an adsorption column generator from a <sup>235</sup>U fission source and irradiation of a <sup>98</sup>Mo target on a nuclear reactor. When the adsorbent materials such as Al<sub>2</sub>O<sub>3</sub> or ZrO<sub>2</sub> were employed, it was simple to use <sup>235</sup>U to create a generator with a high specific activity of <sup>99m</sup>Tc, but it would be challenging to use such materials in nuclear reactor with low flux of neutron like the Da Lat Nuclear Reactor, to manufacture a generator with high activity that satisfies the standards for application in hospitals. It is required that a new material with a large adsorption capacity

could replace low-capacity materials such as  $\text{Al}_2\text{O}_3$  (10-20 mg Mo/g  $\text{Al}_2\text{O}_3$ ) in the orientation of  $^{99}\text{Mo}/^{99\text{m}}\text{Tc}$  generator manufacturing.

In this study AC- $\text{MnFe}_2\text{O}_4$  (MnAC) and AC- $\text{NiFe}_2\text{O}_4$  (NiAC) composite materials were synthesized from activated carbon and ferrite by hydrothermal method.

On nuclear reactor,  $^{99}\text{Mo}$  radioactive isotope were prepared by using neutron activation method. After that, finding the optimal conditions for  $^{99}\text{Mo}$  adsorption onto composite materials as well as optimal conditions for  $^{99\text{m}}\text{Tc}$  desorption from the materials was carried out. The quality control of  $^{99\text{m}}\text{Tc}$  solution with different standards such as radiochemical purity, nuclear purity, and specific activity of  $^{99\text{m}}\text{Tc}$  was taken into account. The main materials and chemicals used for experiment were activated carbon (synthesized from rice husks), chemicals at analytical grade such as: DMF,  $\text{Mn}^{2+}$ ,  $\text{Ni}^{2+}$ ,  $\text{Fe}^{3+}$ , NaOH (Merk) and double-distilled water. The equipment consisted of Dalat nuclear reactor, hydrothermal furnace, ISOMED 2000 meter, gamma spectrometer system. The synthesis of activated carbon from rice husk was implemented as the preliminary treatment of rice husk material, investigation on the effect of time and temperature on the activated process. The obtained activated carbon was used as a raw material for composite synthesis. Besides, under the conditions of temperature and pressure, ferrite was distributed into the structure of activated carbon by hydrothermal reaction. Therefore, the effects of reaction time, temperature, and the MF/AC mass ratios on the structure, morphology, and characteristics of the materials were investigated. Material characterizations were determined by modern physico-analytical methods including SEM, BET, XRD, EDX, FT-IR, Raman, etc.

The results showed that the optimized condition of activated carbon synthesis was at  $750^\circ\text{C}$  for 1 hour, carbon was activated with the mass ratio  $m_{\text{C}}:m_{\text{KOH}} = 1:3$  at the temperature of  $850^\circ\text{C}$  for 2 hours under anaerobic conditions. It presents that the activated carbon synthesized from rice husk has a very large surface area, it has a surface area  $> 2000 \text{ m}^2/\text{g}$ , with a carbon composition  $> 95\%$ , on the surface of activated carbon attached to carbonyl or carboxyl chemical functional groups. make activated carbon more active. On the other hand, the optimum conditions for synthesis of composites were as such: molar ratio of MF:Fe = 1:2 and reaction time of 12 hours, the synthesized temperature at  $190^\circ\text{C}$  (NiAC) and  $180^\circ\text{C}$  (MnAC) with the mass ratio of MnF:AC = 4:6, NiF:AC = 5:5. Both materials had a porous structure and fairly large surface area of  $700 \text{ m}^2/\text{g}$ , which was suitable for the adsorption of  $^{99}\text{Mo}$  produced on the Da Lat Nuclear Reactor. With the Thermal neutron flux of about  $2.10^{13} \text{ n/cm}^2/\text{s}$  was used to irradiate 1 gram of  $^{98}\text{Mo}$ , which had an abundance of 98.42% was irradiated for 150 hours and cooled for 12 hours. The  $^{99}\text{Mo}$  radioactivity was measured about 346 mCi,  $^{99}\text{Mo}$  radioactive target was chemically treated after being irradiated to convert into  $\text{Na}_2^{99}\text{MoO}_4$  salt. Adsorption rate and adsorption temperature of  $^{99}\text{Mo}$ , and pH of the  $^{99}\text{Mo}$  solution were also studied while  $^{99}\text{Mo}$  was loaded in the glass column under various conditions. After 23 hours of  $^{99}\text{Mo}$  adsorption on the material, we desorbed  $^{99\text{m}}\text{Tc}$  by using a 0.9% NaCl solution at various pH values, temperatures, and desorption rates. The results showed that: the optimal conditions for  $^{99}\text{Mo}$  adsorption are pH

6-7, at room temperature, the adsorption speed of 0.5 ml/min, while the optimum desorption conditions are pH between 4 and 7, desorption rate of 5 ml/min, at room temperature.

The  $^{99}\text{Mo}/^{99\text{m}}\text{Tc}$  generator consists of a glass column containing an adsorbent which is a composite material. When  $^{99}\text{Mo}$  solution flows through the glass column at the optimal conditions, the radioactive isotope  $^{99}\text{Mo}$  is uptaken on the material in the column. After some time the  $^{99\text{m}}\text{Tc}$  isotope is produced from the decay of  $^{99}\text{Mo}$  isotope. The separation of  $^{99\text{m}}\text{Tc}$  from the  $^{99}\text{Mo}$  isotope from the composite is simple. The physiological saline solution is flowed through the column,  $^{99\text{m}}\text{Tc}$  is easily washed away because  $^{99\text{m}}\text{Tc}$  seems to have no affinity for the material and  $^{99}\text{Mo}$ , on the contrary, has a great affinity for the material so it is not washed away by 0.9% physiological saline solution. The  $^{99\text{m}}\text{Tc}$  product have reached the requirements such as the specific activity of 23 mCi  $^{99\text{m}}\text{Tc}/\text{ml}$ , the radiochemical purity of 99.95%, and nuclear purity of 99.59%.

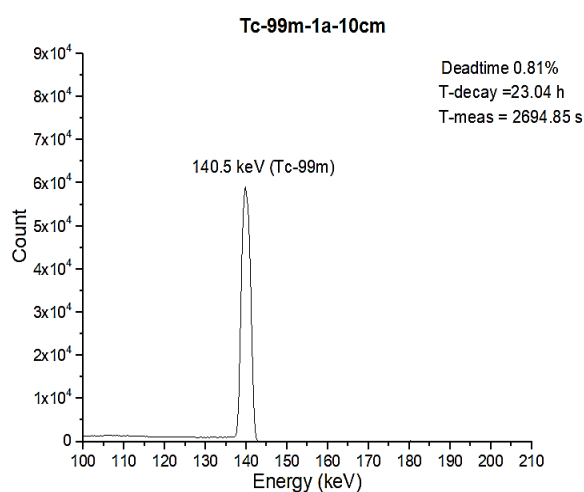


Figure 1. The nuclear purity of  $^{99\text{m}}\text{Tc}$  solution extracted from generator

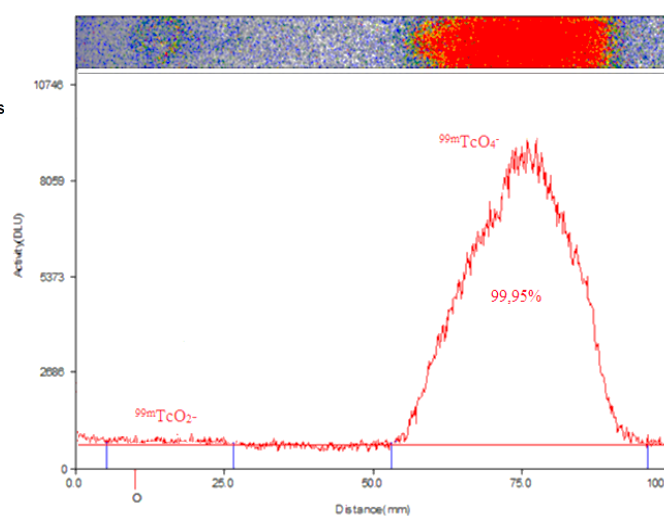


Figure 2. The radiochemical cleanliness of  $^{99\text{m}}\text{Tc}$  solution extracted from the generator

The criteria set out in the study were almost achieved, such as the synthesized ferrite material had a spinel structure, the surface area of activated carbon was 2118  $\text{m}^2/\text{g}$  (the required value  $>2000$ ), the adsorption capacity of AC/MF was 313.40  $\text{mg}/\text{g}$  and AC/NF was 334.06  $\text{mg}/\text{g}$  (the required value  $>200$ ); The test results of  $^{99\text{m}}\text{Tc}$  solution extracted from the generator column: the nuclear purity was  $>99\%$  (the requirement is  $>95\%$ ), the radiochemical purity was 99.95% ( $>99.9\%$  required) and the radioactivity was over than 300mCi. Nonetheless, there are still some limitations, such as the chemical cleanliness of activated carbon (only around 95%) and the quality of  $^{99\text{m}}\text{Tc}$  extracted product can be impacted because the composite materials had a considerable number of residual ferrite nanoparticles that, when rinsed, can go through the filter membrane of the chromatographic column. In the future, we will continue to our study to improve the technological process of preparing activated carbon as well as composite materials with

high chemical purity to reach the quality requirements for production applications of generator on Da Lat nuclear reactor.

## **2.10. COMPUTATION AND OTHER RELATED TOPICS**

## CALCULATION OF PARTITION COEFFICIENTS OF SOME PFCs GAS TRACER IN TWO CONDENSATE-GAS PHASES AT RESERVOIR CONDITIONS

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Nguyen The Duy, Le Thi Thanh Tam, Phan Van Phuc

*Centre for Applications of Nuclear Technique in Industry, No. 01, ĐT723, Ward 12, Da Lat  
City, Lam Dong Province, Viet Nam*

### Project information:

- **Project name:** Calculation of partition coefficients of some PFCs gas tracer in two condensate-gas phases at reservoir conditions
- **Code:** CS/22/06-01
- **Managerial Level:** Institute
- **Duration:** Jan 2022 – Dec 2022
- **Contact email:** sonlv@canti.vn
- **Published papers related to the project:**

1. Le Van Son et al., Validation of the calculating method of the distribution coefficient of PFCs gas tracer in hydrocarbon-gas phases by experiments, Conference on Nuclear Science and Technology for Young Scientists, Hanoi, 2022.

Gas injection is one of the methods applied to improve the extraction efficiency of condensate - gas reservoirs, help to maintain the reservoir pressure higher than the dew point pressure, and reduce damage caused by the back-condensation process. The movement of the injected gas in the condensate-gas reservoir is generally very complicated because the mixing phases vary with each pressure and temperature condition. Therefore, it is necessary to monitor the movement of injected gas by the tracer method, which helps to provide much important information such as the connection between the injection well and production well, reservoir heterogeneity, the saturation of phases, the velocity, and the swept volume of the injected gas.

Perfluorocarbons (PFCs) are widely used in inter-well tracer tests because of their outstanding advantages such as durability and environmental friendliness. During the movement in the reservoir, the distribution of the gas tracer PFCs in the two condensate-gas phases is characterized by the partition coefficient  $K_d$  - the ratio of the concentrations of the PFCs in the two condensate-gas phases at reservoir conditions. This experimental parameter allows determining the gas distribution from the injection well to the production well and the saturation of the phases in the reservoir. However,  $K_d$  measuring experiments are quite costly and require a lot of specialized equipment. Calculating the partition coefficients of the PFCs gas tracers in the two condensate-gas phases will help design the tracer experiment and extrapolate the experimental  $K_d$  values at the desired pressure and temperature.

This research focuses on building a method to calculate the partition coefficient of the gas tracer PFCs in the two condensate-gas phases at reservoir conditions through the relationship between the equilibrium coefficient of the tracer, the density, and the average molecular mass of the phases. To verify the calculation method, the experiments to determine  $K_d$  of PFCs were carried out at the temperature of 70°C and the pressure range of 1000 - 2000 psi on condensate-gas samples collected from the Su Tu Trang reservoir. The selected PFCs in this research are PMCP (Perfluoromethylcyclopentane), PMCH (Perfluoromethylcyclohexane), PDMCH (Perfluoro-1,2-dimethyl cyclohexane), PTCH (Perfluorotrimethylcyclohexane) because of reasonable price as well as its high chromatographic resolution.

The results show that the estimated  $K_d$  coefficient from the calculation method gave an error of about 10% compared to the reference value from the experiment (Figure 1). In addition, the study also proposed a correction for the dependent parameter of empirical correlation (Standing, 1979) for PFCs equilibrium coefficient in condensate – gas phases.

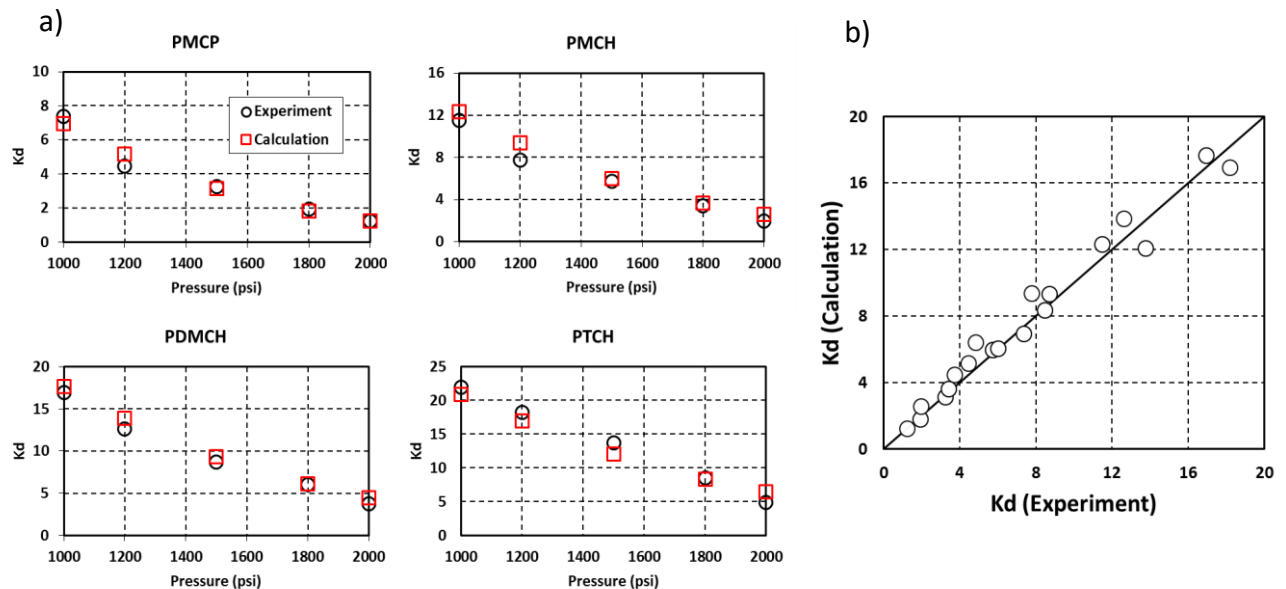


Figure 1. a) The calculated and measured partition coefficient on the condensate-gas phases at 70°C and 1000 – 2000 psi; b) The error between the calculated  $K_d$  and measured  $K_d$  in the range of 10%.

