

ROMANIAN NATIONAL NUCLEAR PROGRAMME (NNP)

Contents

ROMANIAN NATIONAL NUCLEAR PROGRAMME (NNP)	1
A. OVERVIEW OF THE NUCLEAR SECTOR COVERED BY THE NATIONAL NUCLEAR PROGRAMME	4
A.1 Nuclear Power Sector	4
A.2 Non-Power Applications	6
B. OVERVIEW OF THE STRATEGIC OBJECTIVES	7
C. OVERVIEW OF THE MEDIUM- AND LONG-TERM PROJECTS OF THE NATIONAL NUCLEAR PROGRAMME IN THE NUCLEAR POWER SECTOR	8
1. Completion of Cernavodă Nuclear Power Plant Units 3 and 4	8
2. Refurbishment of Cernavodă Unit 1 and Refurbishment of Unit 2.....	9
3. Licensing, Construction and Commissioning of the Final Disposal Facility for Low- and Intermediate-Level Radioactive Waste (DFDSMA).....	10
4. Licensing, Construction and Commissioning of the Deep Geological Repository (DGR)	11
5. Construction of the Heavy Water Detritiation Facility (CTRF) at the Cernavodă Nuclear Power Plant Site.....	12
6. Construction of the First Small Modular Reactor (SMR) Nuclear Power Plant.....	13
7. Construction of the Experimental Support Facilities for the ALFRED Demonstrator	14
8. Construction of the ALFRED Demonstrator for the Validation of Lead-cooled Fast Reactor (LFR) Technology	15
9. Construction of a Research Infrastructure for the Production of Radioactive Ion Beams and Medical Radioisotopes	16
10. Development of Technologies for Fundamental and Applied Nuclear Physics Research Using the High-Power Laser Systems at ELI-NP.....	16
D. OVERVIEW OF NON-POWER NUCLEAR FACILITIES, ACTIVITIES AND PROJECTS