The calculation method will be a useful tool to estimate the partition coefficient for calculating the amount of tracer injected into the reservoir, the amount of recovered tracer, and the phase saturation, which can support the application of tracer techniques of CANTI in condensate-gas reservoir investigations. In addition, the calculation method can also be extended as part of the algorithm for simulating the movement of the PFC gas tracers using the E300 software to explain the tracer results and improve the simulation model of oil companies.

## ADDITIONAL STUDY OF THE SOURCE TERM DUE TO CS-137 FALLING FROM THE ATMOSPHERE ALONG THE RADIOACTIVE CLOUD ORBIT IN THE DELFT-3D MODEL

Tran Quang Thien<sup>1</sup>, Vo Thi Mong Tham<sup>1</sup>, Nguyen Minh Dao<sup>1</sup>, Le Xuan Thang<sup>1</sup>, Tran Tuan Anh<sup>1</sup>, Vu Duy Vinh<sup>2</sup>, Pham Kim Long<sup>3</sup>

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### Project information:

- **Project name:** Additional study of the source term due to Cs-137 falling from the atmosphere along the radioactive cloud orbit in the DELFT-3D model.

- **Code:** CS/22/01-02

- **Managerial Level:** Institute

- **Duration:** 12 months (Jan 2022 - Dec 2022)

- **Contact email:** tranquangthien@outlook.com / tqthien@nri.gov.vn

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

1. Tran Quang Thien, Nguyen Trong Ngo, Vu Duy Vinh, Nguyen Xuan Hai, Pham Kim Long, "Simulation of Cesium-137 dispersion in ocean from Fukushima accident using Delft-3D", The 7th Nuclear Science and Technology Conference of young scientist, Hanoi, October 2022.

2. Tran Quang Thien, Nguyen Trong Ngo, Vu Duy Vinh, Nguyen Xuan Hai, Pham Kim Long, "Effect of air deposition source on the short-period water dispersion simulation of Cesium-137", Nuclear Science and Technology, Vietnam Atomic Energy Institute, Vol. xx, pp. xx-xx, 2023.

The Fukushima accident has been widely studied in simulations utilizing models of radiation dispersion in the aquatic environment with hypothetical scenarios. Most scenarios have assumed that radioactive substances were discharged directly from a nuclear power plant (NPP) as the only source term. The calculations for such hypothetical scenarios are simple in simulations. However, in fact, the source term from Fukushima was due to the discharge of radioactive substances not only from NPP into the marine environment but also from the atmospheric deposition. The lack of connection between the radioactive source deposited from the atmosphere and the source of radioactive discharge directly into the marine environment in the simulation studies of radioactive dispersion in seawater has led to the inaccuracy in simulation results of dispersion, especially in the simulation of

radioactive material dispersion near the NPP site. This project combined two dispersion simulation models, FLEXPART in atmospheric and DELFT-3D to simulate Cs-137 radioactive dispersion in the ocean.

The Lagrangian particle dispersion model in version 9.02 of FLEXPART was driven by hourly meteorological data from the US National Center for Environmental Prediction (NCEP). For the source term, we employed the Cs-137 release rate into the atmosphere based on the estimation by Katata et al., 2015. The FLEXPART model was applied for an area with longitude is from 135.00 to 180.00 and latitude 20.00 to 55.00 and with a grid cell of  $0.10 \times 0.10$  degrees. The emission time of the isotope Cs-137 according to Katata is from 15:00 11/3/2011 to 00:00 20/4/2011 UTC with a total emission of 14.5 PBq. The output of atmospheric dispersion simulation was the radionuclides concentration in the air, dry and wet depositions at the ground and sea surface, the dose rate in the air and other relevant quantities.

The hydrodynamic, wave and particle tracking tool in DELFT3D model were used to simulate the dispersion of Cs-137 in the ocean. The coordination grid used for the model is an orthogonal curved grid system. The coordination grid for this area is more distributed in coastal areas, islands and more widely in offshore areas where the topography is less variable. Specifically, the coordination grid is from 100-500 m in the coastal area of Japan and gradually increases to the middle of the Pacific Ocean with a coordination grid of 1-10 km. The material used in the hydrodynamic model includes:

- The seabed topography of the study area was taken from the GEBCO-08 database with a resolution of 0.50 degrees is processed from satellite images combined with depth data; the topography along the coast of Japan has a depth of less than 1000 m and as far as the middle of the Pacific Ocean is from 1000-8000 m.

- Computational model of the simultaneous association of the basic hydrodynamic - wave - tracer processes in DELFT3D. The meteorological data includes wind, pressure, and temperature fields for the entire East Japan Sea with a space resolution of 0.1 degrees and time step is 6h/time of the NCEP.

- The tidal harmonic constant database with 13 main tidal components (M2, S2, K2, N2, O1, K1, P1, Q1, MF, MM, M4, MS4, MN4) is collected and processed from LEGOS database FES2014, the TPX08 Atlas of Oregon State University (USA) and Hydrographic and Oceanographic Department – Japan Coast Guard (Japan).

The DELFT-3D model has a function for tracking the tracer in the mass fraction. For Cs-137 radioactivity in unit of Bq, the DELFT-3D function was used to convert from the mass to activity conversion factor:  $A = \lambda \cdot m \cdot N_A / M$ ; Where: A is activity of Cs-137;  $\lambda$  is nuclear decay constant; m is mass of Cs-137;  $N_A$  is Avogadro number; M is atomic number of Cs-137.

In addition, the study selected a number of points around the Fukushima nuclear power plant at different distances in order to compare and evaluate the simulation results of the model and the observed values at Fukushima.

Simulation results from FLEXPART showed that the total amount of Cs-137 radionuclides falling into the marine environment was 4.93 PBq. This result is similar to those of some other authors such as Estourn et al. (2012) with a value of 5.1-5.5 PBq or Kawamura et al. (2017) 4.75 PBq. The source term of Cs-137 deposition from the air (4.93 PBq) was combined with the source term of direct discharge from the Fukushima NPP accident due to wastewater leakage during accident (3.53 PBq) for simulation dispersion by DELFT3D. The results of Cs-137 radionuclides content in the marine environment from DELFT3D's simulation for this synthetic source term show that, Cs-137 radionuclide moves faster in the air deposition combined with direct discharge scenario than the direct discharge scenario from NPP. For the depth distribution, the deep water layers have lower concentrations of Cs-137 than the surface layers. It may be due to undersea currents that make the dilution of Cs-137 slower in the bottom layers, as well as the radioactivity mainly deposited on the surface and takes time to diffuse down to the aquifers. After this initial period of dispersion, the depth content will be balanced again between layers. The trend of Cs-137 concentration in the surface layer is also found in 5 dispersion models of Kawamura et al (2017). The simulation results of DELFT3D using combination source terms evaluated through Person correlation test with JAEA observational data set show that they have rather good similarity with correlation coefficient  $r = 0.74$ .

The following are two recommendations for further research. The first is applying different hydrometeorological data sets (NOAA, NCEP, ...) to the DELFT3D model in order to evaluate and find the hydrometeorological data sets suitable for radioactive dispersion in the marine environment. The second is developing codes to automatically integrate the data of the source terms deposition of radioactive isotopes from the air into the DELFT3D model, currently in this topic the source term data is being entered manually.

## RESEARCH AND ASSESSMENT OF THE IMPACTS OF WATER IN TOUCH HEAT TRANSMISSION USING SOME EXPERIMENTAL DATA

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<sup>2</sup>Institute for Nuclear Science and Technology, 179 Hoang Quoc Viet, Cau Giay, Hanoi

### Project information:

- **Project name:** Research and assessment of the impacts of water in touch heat transmission using some experimental data

- **Code:** CS/22/10-02

- **Managerial Level:** Institute

- **Duration:** 12 months (Jan 2022- Dec 2022)

- **Contact email:** tttram80@yahoo.com

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

1. Hoang Tan Hung et al., A study of void fraction correlations used slip-ratio models, The seventh Conference of Nuclear Science and Technology for young nuclear energy staff, Hanoi, Vietnam, Otc. 2022.

2. Tran Thanh Tram et al., A study of void fraction correlations used slip-ratio models, Journal of Nuclear Science and Technology (NST), ISSN:1810-5408, (accepted December 16, 2022).

In thermal-hydraulic safety analysis, the evaluation of the change in flow regimes, heat transfer, and pressure drop is based on knowledge of the void fraction, which varies between 0 and 1, for single-phase liquid and single-phase gas. Scientists have conducted plenty of void fraction measurements to understand and improve the accuracy of the void fraction parameter. Experimental correlations are developed to evaluate theoretical models against measured data as well.

Nowadays, many theoretical and experimental void fraction correlations have been developed and used in the world. Experimental methods have been designed and constructed by varying the size and length of the experimental system over a different temperature and pressure range for vertical and horizontal channels. The theories are mainly based on the simplification of the assumptions which are applicable to a particular flow regime. Therefore, it is impossible to universally apply the results to complex two-phase phenomena such as boiling that includes several different flow regimes, from bubbly to separate flows.

In this research, our research group focus on evaluating these selected correlations based on experimental data measured on mixed steam-water systems on horizontal and vertical channels. However, instead of considering both types of channels as Smith

recommended, we suggest a separate assessment for each type of channel because its unique characteristics.

This project includes three main subjects as such: (1) An overview of void fraction models and experimental systems to measure void fraction; (2) Evaluation of different void fraction models based on horizontal experimental data of Haywood; (3) Evaluation of different void fraction models based on vertical experimental data of Marcheterre and Cook.

**In terms of methodology**, void fraction models were developed based on MATLAB software associated with steam tables taken from REFPROP software.

In this research, our research group used data that are measured on experimental systems on the horizontal channel of Haywood and the vertical channel of Marcheterre and Cook. These systems were chosen because they use a steam-water mixture that was measured over a fairly wide range of pressure variations. Haywood's horizontal channel experimental system was measured over a wide pressure range of 1.72 to 14.5 MPa to measure void fraction based on the gamma-ray beam method. The Marcheterre and Cook systems were also performed over a relatively wide pressure range from 0.69 MPa to 4.14 MPa.

**Regarding tools**, calculations and evaluation of void fraction correlations were developed based on MATLAB software in combination with the Steam Table taken from REFPROP software. The MATLAB is packed with many commands and mathematical functions, helping users to perform numerical calculations, plot graphs and perform numerical methods in a convenient way. Another special feature of this software which makes it to be quite widely used is that it enables users to exploit available libraries taken from other software. The REFPROP provides vapor tables based on subroutines that calculate the thermodynamic and transport properties at a given  $(T, x)$  state. An in-house interface program were developed for iteration calculation to obtain the saturation properties for a particular state  $(T, x)$  or  $(P, x)$  and quick computation in one or two phase states with multiple input types combined  $[(P, h, x), (P, T, x), \text{etc.}]$

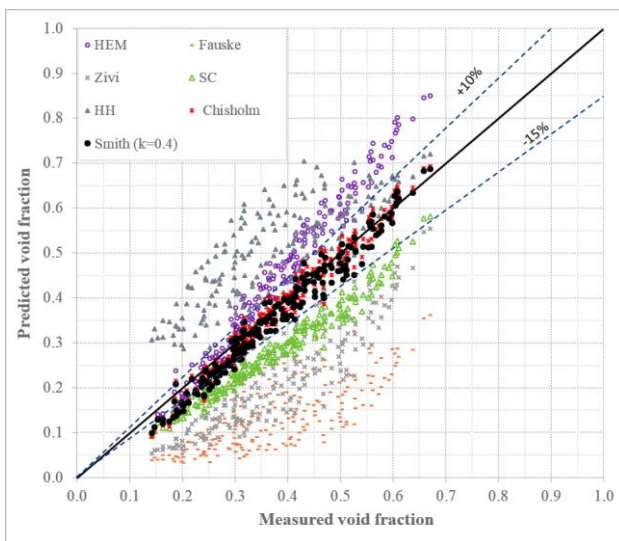
The main results of the research is presented below.

Based on 14 original void fraction correlations, through the survey, seven representative correlations were selected. Those seven correlations were further evaluated based on the experimental data measured on the horizontal channel of Haywood and the vertical channel of Marcheterre and Cook.

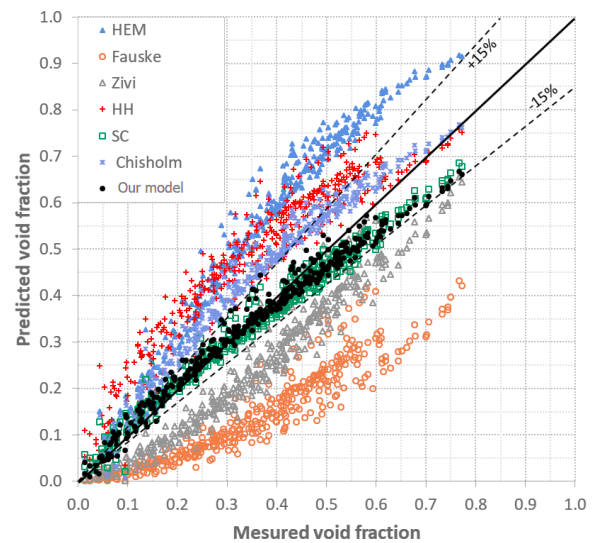
The analysis results show that the entrainment factor,  $k$ , in the Smith model, were found out be well applied to the horizontal channel with the entrainment factor  $k$  of 0.4. However, Smith's model in the horizontal channel is not as accurate as that in the proposed vertical channel. As the analysis results, the entrainment factor of 0.2 was selected for the vertical channel in the Smith. Therefore, Smith model was used for the calculations of void fractions on horizontal channels. Our proposed model primarily based on Smith model and

then modified with a modified entrainment factor of 0.2, was used in the calculation of vertical channel void fraction.

The comparisons of the void fraction predictions of the horizontal and vertical channels are shown in the Fig. 1. Based on the compared results of void fraction predictions between the horizontal and vertical channels, it can be concluded that Smith model with his entrainment factor  $k$  of 0.4 presents the best model for predicting void fraction in the horizontal channel. Our proposed model, modified the Smith model with the entrainment factor of 0.2, gives a better prediction the void fraction on the vertical channel.



a, Comparing the predictive accuracy of the chosen void fraction correlations on the horizontal channel



b, Comparing the predictive accuracy of the chosen void fraction correlations on the vertical channel

Figure 1. Comparing the predictive accuracy of the chosen void fraction correlations.

In conclusion, our research group has achieved the research objectives and fully completed the registered contents and products. It could be found from this research that each type of horizontal or vertical channels should use a certain void fraction correlation because of its own physical characteristics. The results from our evaluation reconfirm that the Smith correlation with his entrainment factor  $k$  value of 0.4 can be applied to calculate the void fraction for the horizontal channel. Our proposed model based on the modified Smith correlation with a entrainment factor  $k$  value of 0.2 can be used in the calculation of the void fraction for the vertical channel.

By implementing this project, the project team has gradually improved the programming ability using MATLAB software, digitizing most of the drawings which were previously done by the Excel. Also, the results of this project have partly supported the research team leader's doctoral thesis. In the upcoming time, the research team plans to further evaluate the proposed porosity models for gas-water mixtures or other refrigerants.

# **3- PHOTO ALBUM**

**A Wrap-up of VINATOM significant EVENTS  
in 2022**

### 3.1. RESEARCH AND DEVELOPMENT CENTER FOR RADIATION TECHNOLOGY



*The visit of the Minister of science and technology to Vinagamma Center*



*Welcome the Minister of science and technology to visit and work at Vinagamma Center*



*Scientific visit of FIJI officials at Vinagamma Center*



*Scientific visit of FIJI officials at Vinagamma Center*



*Workshop on phytosanitary irradiation for fruits*

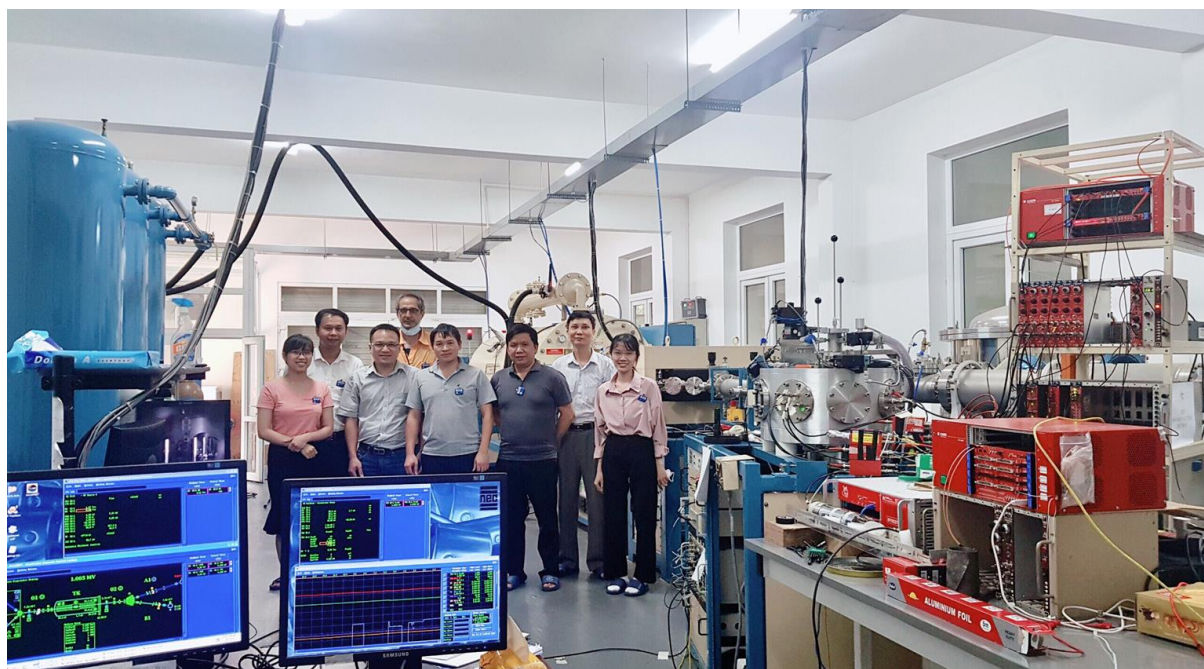


*The closing ceremony and conference of Official –Labour 2022*

## 3.2. INSTITUTE FOR NUCLEAR SCIENCE AND TECHNOLOGY



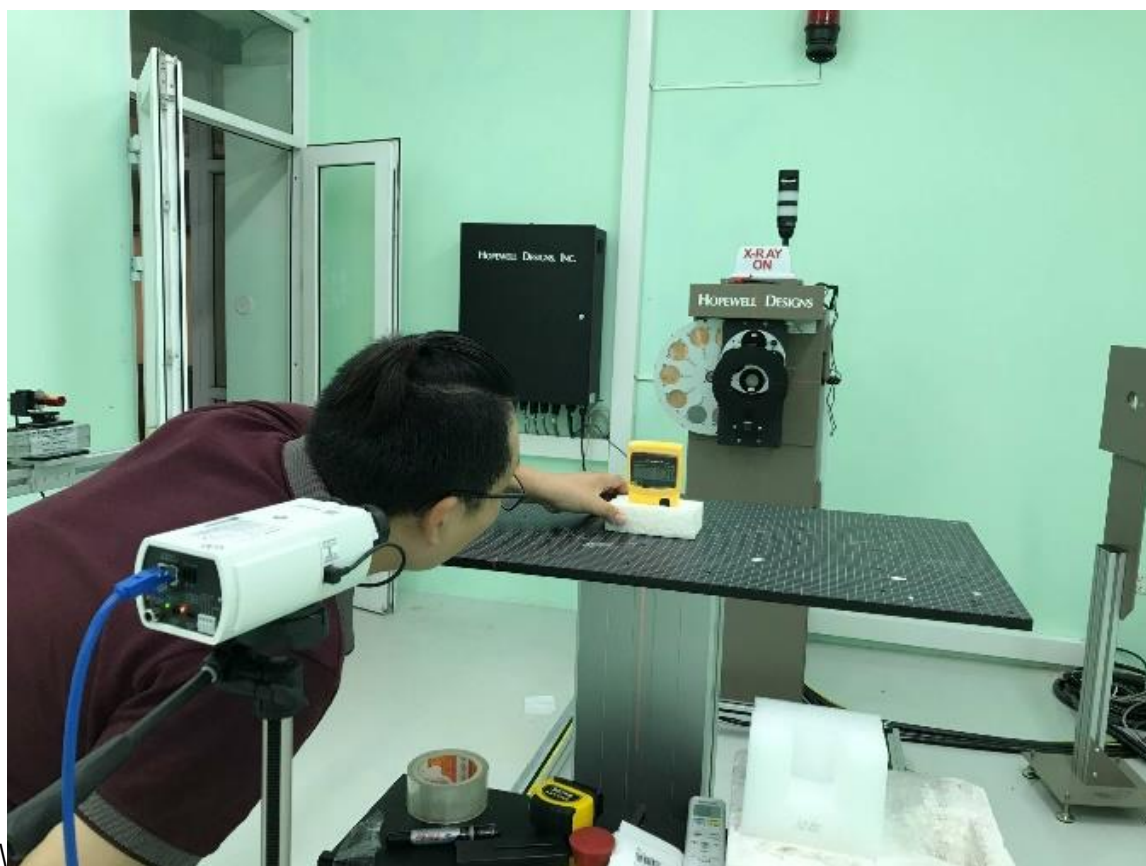
*Training on Nuclear/Radiological Emergency Preparedness*



*The research team of the Center for Nuclear Physics, INST conducted an experiment at the Hanoi University of Science*



*Dr. Le Xuan Chung presents a research result at OMEG16 symposium.*



*Calibration of radiation equipment*



*QA-QC linear accelerator in radiotherapy according to National technical regulation on linear accelerator in radiotherapy*



*Radiological and Nuclear Emergency Preparedness Training Course.*



*Ph.D Nguyen Huu Tiep presented his PhD research results after graduating from UST university of Korea*



*MSc. Nguyen Thi Dung reported at the 7th Conference on Nuclear Science and Technology for Young Researchers*



*Successfully organized the 10<sup>th</sup> Training Course on Reactor Engineering*



*Environmental radiation monitoring system VinaERMS-INST have installed in Lang Son*



*COSMOS-VINATOM System-Cosmic-ray Soil Moisture Observing System  
(Ministerial Project of 2021-2022)*

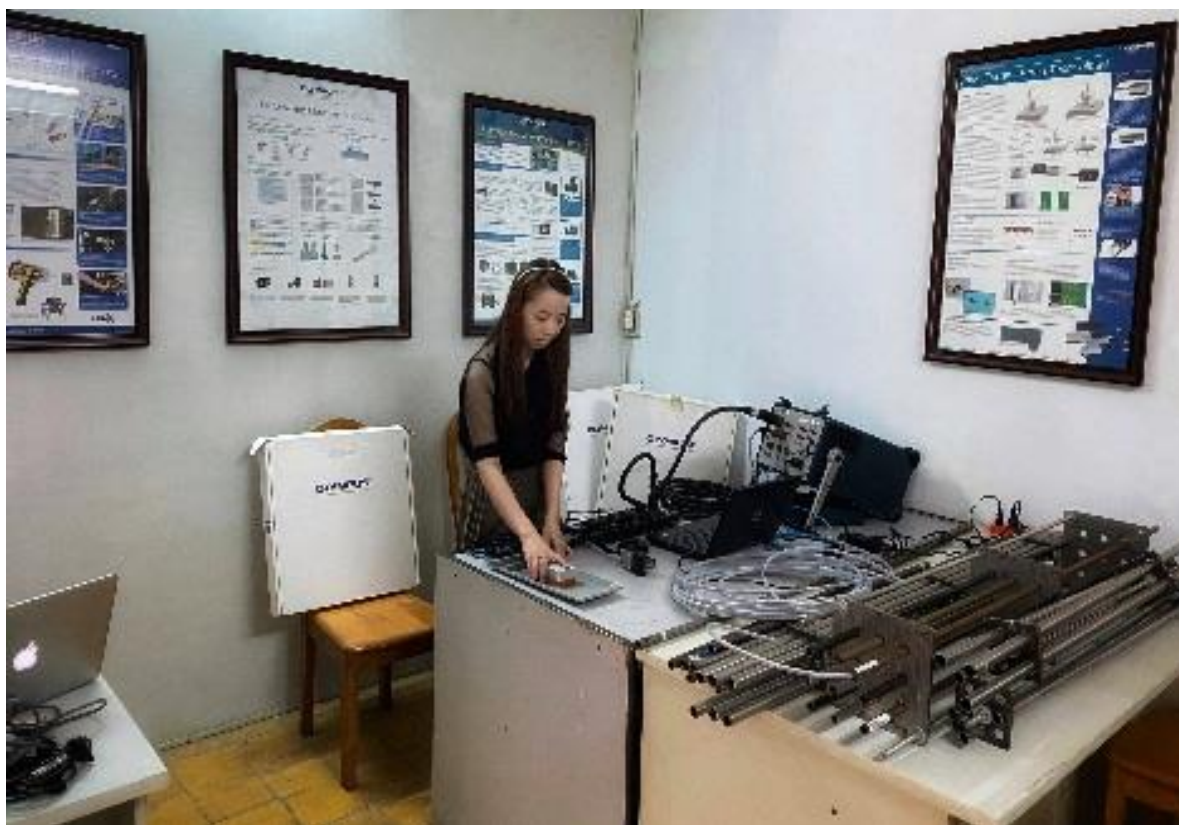


*Scientists from the Joint Institute of Nuclear Research, Dubna, Russia visit INST*



*Students and lecturers from the University of Wollongong, Australia visited neutron calibration laboratory at INST*

### 3.3. CENTER FOR NUCLEAR TECHNIQUES



*Eddy Current and Eddy Current Array Examination in the studies on Laboratory.*



*Eddy current Examination for in-service inspection on site.*

### 3.4. NON-DESTRUCTIVE EVALUATION CENTER



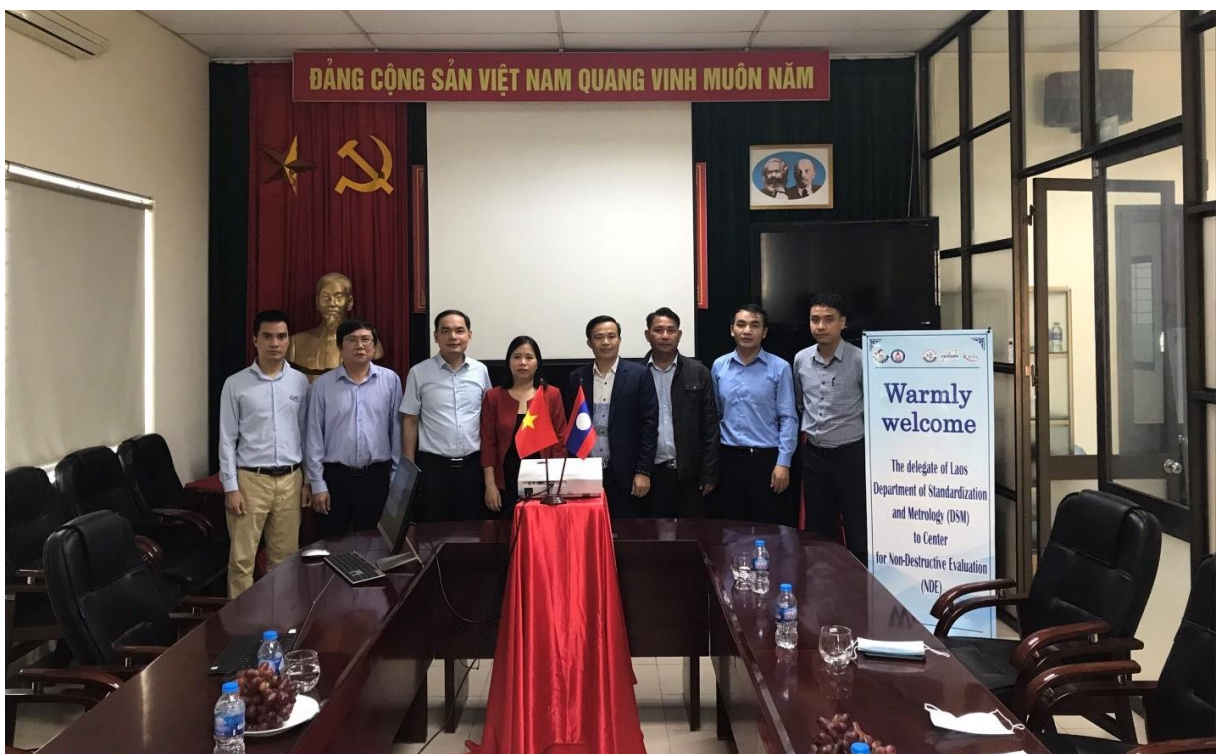
*Attend the Training Course on Radiographic Testing - Digital (RT-D) Level 3 in Thailand*



*Meeting of Advisory Council for Evaluation and Acceptance of ministerial-level projects:  
Building up a quality system for training NDT technicians according to ISO 9001:2015 and  
ISO 25108*



*Member of the IAEA Expert Delegation to help the Lao People's Democratic Republic develop atomic energy applications within the framework cooperation between Vietnam-IAEA-Laos*



*Training course on Non-Destructive Testing methods level 1 for Department of Standardization and Metrology (DSM), Laos*



*The delegation of the Ministry of Mines and Energy (MME), Cambodia visited and worked at the Center for Non-Destructive Evaluation*



*The seminar on “The method of measuring density, moisture by nuclear method” at NDE*



*Training course on Non-Destructive Testing according to ISO 9712*



*The trainees of the training course on Non-Destructive Testing methods*



*Deployment maintenance of thermal power plant in AES Mong Duong*



*Deployment Non-Destructive Testing (NDT) service*

### 3.5. NUCLEAR RESEARCH INSTITUTE



*Radiopharmaceutical products and tracer KITS are produced and supplied to Nuclear Medicine departments*



*Products for agriculture*



*Cymbidium orchid tissue culture room*

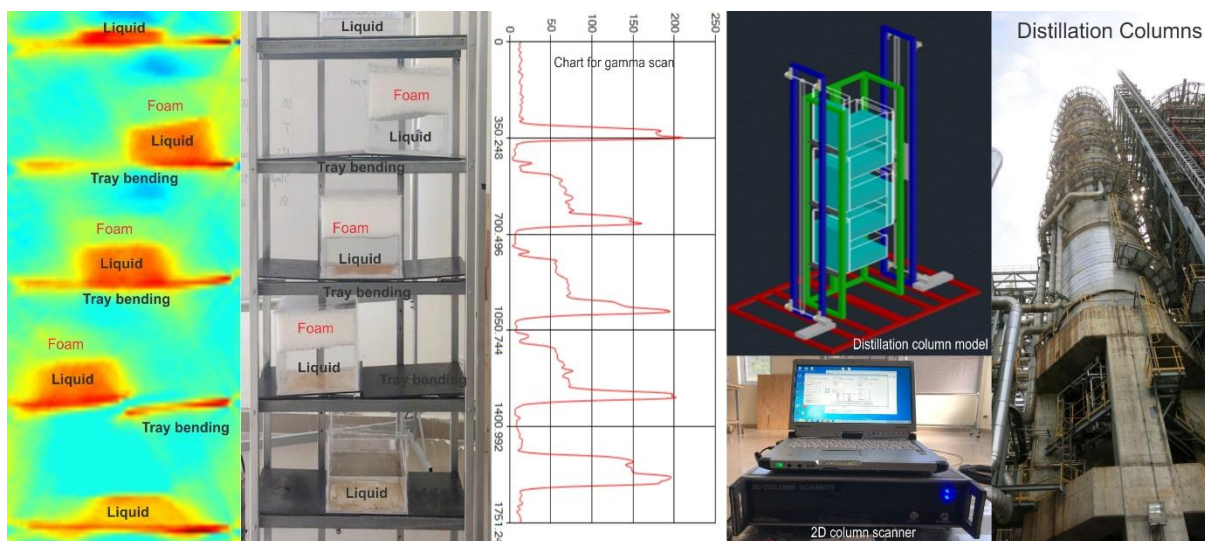


*Practical guide for students in the Reactor control room*

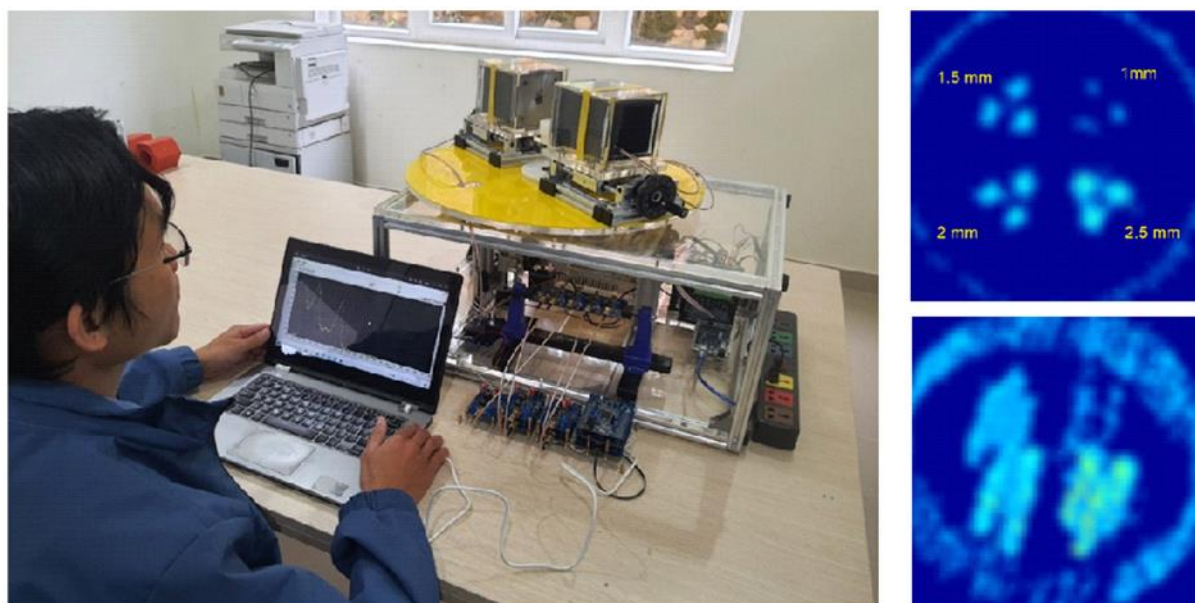


*Some agricultural products are certified by Nuclear Research Institute with VietGap*

### 3.6. CENTER FOR APPLICATION OF NUCLEAR TECHNIQUES IN INDUSTRY



*2D Tomography – New gamma scan technique for distillation column in industry*



*The prototype small-animal SPECT scanner. Upper and lower right: 2D and 3D distribution of Tc-99m inside Derenzo phantom obtained by the scanner.*

### 3.7. NUCLEAR TRAINING CENTER



*Organizing the Committee of Professors at the Vietnam Atomic Energy Institute in evaluating of considered qualification of Associate Professor*



*Organizing the short training course for staffs of Vinatom and EVN on thermal-hydraulic nuclear safety- Hanoi October 25-26, 2022)*



*Teachers' Gratitude Ceremony and PhD Award Ceremony in 2022 – Nov 17, 2022)*



*The Institute-level defense ceremony of PhD thesis of PhD student Nguyen Huu Quyet - Hanoi, January 26, 2022)*



*The Institute-level defense ceremony of PhD thesis of PhD student Ly Duy Nhat*



*The Institute-level defense ceremony of PhD thesis of PhD student Tran Viet Phu*



*The Institute-level defense ceremony of PhD thesis of PhD student Bui Duy Linh*



*The Institute-level defense ceremony of PhD thesis of PhD student Nguyen Van Dung - Hanoi, August 27, 2022)*



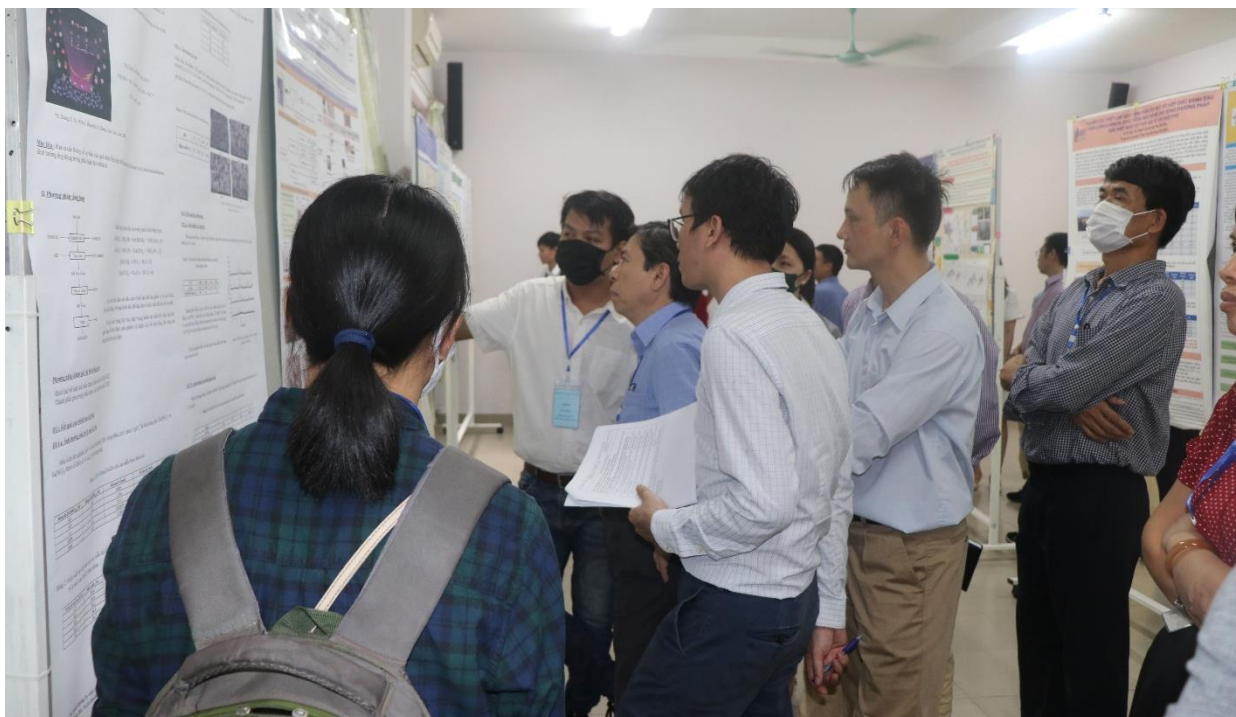
*The Institute-level defense ceremony of PhD thesis of PhD student Kieu Ngoc*



*The Institute-level defense ceremony of PhD thesis of PhD student Nguyen Hoang Phuc in supporting Company (Hung Thinh) on placer research*



*Group photo of Conference on Nuclear Science and Technology for young researchers in the field of atomic energy*



*Poster Session at Conference on Nuclear Science and Technology for young researchers in the field of atomic energy*



*Opening Ceremony at Conference on Nuclear Science and Technology for young researchers in the field of atomic energy*



*The participation of Youth Union in the Conference on Nuclear Science and Technology for young researchers in the field of atomic energy*

### 3.8. HANOI IRRADIATION CENTER



*Maintaining the operation of the KOTRON-13 Accelerator*



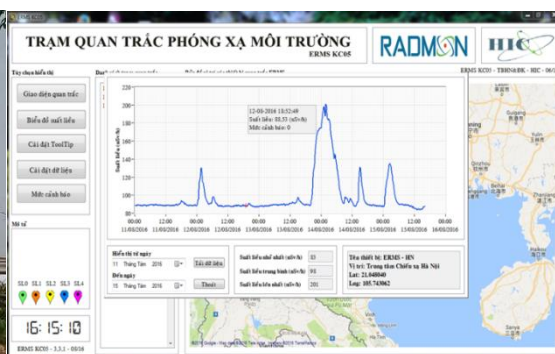
*Maintaining the operation of the KOTRON-13 Accelerator*



*Fabrication of  $^{18}\text{F}$ -NaF radiopharmaceutical production module and pre-clinical testing of  $^{18}\text{F}$ -NaF radiopharmaceutical produced at Hanoi Irradiation Center*



*Connect the waveguide and adjust the RF system for the KOTRON-13 Accelerator device within the framework of a ministerial-level project*

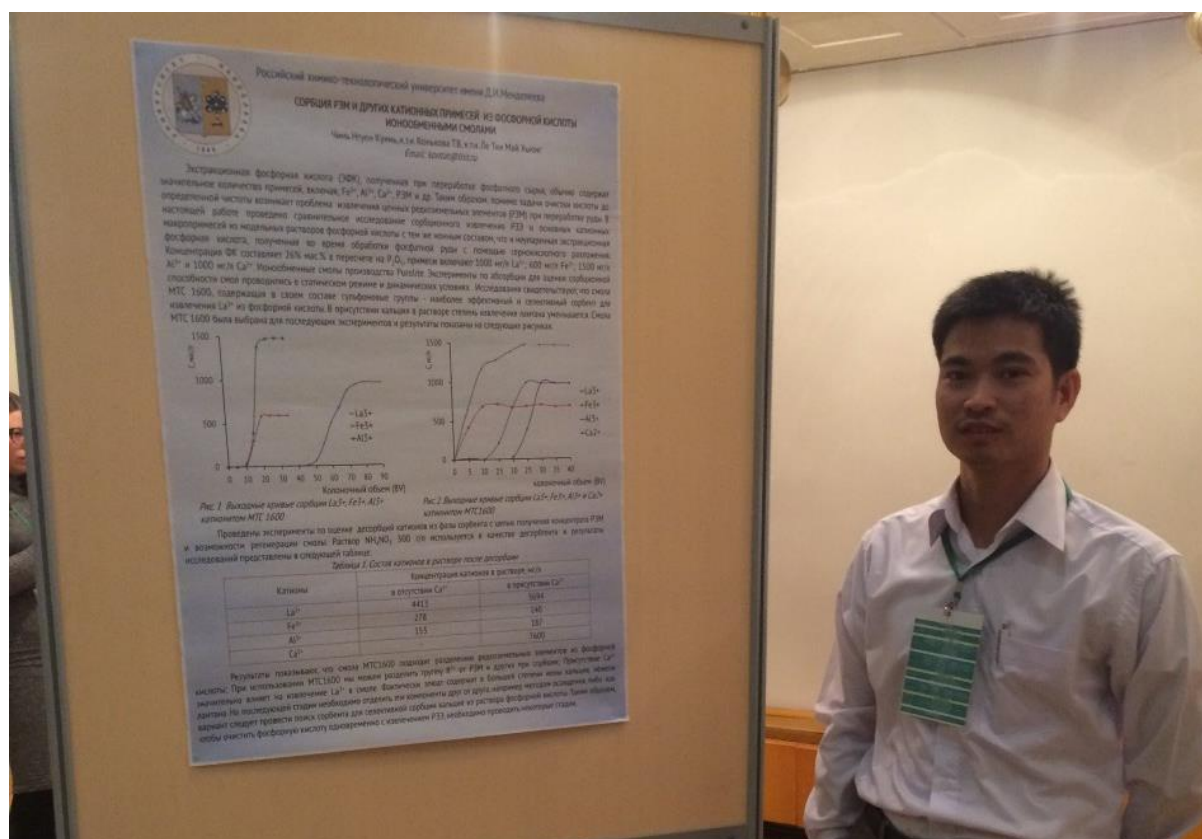


*Fabrication and installation of environmental radiation monitoring equipment in Lao Cai province within the framework of State level project KC05*

### 3.9. INSTITUTE FOR TECHNOLOGY OF RADIOACTIVE AND RARE ELEMENTS



Technical support on the response to the nuclear and radiation incidents in DaK Nong



The center's representative participated in a scientific conference in Moscow, Russia 2021.



*Scientific research in the Laboratory*



*Applications in agriculture*



*Application of rare earths in agriculture*

### 3.10. HEADQUARTERS, HA NOI



*Working Session with Cambodia Ministry of Mines and Energy*



*Representative of Cambodia Ministry of Mines and Energy delivered a speech*



*Representatives from Indian Embassy in Hanoi paid a visit and worked with VINATOM*



*Virtual training about Beach sand processing given by Profs and Lecturers from Indian rare earth corporation (DAE)*



*The 1<sup>st</sup> Meeting of Vietnam-Russia Working group on Cooperation in SMR research*



*The 1<sup>st</sup> Meeting of Vietnam-Russia Working group on Cooperation in SMR research*



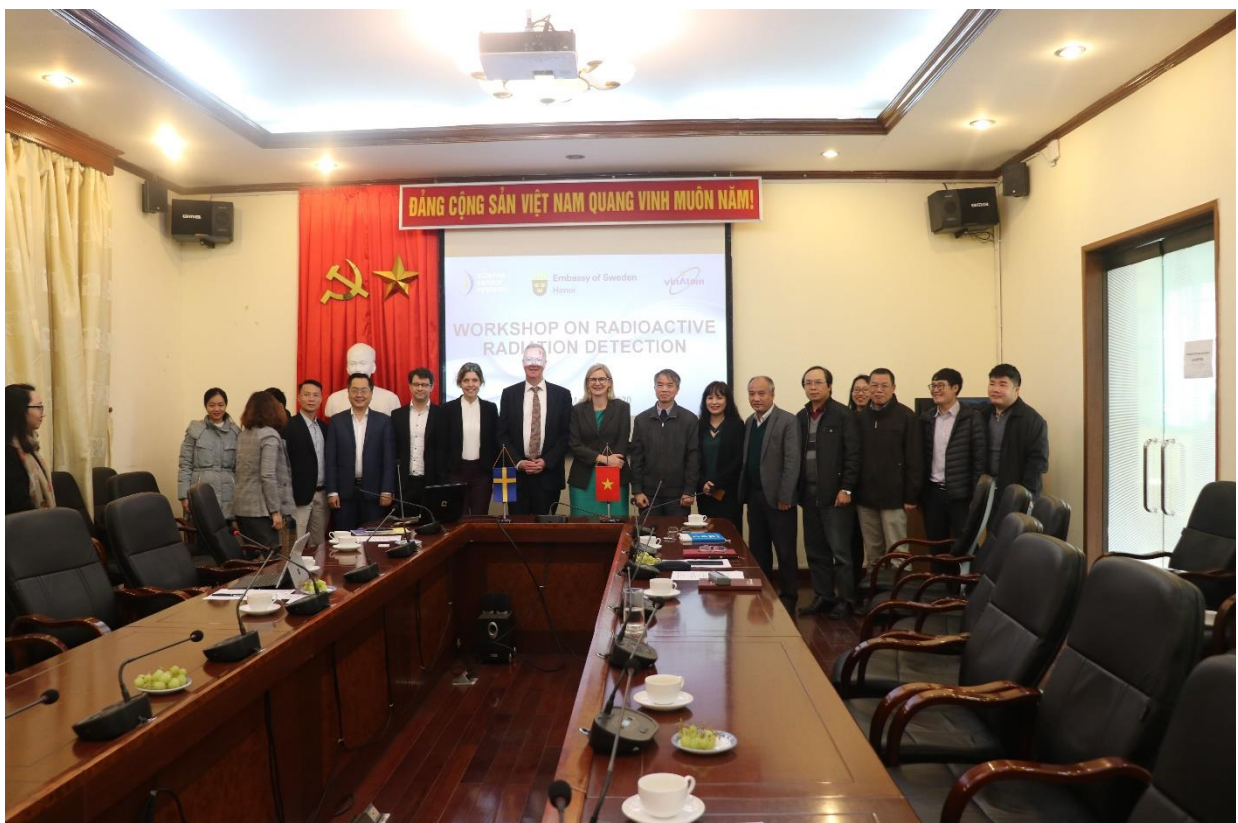
*The 44<sup>th</sup> Regional Meeting of National RCA Representatives*



*The 44<sup>th</sup> Regional Meeting of National RCA Representatives*



*Collaboration with Tokyo Institute of Technology on research of Thermal-hydraulic and nuclear safety*



*The workshop on radiation protection*



*The workshop on radiation protection*



*The workshop on radiation protection*



*President Tran Chi Thanh made opening speech at the IAEA/RCA Regional Training Course on Developing a protection strategy for a nuclear or radiological emergency*



*Participants at the IAEA/RCA Regional Training Course on Developing a protection strategy for a nuclear or radiological emergency*



*The 12<sup>th</sup> Forum of Vietnam -Japan on Nuclear Power Development (Vietnam side in Hanoi)*



*The 12<sup>th</sup> Forum of Vietnam -Japan on Nuclear Power Development (Japanese side)*



*The 12<sup>th</sup> Forum of Vietnam -Japan on Nuclear Power Development (Vietnam side in Dalat)*



*The Year-End meeting*



*The Minister made a speech at the Year-End Meeting*



*The President made a speech at the Year-End Meeting*



*The Ceremony of Awarding Associate Professor Degree*

# 4- APPENDICES

#### 4.1. LIST OF VINATOM'S INTERNATIONAL SCIENTIFIC PUBLICATIONS IN 2022

| No | Name of publications                                                                                                                                  | Authors                                                                        | Journals                                                                                  |
|----|-------------------------------------------------------------------------------------------------------------------------------------------------------|--------------------------------------------------------------------------------|-------------------------------------------------------------------------------------------|
| 1  | $\gamma$ -ray spectroscopy of low-lying yrast and non-yrast states in neutron-rich $^{94,95,96}\text{Kr}$                                             | R.-B. Gerst, L.X. Chung, et al.                                                | Physical Review C 105 (2022) 024302<br>Published: 3 Feb. 2022                             |
| 2  | A first glimpse at the shell structure beyond $^{54}\text{Ca}$ : Spectroscopy of $^{55}\text{K}$ , $^{55}\text{Ca}$ , and $^{57}\text{Ca}$            | T.Koiwai, K. Wimmer,..., L.X. Chung, et al.                                    | Physics Letters B, Volume 827, 10 April 2022, 136953                                      |
| 3  | Implementation of a Geant4-based code using low-energy gamma-nuclear final state model for photonuclear studies                                       | L.T. Anh, et al.                                                               | Nuclear Instruments and Methods in Physics Research A, Volume 1027, 11 March 2022, 166285 |
| 4  | Spin symmetry energy and equation of state of spin-polarized neutron star matter                                                                      | Nguyen Hoang Dang Khoa, Ngo Hai Tan, and Dao T. Khoa                           | Phys. Rev. C 105, 065802 (2022)<br>Published: 14 June 2022                                |
| 5  | An improved analysis of the OECD/NRC PWR MOX/UO <sub>2</sub> core transient benchmark with PARCS/Serpent                                              | Pham Nhu Viet Ha, Donny Hartanto, Thanh Mai Vu, Vinh Thanh Tran, Viet Phu Tran | Annals of Nuclear Energy, Volume 168, April 2022, 108922                                  |
| 6  | Sensitivity and uncertainty analysis of neutronic and kinetic parameters for CERCER and CERMET fueled ADS using SERPENT 2 and ENDF/B-VIII.0           | Thanh Mai Vu, Donny Hartanto, Thoi Nam Chu, Nhu Viet Ha Pham, Thi Hong Bui     | Annals of Nuclear Energy, Volume 168, April 2022, 108912                                  |
| 7  | Comparative evaluation of the performance of improved genetic algorithms and differential evolution for in-core fuel management of a research reactor | Hoai-NamTran, Giang T.T.Phan, Quang BinhDo, Viet-PhuTran                       | Nuclear Engineering and Design, Volume 398, November 2022, 111953                         |

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|----|-----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|--------------------------------------------------------------------------------------------------------|
| 8  | A newly proposed data assimilation framework to enhance predictions for reflood tests                                                                                             | Nguyen Huu Tiep, Kyung Doo Kim, Jaeseok Heo, Chi Woong Choi, HaeYong Jeong                                                                                                   | Nuclear Engineering and Design, Volume 390, 15 April 2022, 111724                                      |
| 9  | Monte Carlo calculation of organ and effective doses due to photon and neutron point sources and typical X-ray examinations: Results of an international intercomparison exercise | Christelle Huet, ..., Duc-Ky BUI, .., Thi-My-Linh DANG, ..., Ngoc-Thiem LE, ..., Ngoc-Quynh NGUYEN, et al.                                                                   | Radiation Measurements Volume 150, January 2022, 106695                                                |
| 10 | Application of stable isotope technique to authenticate the geographical origin of imported apple products                                                                        | Ha Lan Anh, Dang Duc Nhan, Russell Frew, Tran Minh Quynh                                                                                                                     | Journal of Radioanalytical and Nuclear Chemistry 331, 3613-3621 (2022)<br>Published: 23 August 2022    |
| 11 | Pseudo-dielectric function spectra of the near surface layer of GaAs implanted with various fluence of Xe+ ions                                                                   | P.L. Tuan, M. Kulik, T.V. Phuc, A.I. Madadzada, T.Yu. Zelenyak, M. Turek, J. Zuk, C. Mita, A. Stanculescu, A.S. Doroshkevich, B. Jasinska, L.H. Khiem, N.N. Anh, N.T. Bao My | Thin Solid Films, Volume 756, 31 August 2022, 139376                                                   |
| 12 | Investigation of airborne trace element pollution in Hai Phong city (Vietnam) using Barbula Indica moss and neutron activation analysis                                           | Le Hong Khiem, ..., Nguyen Thi Bao My, ..., Duong Duc Thang, Nguyen Thi Dinh, et al.                                                                                         | Journal of Radioanalytical and Nuclear Chemistry 331, 4649-4662 (2022)<br>Published: 26 September 2022 |

|    |                                                                                                                                                |                                                                                                                                                                                  |                                                                                                  |
|----|------------------------------------------------------------------------------------------------------------------------------------------------|----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|--------------------------------------------------------------------------------------------------|
| 13 | Radiation exposure in a region with natural high background radiation originated from rare earth element deposits at Bat Xat district, Vietnam | N. Van Dung, D. D. Thuan, D. D. Nhan, F. P. Carvalho, D. Van Thang, and N. H. Quang                                                                                              | Radiation and Environmental Biophysics (2022) 61:309–324<br><br>Published online: 24 March 2022  |
| 14 | Gross beta and alpha activities in the selected commercial freshwater fish species in Vietnam                                                  | Van Hao Duong, Tien Trung Chu, Thanh Nam Nguyen, Cuong Dinh Le, Luan Thanh Pham, Duc Thang Duong, Huyen Trang Nguyen, Quan Tien Nguyen, Muhammad Yaseen, Mohamed Saiyad Musthafa | Environmental Science and Pollution Research 29, 26002–26010 (2022)<br>Published: 05 March 2022  |
| 15 | Design of reactor physics experiments in support of chloride-fueled Molten Salt Reactor research & development                                 | Thi-Dung Nguyen, W.F.G. van Rooijen                                                                                                                                              | Annals of Nuclear Energy, Volume 181, February 2023, 109479<br>Available online: 18 October 2022 |
| 16 | Feasibility of Breed-and-Burn Reactor Core Design with Nitride Fuel and Lead Coolant                                                           | Odmaa Sambuu, Van Khanh Hoang, Jun Nishiyama & Toru Obara                                                                                                                        | Annals of Nuclear Energy, Volume 182, March 2023, 109583<br>Available online: 28 November 2022   |
| 17 | Assessment of the distribution and ecological risks of heavy metals in coastal sediments in Vietnam's Mong Cai area                            | Bui TTL, Dang HN, Nguyen DV, Nguyen TML, Le NS, Nguyen TH, Bui VV, Duong TN, Le VN, Pham TD, Vo TA, Ha LA, Nguyen TKD, Nguyen MH, Nguyen VC, Nguyen THL                          | Environmental Monitoring and Assessment 195, 164 (2023)<br>Published: 29 November 2022           |
| 18 | Synthesis and characterization of lithium aluminate for passive dosimetry                                                                      | Nguyen Thi Thu Ha, Trinh Van Giap, and Bui Duc Ky                                                                                                                                | World Journal of Nuclear Science and Technology, Vol. 12, No. 1, January 2022.                   |

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| 19 | Evaluation of Interaction between Surface Water and Groundwater in the South of Hanoi City by Stable Isotope Technique                                                | Anh, V., Minh, T., Anh, H., Kien, M., Hoai, V. and Nhan, D.                                                                                                                                                                                                                                                                                                                                                                                                                                                     | Journal of Environmental Protection, Vol.13 No.11, November 2022                                         |
| 20 | Design synthesis of Y-90 glass microspheres and study of their therapeutic effects on mouse liver cancer cell line Hep3B                                              | Pham Thanh Minh, Duong Van Dong, Van-Dat Doan, Van Thanh Vo, Van Thuan Le                                                                                                                                                                                                                                                                                                                                                                                                                                       | Chemosphere Volume 299, July 2022, 134431                                                                |
| 21 | Triple-conjugated photo-/temperature-/pH-sensitive chitosan with an intelligent response for bioengineering applications                                              | Che Quang Tuan Korakot Charoensri, Jeong Wook Seo, Nguyen Minh Hiep, Goo Jang, Hojae Bae, Hyun Jin Park                                                                                                                                                                                                                                                                                                                                                                                                         | Volume 298, Carbohydrate Polymers 15 December 2022, 120066                                               |
| 22 | Investigation of empirical heat capacity in hot-rotating $A \sim 200$ nuclei                                                                                          | Tran Dong Xuan*, Nguyen Quang Hung*, Le Thi Quynh Huong, Vu Duc Cong, Nguyen Ngoc Anh                                                                                                                                                                                                                                                                                                                                                                                                                           | Journal of Physics G: Nuclear and Particle Physics Volume 49, Number 10, 105102 Published 25 August 2022 |
| 23 | $^6\text{H}$ states studied in the $^2\text{H}(^8\text{He}, ^4\text{He})$ reaction and evidence of an extremely correlated character of the $^5\text{H}$ ground state | E. Yu. Nikolskii, I. A. Muzalevskii, A. A. Bezbakh, V. Chudoba, S. A. Krupko, S. G. Belogurov, D. Biare, A. S. Fomichev, E. M. Gazeeva, A. V. Gorshkov, L. V. Grigorenko, G. Kaminski, M. S. Khirk, O. Kiselev, D. A. Kostyleva, M. Yu. Kozlov, B. Mauey, I. Mukha, Yu. L. Parfenova, W. Piatek, Mai Quynh Anh V. N. Schetinin, A. Serikov, S. I. Sidorchuk, P. G. Sharov, N. B. Shulgina, R. S. Slepnev, S. V. Stepantsov, A. Swiercz, P. Szymkiewicz, G. M. Ter-Akopian, R. Wolski, B. Zalewski, M. V. Zhukov | Physical Review C 105, 064605, 2022                                                                      |

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|----|-------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|--------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|----------------------------------------------------------------------------------------|
| 24 | Determination of the activity inventory in the structural components of the Dalat Nuclear Research Reactor for its decommissioning planning                                                           | Tran Quoc Duong, Nguyen Kien Cuong, Luong Ba Vien, Huynh Ton Nghiem, Pham Quang Huy, Vo Doan Hai Dang, Nguyen Nhi Dien                                                                                                               | Science and Technology of Nuclear Installations<br>Volume 2022, Article ID 5174696     |
| 25 | Determination of Fe and Tb concentrations in geological and environmental samples using the instrumental neutron activation analysis method combined with the $\gamma - \gamma$ coincidence technique | Minh Truong Van, Nguyen Xuan Hai, Cao Dong Vu Tai Duong Thanh, Khang Pham Dinh, Phuc Nguyen Hoang, Tiep Nguyen Huu, Hung Dinh Tien, Hiep Cao Van, Phan Chuan Van, Hiba Omer, Abdelmoneim Suleiman, David A. Bradley, Nguyen Ngoc Anh | Radiation Physics and Chemistry<br><br>Volume 200, November 2022, 110203               |
| 26 | Nuclide Identification Algorithm for the Large-size plastic detectors based on Artificial Neural Network                                                                                              | Cao Van Hiep, Dinh Tien Hung*, Nguyen Ngoc Anh*), Nguyen Ninh Giang, Pham Dinh Khang; Nguyen Xuan Hai, Nguyen Kien Cuong, Tran Van Ninh, Phan Van Chuan                                                                              | IEEE Transactions on Nuclear Science<br>Volume 69, Issue 6, June 2022                  |
| 27 | Investigation the grain size effect on multi-element concentration using statistical analysis of INAA and laser-diffraction data for estuarine sediments of Hau River, Vietnam                        | Tran Quang Thien, Phan Quang Trung, Nguyen Minh Dao, Nguyen Thi Huong Lan, Vo Thi Mong Tham, Le Xuan Thang, Nguyen Van Phuc, Nguyen Huu Nghia, Tran Tuan Anh, Phan Son Hai, Cao Dong Vu                                              | Journal of Radioanalytical and Nuclear Chemistry<br>29 October 2022                    |
| 28 | Electrochemical determination of methylparaben with manganese ferrite/activated carbon-modified electrode                                                                                             | Nguyen Thanh Binh, Nguyen Nho Dung, Nguyen Mau Thanh, Dao Ngoc Nhiem, Doan Manh Dung, Le Lam Son, Nguyen Duc Vu Quyen, Tran Ngoc Tuyen, Nguyen Hoang Tuan, Dinh Quang Khieu                                                          | Journal of Materials Science: Materials in Electronics<br>33, pages 20884–20899 (2022) |
| 29 | Variation of $\text{TiO}_2/\text{SiO}_2$ mixed layers                                                                                                                                                 | Tran Van Phuc*, Miroslaw Kulik, Le Hong Khiem, Afag                                                                                                                                                                                  | Materials Science and Engineering: B                                                   |

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|----|--------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|---------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|------------------------------------------------------------------------------------------|
|    | induced by Xe <sup>+</sup> ion irradiation with energies from 100 to 250 keV                                                                                                   | Madadzada, Marcin Turek, Dorota Kołodyńska, Phan Luong Tuan, Nguyen Ngoc Anh, Mai Quynh Anh, NguyenVan Tiep, Krzysztof Siemek                                                                                       | Volume 277, March 2022, 115566                                                           |
| 30 | Comparison of efficiency calibration techniques of HPGe detector for radioactivity measurement of soil sample in Marinelli geometry                                            | Van Doanh Ho, Phan Bao Quoc Hieu, Pham Bao Son, Van Hoang Dao, Hoang Duc Tam, Manh Dung Ho                                                                                                                          | Journal of Radioanalytical and Nuclear Chemistry<br>Volume 331, pages 1361–1365 (1/2022) |
| 31 | Positron annihilation study of lattice defects and nanoporous structures in Mn <sup>4+</sup> doped K <sub>2</sub> SiF <sub>6</sub> nanophosphors exhibiting high quantum yield | Lo Thai Son, Tuyet-Thi Doan, Phan Trong Phuc, Nguyen Thi Ngoc Hue, Pham Thi Hue, La Ly Nguyen, Van-Phuc Dinh, Tran Dong Xuan, Hoang Anh Tuan Kiet, Le Van Toan, Nguyen Hoang Duy, Nguyen Quang Hung*, Luu Anh Tuyen | Radiation Physics and Chemistry<br>Volume 195, June 2022, 110064                         |
| 32 | Novel design of amine and metal hydroxide functional group modified onto sludge biochar for arsenic removal                                                                    | Chih-Kuei Chen, Nhat-Thien Nguyen, Thuy-Trang Le, Cong-Chinh Duong, Cong-Nguyen Nguyen, Truong Duc Toan, Chun-Hsing Liao                                                                                            | Water Science & Technology<br>85 (5): 1384–1399<br>Feb. 08 (2022)                        |
| 33 | Pseudo-dielectric function spectra of the near surface layer of GaAs implanted with various fluence of Xe <sup>+</sup> ions                                                    | P.L. Tuan, M. Kulik, T.V. Phuc, A.I. Madadzada, T.Yu. Zelenyak, M. Turek, J. Žuk, C. Mita, A. Stanculescu, A.S. Doroshkevich, B. Jasinska, L.H. Khiem, Nguyen Ngoc Anh, N.T. Bao My                                 | Thin Solid Films<br>Volume 756, 31 August 2022, 139376                                   |
| 34 | Hematological Parameters of Red Tilapia ( <i>Oreochromis sp.</i> ) Fed Essential Oils of <i>Mentha piperita</i> after Challenge with <i>Streptococcus agalactiae</i>           | Van-Thanh Vo, Thi-Hieu Tran, Thi-Truc-Thao Nguyen, Van-Tri Truong, Cu-Thien Pham, Pham Thanh Minh and Huyen Nguyen Thi Thuong                                                                                       | Pakistan J. Zool<br>pp 1-8, 2022                                                         |

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|----|---------------------------------------------------------------------------------------------------------------------------------|-------------------------------------------------------------------------------------------------------------------------------------------------------------------|--------------------------------------------------------------------------------------------|
| 35 | Simulations of X-ray spectra, half value layer, and mean energy from mammography using EGSnrc Monte Carlo and SpekPy            | Bui Ngoc Huy, Pham Van Dung                                                                                                                                       | Radiography<br>Volume 29, Issue 1, January 2023,<br>Pages 28-37                            |
| 36 | Comparison of the nematode-controlling effectiveness of 10 different essential oil-encapsulated lipid nanoemulsions             | Nguyen Minh Hiep, Thi-Huynh-Nga Nguyen, Tran Thi Ngoc Mai, Vu Thi Bich Dao, Trung-Tin Tran                                                                        | Archives of<br>Phytopathology and<br>Plant Protection<br>55 (4), 420-432, 2022             |
| 37 | Long QT syndrome: identification of a novel de novo mutation of calmodulin in a newborn girl                                    | Thi Huynh Nga Nguyen, Chi Bao Bui, Vuong Thao Vy Nguyen, Manh Cong Nguyen, Nguyen Thanh Tung Vu, Nguyen Minh Hiep                                                 | Biomedical Research<br>and Therapy<br>Vol 9 No 1 (2022) /<br>4822-4831                     |
| 38 | Identification of a novel de novo deletion mutation of desmin in a neonate with desminopathy                                    | Thi-Huynh-Nga Nguyen, Chi-Bao Bui, Vuong-Thao Vy Nguyen, Manh-Cong Nguyen, Nguyen Minh Hiep                                                                       | Biomedical Research<br>and Therapy<br>Vol 8 No. 12 (2021) /<br>4809-4817                   |
| 39 | Measuring and unfolding fast neutron spectra using solution-grown trans-stilbene scintillation detector                         | Nguyen Duy Quang, Hong Joo Kim, Phan QuocVuong, Nguyen Duc Ton, Uk-Won Nam, Won-Kee Park, Jong Dae Sohn Young-Jun Choi, Sung Hwan Kim, Suk Won Youn, Sung-Joon Ye | Nuclear Engineering<br>and Technology<br><br>Available online 3<br>November 2022           |
| 40 | Status and initial physics performance studies of the MPD experiment at NICA                                                    | V. Abgaryan, R. Acevedo Kado, S.V. Afanasyev, ...Luong Ba Vinh & the MPD Collaboration.                                                                           | <i>The European<br/>Physical Journal A</i><br>Volume 58,<br>Article number: 140 (2<br>022) |
| 41 | Synthesis and elemental analysis of gadolinium halides (GdX <sub>3</sub> ) in glass matrix for radiation detection applications | Sudipta Saha, Amos V.Ntarisa, Nguyen Duy Quang, H.J.Kim, S.Kothan, J.Kaewkhao                                                                                     | Optical Materials<br><br>Volume 129, July<br>2022, 112490                                  |

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|----|--------------------------------------------------------------------------------------------------------------------------------------------------------------|---------------------------------------------------------------------------------------------------------------------------------------------------------------------|---------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| 42 | Fabrication and investigation of the effects of various gadolinium compounds on Ce <sup>3+</sup> -activated phosphate glasses for scintillation applications | Amos V.Ntarisa, Sudipta Saha, Nguyen Duy Quang, H.J.Kim, N.Wantana, I.R.Pandey, P.Aryal, S.Kothan, J.Kaewkhao                                                       | Optik<br><br>Volume 262, July 2022, 169303                                                                                                                          |
| 43 | Development of novel crystal scintillators for lunar surface science                                                                                         | Phan Quoc Vuong, Nguyen Duy Quang, Hong Joo Kim, J.Y.Lee, S.C.Kang, Uk-Won Nam, Won-Kee Park, Jongdae Sohn, Young-Jun Choi, Sukwon Youn, Sung-Joon Ye, Sunghwan Kim | Radiation Physics and Chemistry<br><br>Volume 201, November 2022, 110425                                                                                            |
| 44 | Novel technique for simultaneous detecting three naturally occurring radon isotopes ( <sup>222</sup> Rn, <sup>220</sup> Rn and <sup>219</sup> Rn)            | Amos Vincent Ntarisa, H.J. Kim, Pabitra Aryal, Nguyen Duy Quang, Sudipta Saha                                                                                       | Radiation Physics and Chemistry<br><br>Volume 200, November 2022, 110202                                                                                            |
| 45 | Scintillation performance of the Ce <sup>3+</sup> – activated lithium phosphate glass                                                                        | Sudipta Saha, A.V. Ntarisa, Nguyen Duy Quang, N.T. Luan, P.Q. Vuong, H.J. Kim, N. Intachai, S. Kothan, J. Kaewkhao                                                  | Radiation Physics and Chemistry<br><br>Volume 199, October 2022, 110285                                                                                             |
| 46 | Influence of post-annealing on Mn-doped (K <sub>0.5</sub> Na <sub>0.5</sub> )NbO <sub>3</sub> thin films                                                     | Muhammad Sheeraz, Nguyen Bich Thuy, Hyung-Su Han, Jong-Seong Bae, Shinuk Cho, Tae Heon Kim, Chang Won Ahn, Il Won Kim*                                              | Journal of the Korean Physical Society<br><br>80, 628-633 (8 March 2022)                                                                                            |
| 47 | Comparison of Methods for Elliptic Flow Measurements at NICA Energy Range                                                                                    | Luong Ba Vinh                                                                                                                                                       | Moscow University Physics Bulletin<br><br>77, 237-238 (2022)                                                                                                        |
| 48 | Selective recovery of thorium and uranium from leach solutions of rare earth concentrates in continuous solvent extraction mode                              | Nguyen Trong Hung, Le Ba Thuan, Tran Chi Thanh, Nguyen Thanh Thuy, Doan Thi Thu Tra, Khoai Do Van, Masayuki Watanabe, Pham                                          | Hydrometallurgy<br>, Volume 213, August 2022, 105933<br><a href="https://doi.org/10.1016/j.hydromet.2022.105933">https://doi.org/10.1016/j.hydromet.2022.105933</a> |

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|----|----------------------------------------------------------------------------------------------------------|----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
|    | with primary amine N1923                                                                                 | Quang Minh, Hoang Sy Than, Nguyen Duc Vuong, Dinh Van Phuc, Jin-Young Lee, Jong Hyuk Jeon, Rajesh Kumar Jyothi                                                                   | 33                                                                                                                                                                                                   |
| 49 | Studies on Red Mud Material to Use for Combustion of Vietnam Pulverized Coal                             | Thi Thuc Phuong Nguyen, Van Tung Nguyen, Nhuan Hoang, Van Duc Hoang, Xuan Dinh Luu, Thi Mai Huong Le, Trong Hung Nguyen, Ngoc Bich Hoang, Thi Kim Ngan Tran, and Manh Nhuong Chu | Inorganics 2022, 10, 58<br>Published: 24 April 2022                                                                                                                                                  |
| 50 | Evaluation of heavy metal contamination in the coastal aquaculture zone of the Red River Delta (Vietnam) | Da Le.Nhu , Hoang T.T.H, Phung Vu.Phong, Nguyen Thi.Lien, et al.                                                                                                                 | Chemosphere Volume 303, Part 1, September 2022, 134952<br><a href="https://doi.org/10.1016/j.chemosphere.2022.134952">https://doi.org/10.1016/j.chemosphere.2022.134952</a>                          |
| 51 | Surface sediment quality of the Red River (Vietnam): impacted by anthropogenic and natural factors       | T. P. Q. Le, N. D. Le, Vu Phong Phung et al.                                                                                                                                     | International Journal of Environmental Science and Technology.19, pages 12477–12496, Jan 2022<br><a href="https://doi.org/10.1007/s13762-022-03936-z">https://doi.org/10.1007/s13762-022-03936-z</a> |
| 52 | Thermodynamics and Kinetics Research of the Fluorination Process of the Concentrate Rutile               | Vladimir A. Karelin, Son Hai Le, Nadezhda V. Karelina, Alexander N. Strashko, Alexander V. Sazonov and Huong M. T. Le                                                            | Metals 2022, 12, 34.<br><a href="https://doi.org/10.3390/met12010034">https://doi.org/10.3390/met12010034</a><br>Published: 24 December 2021                                                         |
| 53 | Li-ion Storage in Orthorhombic Hydrated Sodium Molybdate with Oxygen-vacancy Defects.                    | Tuan Loi Nguyen, Thuan Ngoc Vo, Viet Duc Phung, Kaleab Ayalew, Dongwon Chun, Luu Anh Tuyen, Nguyễn Quang Hưng, Kwang J. Kim, Il Tae Kim, JaeyunMoon                              | Chemical Engineering Journal, Number 446 (3), 137174, 2022                                                                                                                                           |
| 54 | Hexagonal annular-NiO nanoarchitecture with local pn homojunctions: novel                                | Tran Khoa Dang, Nguyen Duc Cuong, Vu Hung Sinh, Hoang Thai Long, Pham Ngoc Anh                                                                                                   | Journal of Alloys and Compounds                                                                                                                                                                      |

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|    | formation mechanism and H <sub>2</sub> S gas sensing properties.                                                                                                                | Thy, Duong Tuan Quang, Lo Thai Son, Phan Trong Phuc, Pham Thi Hue, Nguyen Thi Ngoc Hue, La Ly Nguyen, Van Phuc Dinh, Tran Dong Xuan, Nguyen Quang Hung, Luu Anh Tuyen, Nguyen Van Hieu                                                   | Number 933, 167782, 2022                                       |
| 55 | Adsorption of Pb (II) from aqueous solution by pomelo fruit peel-derived biochar.                                                                                               | Van Phuc Dinh, Duy Khoi Nguyen, Thi Thuy Luu, Quang Hung Nguyen, Luu Anh Tuyen, Diep Dinh Phong, Hoang Anh Tuan Kiet, Thien Hoang Ho, Tu Thi Phuong Nguyen, Tran Dong Xuan, Pham Thi Hue, Nguyen Thi Ngoc Hue                            | Materials Chemistry and Physics<br>Number 285, 126105, 2022    |
| 56 | Positron annihilation study of lattice defects and nanoporous structures in Mn <sup>4+</sup> doped K <sub>2</sub> SiF <sub>6</sub> nanophosphors exhibiting high quantum yield. | Lo Thai Son, Tuyet Thi Doan, Phan Trong Phuc, Nguyen Thi Ngoc Hue, Pham Thi Hue, La Ly Nguyen, Van Phuc Dinh, Tran Dong Xuan, Hoang Anh Tuan Kiet, Nguyen Hoang Duy, Nguyen Quang Hung, Luu Anh Tuyen                                    | Radiation Physics and Chemistry<br>Number 195, 110064, 2022    |
| 57 | Morphological characterization of grafted polymer electrolyte membranes at a surface layer for fuel cell application.                                                           | Lam Hoang Hao, Tran Duy Tap, Dinh Tran Trong Hieu, Ekaterina Korneeva, Nguyen Van Tiep, Kimio Yoshimura, Shin Hasegawa, Shin-ichi Sawada, Tran Van Man, Nguyen Quang Hung, Luu Anh Tuyen, Van-Phuc Dinh, Le Quang Luan, Yasunari Maekawa | Journal of Applied Polymer Science,<br>Number 139, 51901, 2022 |
| 58 | Electron and gamma irradiation-induced effects in poly (ethylene-co-tetrafluoroethylene) films.                                                                                 | Lam Hoang Hao, Dinh Tran Trong Hieu, Le Quang Luan, Huynh Truc Phuong, Van-Phuc Dinh, Luu Anh Tuyen, Pham Thi Thu Hong, Tran Van Man, Tran Duy Tap                                                                                       | Journal of Applied Polymer Science<br>Number 139, e52620, 2022 |
| 60 | Measurement of Neutron Flux Parameters for Implementation of k <sub>0</sub> -INAA                                                                                               | Mohamed Ali Soliman; Fatma S. Abdou; Ho Van Doanh;                                                                                                                                                                                       | Journal of Radioanalytical and Nuclear Chemistry               |

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|    | at Kyoto University Research Reactor.                                                                                                 | Shun Sekimoto;<br>Koichi Takamiya;<br>Nader M.A. Mohamed;<br>Tsutomu Ohtsuki.                                                                                                            | 331, pages3949–3956<br>(2022)                                                        |
| 61 | The 2021 IAEA software intercomparison for k0-INAA.                                                                                   | Menno Blaauw;<br>Giancarlo D'Agostino;<br>Marco di Luzio;<br>Ho Manh Dung;<br>Radojko Jacimovic;<br>Mauro Da Silva Dias;<br>Renato Semmler;<br>Robbert van Sluijs; Nuno Pessoa Barradas. | Journal of Radioanalytical and Nuclear Chemistry<br>Published online 30 October 2022 |
| 62 | Investigation of chemical degradation and water states in the graft-type polymer electrolyte membranes.                               | Dinh Tran Trong Hieu, Lam Hoang Hao, Tran Hoang Long, Vo Van Tien, Nguyen Tien Cuong, Tran Van Man, Truong Thi Hong Loan, Tran Duy Tap                                                   | Polymer Engineering & Science<br>Number: 2757, 2022                                  |
| 63 | Efficient removal of reactive red 24 from aqueous solution through electron beam and aeration tank using response surface methodology | Nguyen Ngoc Duy, Bui Nghia Hiep, Kun-Yi Andrew Lin, Yuan-Shing Perng, Tran Thanh, Nguyen Thi Kim Lan, Nguyen Trung Hieu, Bui Manh Ha.                                                    | Sustainable Energy Technologies and Assessments, 53 (Part A, October 2022)<br>102452 |
| 64 | Removal of leucomalachite green in an aqueous solution by the electron beam process                                                   | Nguyen Ngoc Duy, Nguyen Trung Hieu, Pham Thanh Luu, Bui Thanh Xuan, Duong Thi Thuy, Jheng-Jie Jiang, Yuan-Shing Perng, Faten Boujelbane, Bui Manh Ha                                     | Journal of Water Process Engineering, 40 (2021)                                      |
| 65 | Electron and gamma irradiation-induced effects in poly(ethylene-co-tetrafluoroethylene) films                                         | Lam Hoang Hao, Dinh Tran Trong Hieu, Le Quang Luan, Huynh Truc Phuong, Van Phuc Dinh, Luu Anh Tuyen, Pham Thi Thu Hong, Tran Van Man, Tran Duy Tap                                       | Journal of Applied Polymer Science, 139 (29) (2022)                                  |
| 66 | Implementation of a Geant4-based code using low-energy gamma-nuclear final state model for photonuclear studies                       | Le Tuan Anh, Phan Viet Cuong, Ho Thi Thao, Ngo Hai Tan, Kim Tien Thanh                                                                                                                   | Nuclear Instrument and Methods in Physics Research A 1027 (2022)                     |

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|----|-------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|-----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|---------------------------------------------------------------------------------------|
| 67 | Effect of copper ions concentration on the particle size of alginate-stabilized Cu <sub>2</sub> O-Cu nanocolloids and its antibacterial activity against rice bacterial leaf blight ( <i>Xanthomonas oryzae</i> pv. <i>oryzae</i> ) | Doan Thi Bich Ngoc, Bui Duy Du, Le Nghiem Anh Tuan, Bui Dinh Thach, Tran Phuoc Tho va Dang Van Phu                                                                                      | Advances in Natural Sciences: Nanoscience and Nanotechnology, 12 (2021)               |
| 68 | Pseudo-dielectric function spectra of the near surface layer of GaAs implanted with various fluence of Xe <sup>+</sup> ions                                                                                                         | Phan Luong Tuan, M. Kulik, T.V. Phuc, A.I. Madadzada, T.Yu. Zelenyak, M. Turek c, J. Zuk, C. Mita d, A. Stanculescu, A.S. Doroshkevich, B. Jasinska , L.H. Khiem, N.N. Anh, N.T. Bao My | Thin Solid Films Volume 756, 2022, 139376 119-124 (T8/2022)                           |
| 69 | Influence of synthesis routes on the performance of Ni nano-sized catalyst supported on CeO <sub>2</sub> -Al <sub>2</sub> O <sub>3</sub> in the dry reforming of methane                                                            | Pham Quynh Cham, Cao Thi Anh Ngoc, Pham Le Kim Hoang, Pham Thi Thu Phuong, Tran Thi Tuong Vi, Vo Cao Minh, Nguyen Thi Hong Ha, Nguyen Quang Anh, Nguyen Manh Tung, Vo Nguyen Dai Viet   | Advances in Natural Sciences: Nanoscience and Nanotechnology, 13 (2022) 035011 (11pp) |
| 70 | Hydrodemetallization of heavy oil: Recent progress, challenge, and future prospects                                                                                                                                                 | Nguyen Thanh Huong, Nguyen Quang Anh., Cao Thi Anh Ngoc, Takyi Ernest, Nguyen Thanh Binh, Pham Thi Hong Phuong, Nguyen Manh Tung                                                        | Journal of Petroleum Science and Engineering, Volume 216, September 2022, 110762      |
| 71 | Gamma radiation modification of cassava starch and its characterization.                                                                                                                                                            | Tran Minh Quynh, Nguyen Van Binh, Tran Xuan An                                                                                                                                          | Polymer engineering and science, 2022, 62(4), 1197-1204                               |
| 72 | Enhancing radical scavenging activity of <i>cordyceps militaris</i> extract by gamma irradiation                                                                                                                                    | Tran Minh Quynh                                                                                                                                                                         | Vietnam Journal of Chemistry 2022, 60 (5); 681-684. Tạp chí Scopus (0.74, Q4)         |
| 73 | Study on cesium compound formation by chemical interaction of CsOH and                                                                                                                                                              | Luu Vu Nhut, Kunihsa Nakajima                                                                                                                                                           | Journal of Nuclear Science and Technology (In Press),                                 |

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|----|--------------------------------------------------------------------------------------------------------------------------------------------|------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|----------------------------------------------------------------------------------------------------------------------------------------|
|    | concrete at elevated temperatures                                                                                                          |                                                                                                                                                                              | Published online: 08 Jul 2022                                                                                                          |
|    | Effect of solute elements (Ni, Mn) in Fe-based alloys on dislocation loop evolution under Fe <sup>2+</sup> ion irradiation                 | Luu Vu Nhut, Phongsakorn Prak Tom, Kenta Murakami, Ba Vu Chinh Nguyen, Liang Chen                                                                                            | Journal of Nuclear Materials, Volume 559, February 2022, 153489                                                                        |
| 74 | Which-way identification by an asymmetrical double-slit experiment with monochromatic photons                                              | Vu Duc Vinh, Vo Van Thuan                                                                                                                                                    | Nature, Article number: 3709 (2022)                                                                                                    |
| 75 | Determination of the Pore Water Velocity Using a Salt Tracer Combined With Self-potential Measurements                                     | Huynh Thi Thu Huong, Le Van Son, Tran Trong Hieu, Lai Viet Hai, Nguyen Huu Quang, Phan Thi Luan                                                                              | Journal of Geoscience and Environment Protection                                                                                       |
| 76 | Urbanization and seasonality strengthen the CO <sub>2</sub> capacity of the Red River Delta, Vietnam                                       | Jorge Salgado· Trinh Anh Duc, Do Thu Nga, Virginia N Panizzo, Adrian M Bass, Ying Zheng, Sarah Taylor, Lucy R Roberts, Jack H Lacey, Melanie J Leng and Suzanne McGowan      | October 2022<br>Environmental Research Letters<br>17(10)<br>DOI: 10.1088/1748-9326/ac9705                                              |
| 77 | In flux: Annual transport and deposition of suspended heavy metals and trace elements in the urbanised, tropical Red River Delta, Vietnam. | Lucy R. Roberts· Nga T. Do, Virginia N. Panizzo, Sarah Taylo· Michael Watts, Elliot Hamilton, Suzanne McGowan, Duc Anh. Trinh, Melanie J. Leng, Jorge Salgado                | September 2022<br>Water Research 224:119053<br>DOI: 10.1016/j.watres.2022.119053                                                       |
| 78 | Utilization of biogas as an untapped renewable energy source in Vietnam                                                                    | Truong Dinh Duc, Do Thu Nga, Le Thi Thoa, Pham Ngoc Bao, Trinh Anh Duc, Nguyen Huu Duc                                                                                       | November 2021<br>Economics and Policy of Energy and the Environment<br>DOI: 10.3280/EFE2021-001006                                     |
| 79 | Studies on Red Mud Material to Use for Combustion of Vietnam Pulverized Coal                                                               | Thi Thuc Phuong Nguyen, Van Tung Nguyen, Nhuan Hoang, Van Duc Hoang, Xuan Dinh Luu, Thi Mai Huong Le, Trong Hung Nguyen, Ngoc Bich Hoang, Thi Kim Ngan Tran,* and Manh Nhung | <i>Inorganics</i> 2022, 10(5), 58; <a href="https://doi.org/10.3390/inorganics10050058">https://doi.org/10.3390/inorganics10050058</a> |

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|----|------------------------------------------------------------------------------------------------------------------------------------------------------------------|--------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|-----------------------------------------------------------------------------------------------------------------------|
|    |                                                                                                                                                                  | Chu.                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                 |                                                                                                                       |
| 80 | Third international challenge to model the medium- to long-range transport of radioxenon to four Comprehensive Nuclear-Test-Ban Treaty monitoring stations.      | C.Maurer (ZAMG), S.Galmarini, E.Solazzo (JRC), J.Kuśmierczyk-Michulec, J.Bar'ę, M.Kalinowski, M.Schoeppner, P.Bourgouin (CTBTO), A.Crawford, A.Stein, T.Chai, F.Ngan (NOAA-ARL), A.Malo (ECCC-CMC), P.Seibert (BOKU), A.Axelsson, A.Ringbom (FOI), R.Britton, A.Davies, M.Goodwin (AWE/UK-NDC), P.W.Eslinger, T.W.Bowyer (PNNL), L.G.Glascoe, D.D.Lucas, S.Cicchi, P.Vogt (NARAC), Y.Kijima, A.Furuno (JAEA), P.K. Long (VINATOM), B.Orr (ARPANSA), A.Wain (BOM), K.Park, K.-S.Suh (KAERI), A.Qu'ere'el, O.Saunier, D.Qu'elo (IRSN). | Journal of Environmental Radioactivity Volume 255, December 2022, 106968                                              |
| 81 | Simulation of Leksell Gamma Knife-4C System with Different Phantoms Using PHITS and Geant4.                                                                      | Bui Tien Hung, Tran Thuy Duong, Bui Ngoc Ha                                                                                                                                                                                                                                                                                                                                                                                                                                                                                          | Atom Indonesia                                                                                                        |
| 82 | Optimization of Oligomer Chitosan/Polyvinylpyrrolidone Coating for Enhancing Antibacterial, Hemostatic Effects and Biocompatibility of Nanofibrous Wound Dressin | Vinh Khanh Doan, Chien Minh Tran, Trinh Thi-Phuong Ho, Linh Kim-Khanh Nguyen, Yen Ngoc Nguyen, Ngan Tuan Tang, Tin Dai Luong, Nhi Ngoc-Thao Dang, Nam Minh-Phuong Tran, Binh Thanh Vu, Hoai Thi-Thu Nguyen, Quyen Thuc Huynh, Hien Quoc Nguyen, Chien Mau Dang, Thang Bach Phan, Hanh Thi-Kieu Ta, Viet Hung Pham, Thanh Dinh Le, Toi Van Vo and Hiep Thi Nguyen                                                                                                                                                                     | Polymers 2022, 14, 3541.<br><a href="https://doi.org/10.3390/polym14173541">https://doi.org/10.3390/polym14173541</a> |



## 4.2. LISTS OF INTERNATIONAL PROJECTS 2022

### 4.2.1 - LIST OF VIE PROJECTS 2022 (Implemented by VINATOM)

| Code           | Project Title                                                                                                        | Start Year | Finish Year | Budget (Euro) | Field code     | Project Counterpart |
|----------------|----------------------------------------------------------------------------------------------------------------------|------------|-------------|---------------|----------------|---------------------|
| <b>VIE1010</b> | Promoting the Reactor Safety Development Programme — Phase III                                                       | 2020       | 2023        | 210,000.00    | Tran Chi Thanh | VINATOM             |
| <b>VIE7006</b> | Assessing Flow Regimes and River Biogeochemistry of Lower Red River in an Integrated Manner Using Isotope Techniques | 2020       | 2023        | 150,885.00    | Trinh Anh Duc  | NTC                 |

### 4.2.2. LIST OF INT AND NON-RCA PROJECT 2022 (Implemented by VINATOM)

| Code           | Project Title                                                                                                                                  | Start Year | Finish year | Budget (Euro) | Field code      | Project Counterpart |
|----------------|------------------------------------------------------------------------------------------------------------------------------------------------|------------|-------------|---------------|-----------------|---------------------|
| <b>INT9186</b> | Sustaining Cradle-to-Grave Control of Radioactive Sources - Phase II                                                                           | 2020       | 2024        | 1,653,718.75  | Hoang Nhuan     | ITRRE               |
| <b>INT9186</b> | Sustaining Cradle-to-Grave Control of Radioactive Sources - Phase II                                                                           | 2020       | 2024        | 1,653,718.75  | Tran The Dinh   | ITRRE               |
| <b>INT2022</b> | Supporting Capacity Building in Member States for Uranium Production and Safety of Naturally Occurring Radioactive Material Residue Management | 2020       | 2024        | 400,050.00    | Cao Dong Vu     | NRI                 |
| <b>RAS1026</b> | Strengthening Nuclear Instrumentation Capacity in the Areas of Nuclear Sciences and Applications                                               | 2020       | 2023        | 620.442,00    | Nguyen Duc Tuan | INST                |
| <b>RAS7038</b> | Monitoring the Marine Environment for Enhanced Understanding of the Abundance and Impact of                                                    | 2022       | 2025        | 892.800,00    | Ha Lan Anh      | INST                |

|                          |                                                                                                                                      |      |      |            |                     |       |
|--------------------------|--------------------------------------------------------------------------------------------------------------------------------------|------|------|------------|---------------------|-------|
| Marine Plastic Pollution |                                                                                                                                      |      |      |            |                     |       |
| <b>RAS1027</b>           | Improving the Utilization of Nuclear Techniques for Cultural Heritage Characterization, Consolidation, and Preservation              | 2022 | 2025 | 270.900,00 | Tran Quang Thien    | NRI   |
| <b>RAS1030</b>           | Using Radioisotope Techniques and Computational Fluid Dynamics Simulation for Troubleshooting and Optimizing of Industrial Processes | 2022 | 2025 | 419.250,00 | Dang Nguyen The Duy | CANTI |
| <b>RAS9094</b>           | Enhancing Nuclear Emergency Preparedness and Response in the Member States of the Association of Southeast Asian Nations             | 2022 | 2025 | 1,286,670  | Pham Quang Huy      | NRI   |

#### 4.2.3 - LIST OF FNCA PROJECTS 2022

(Participated by VINATOM and other Vietnam organizations)

| Field                                                                                                      | Project Title                                                                                                  | Project Coordinator                                                                                                                                                                              |
|------------------------------------------------------------------------------------------------------------|----------------------------------------------------------------------------------------------------------------|--------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| <b>Research Reactor Utilization Development</b>                                                            | Research Reactor Network                                                                                       | <b>Dr. Duong Van Dong</b><br>Director, Center for Research and Production of Radioisotope,<br>Nuclear Research Institute (NRI)<br>Vietnam Atomic Energy Institute (VINATOM)                      |
|                                                                                                            | Neutron Activation Analysis                                                                                    | <b>Dr. Tran Tuan Anh</b><br>Researcher,<br>Center for Nuclear Physics & Electronics<br>Nuclear Research Institute (NRI)<br>Vietnam Atomic Energy Institute (VINATOM)                             |
| <b>Radiation Utilization Development (Agricultural/ Healthcare /Industrial/ Environmental Utilization)</b> | Mutation Breeding                                                                                              | <b>Dr. Le Duc Thao</b><br>Deputy General Director<br>Agricultural Genetics Institute (AGI)<br>Ministry of Agriculture and Rural Development (MARD)                                               |
|                                                                                                            | Radiation Oncology                                                                                             | <b>Dr. Nguyen Cong Hoang</b><br>Head of General Radiation Oncology Department,<br>National Cancer Hospital (K Hospital)                                                                          |
|                                                                                                            | Radiation Processing and Polymer Modification for Agricultural, Environmental and Medical Applications Project | <b>Dr. Nguyen Ngoc Duy</b><br>Head of Research and Development Department,<br>Research and Development Center for Radiation Technology (VINAGAMMA),<br>Vietnam Atomic Energy Institute (VINATOM) |
|                                                                                                            | Research on Climate Change using Nuclear and Isotopic Techniques                                               | <b>Dr. Nguyen Trong Ngo</b><br>Nuclear Research Institute (NRI),<br>Vietnam Atomic Energy Institute (VINATOM)                                                                                    |
| <b>Nuclear Safety Strengthening</b>                                                                        | Radiation Safety and Radioactive Waste Management                                                              | <b>Assoc. Prof. Dr. Le Thi Mai Huong</b><br>Deputy Director<br>Nuclear Training Center (NTC)<br>Vietnam Atomic Energy Institute (VINATOM)                                                        |

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|---------------------------------------------|--------------------------------|-----------------------------------------------------------------------------------------------------------------------------------------|
| <b>Nuclear Infrastructure Strengthening</b> | Nuclear Security and Safeguard | <b>Ms. Bui Thi Thuy Anh</b><br>Director, International Cooperation Division<br>Vietnam Agency for Radiation and Nuclear Safety (VARANS) |
|---------------------------------------------|--------------------------------|-----------------------------------------------------------------------------------------------------------------------------------------|

**4.2.4 - LIST OF RAS PROJECTS 2022**  
(Participated by VINATOM and other Vietnam organizations)

| Code           | Title                                                                                                                                                                                                            | Year of approval | Budget (EUR) | Project Type | Project Coordinators                                                       |
|----------------|------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|------------------|--------------|--------------|----------------------------------------------------------------------------|
| <b>RAS1022</b> | Strengthening Regional Capacity in Non-Destructive Testing and Examination Using Nuclear and Related Techniques for Safer, Reliable, More Efficient and Sustainable Industries Including Civil Engineering (RCA) | 2019             | 558.600,00   | RCA          | <b>Tran Dang Manh</b><br>Non-Destructive Evaluation Center                 |
| <b>RAS1028</b> | Improving the Quality Management Practices in Radiation Processing Facilities for Better Performance and Applications (RCA)                                                                                      | 2022             | 641.150,00   | RCA          | <b>Tran Minh Quynh</b><br>Hanoi Irradiation Center                         |
| <b>RAS5081</b> | Enhancing Food Safety and Supporting Regional Authentication of Foodstuffs through Implementation of Nuclear Techniques                                                                                          | 2018             | 646.250,00   | RCA          | <b>Nguyen Thi Hong Thinh</b><br>Institute for Nuclear Science & Technology |
| <b>RAS5091</b> | Assessing and Mitigating Agro-Contaminants to Improve Water Quality and Soil Productivity in Catchments Using Integrated Isotopic Approaches                                                                     | 2022             | 541.800,00   | RCA          | <b>Nguyen Thi Huong Lan</b><br>Nuclear Research Institute                  |

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|----------------|-----------------------------------------------------------------------------------------------------------------------------|------|------------|-----|----------------------------------------------------------------------------|
| <b>RAS5087</b> | Promoting Food Irradiation by Electron Beam and X Ray Technology to Enhance Food Safety, Security and Trade (RCA)           | 2020 | 300.300,00 | RCA | <b>Tran Minh Quynh</b><br>Hanoi Irradiation Center                         |
| <b>RAS5088</b> | Enhancing Crop Productivity and Quality through Mutation by Speed Breeding (RCA)                                            | 2021 | 425.250,00 | RCA | <b>Le Duc Thao</b><br>Agricultural Genetics Institute                      |
| <b>RAS6101</b> | Improving the Quality and Safety of Radiation Medicine through Medical Physicist Education and Training (RCA)               | 2022 | 617.000,00 | RCA | <b>Tran Ngoc Toan</b><br>Vice President<br>Vietnam Atomic Energy Institute |
| <b>RAS6093</b> | Strengthening Capacity to Manage Non-Communicable Diseases Using Imaging Modalities in Radiology and Nuclear Medicine (RCA) | 2019 | 490.450,00 | RCA | <b>Lam Khanh</b><br>Central Military Hospital 108                          |
| <b>RAS6096</b> | Empowering Regional Collaboration among Radiotherapy Professionals through Online Clinical Networks (RCA)                   | 2020 | 201.000,00 | RCA | <b>Bui Quang Bieu</b><br>Central Military Hospital 108                     |
| <b>RAS6097</b> | Enhancing Capacity and Capability for the Production of Cyclotron-Based Radiopharmaceuticals (RCA)                          | 2020 | 445.200,00 | RCA | <b>Mr Nguyen Quang Anh</b><br>Hanoi Irradiation Center                     |
| <b>RAS6098</b> | Standardizing Radiotherapy in Palliative Care (RCA)                                                                         | 2022 | 416.050,00 | RCA | <b>Mr. Nguyen Cong Hoang</b><br>National Cancer Hospital                   |

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|----------------|----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|------|------------|-----|-----------------------------------------------------------------------|
| <b>RAS7028</b> | Enhancing Regional Capabilities for Marine Radioactivity Monitoring and Assessment of the Potential Impact of Radioactive Releases from Nuclear Facilities in Asia-Pacific Marine Ecosystems (RCA) | 2016 | 790,222.85 | RCA | <b>Nguyen Van Phuc</b><br>Nuclear Research Institute,<br>VINATOM      |
| <b>RAS7031</b> | Assessing the Vulnerability of Coastal Landscapes and Ecosystems to Sea-Level Rise and Climate Change (RCA)                                                                                        | 2019 | 504.000,00 | RCA | <b>Le Nhu Sieu</b><br>Nuclear Research Institute,<br>VINATOM          |
| <b>RAS7035</b> | Enhancing Regional Capability for the Effective Management of Ground Water Resources Using Isotopic Techniques (RCA)                                                                               | 2020 | 404.225,00 | RCA | <b>Nguyen Kien Chinh</b><br>Center for Nuclear Techniques,<br>VINATOM |
| <b>RAS7037</b> | Enhancing Wetland Management and Sustainable Conservation Planning (RCA)                                                                                                                           | 2020 | 390.075,00 | RCA | <b>Tran Thi Nhu Trang</b><br>Nguyen Tat Thanh University              |
| <b>RAS7040</b> | Improving Water Resources Management Practices by Enhancing the Regional Collaboration in Environmental Isotope Analysis and Applications (RCA)                                                    | 2022 | 630.775    | RCA | <b>Dang Duc Nhan</b><br>Institute for Nuclear Science & Technology    |
| <b>RAS9092</b> | Strengthening the Capacity to Respond to Radiological Emergencies of Category II and III Facilities (RCA)                                                                                          | 2020 | 324.450,00 | RCA | <b>Pham Hung Thai</b><br>Nuclear Research Institute,<br>VINATOM       |



4.2.5. LIST OF NATIONAL COORDINATOR AND TOPICAL GROUP MEMBER, ASIAN  
NUCLEAR SAFETY NETWORK (ANSN) 2022  
(Implemented by VINATOM)

| Topical Group                                                | National Coordinator | Topical Group Member | Institution                                           |
|--------------------------------------------------------------|----------------------|----------------------|-------------------------------------------------------|
| <b>Asian Nuclear Safety Network (ANSN)</b>                   | Tran Ngoc Toan       |                      | VINATOM                                               |
| <b>Regulatory Infrastructure (RITG)</b>                      |                      | Cao Hong Lan         | Department of International Cooperation, VINATOM      |
| <b>Education and Training (ETTG)</b>                         |                      | Duong Thanh Tung     | Nuclear Training Centre, VINATOM                      |
| <b>Sitting (STG)</b>                                         |                      | Bui Trung Thong      | Department of International Cooperation, VINATOM      |
| <b>Safety Assessment (SATG) (OS)</b>                         |                      | Pham Quang Huy       | Nuclear Research Institute, VINATOM                   |
| <b>SATG (SA)</b>                                             |                      | Tran Thanh Tram      | Nuclear Education and Training Center, VINATOM        |
| <b>Radioactive Waste Management (RWMTG)</b>                  |                      | Bui Dang Hanh        | Department of International Cooperation, VINATOM      |
| <b>Emergency Preparedness and Response (EPRTG)</b>           |                      | Vuong Thu Bac        | Institute for Nuclear Science and Technology, VINATOM |
| <b>Safety Management of Research Reactor (SMRRTG)</b>        |                      | Nguyen Kien Cuong    | Nuclear Research Institute, VINATOM                   |
| <b>Communication (CTG)</b>                                   |                      | Hoang Sy Than        | Department of International Cooperation, VINATOM      |
| <b>Self-Assessment Coordination Group (SACG)</b>             |                      | Cao Hong Lan         | Department of International Cooperation, VINATOM      |
| <b>IT Support Group (ITSG)</b>                               |                      | Le Anh Tuan          | Department of International Cooperation, VINATOM      |
| <b>Radiation Protection and Transport Safety (RTTG) (RP)</b> |                      | Pham Khac Tuyen      | Department of International Cooperation, VINATOM      |
| <b>RTTG (TS)</b>                                             |                      | Nguyen Huu Quyet     | Institute for Nuclear Science and Technology, VINATOM |



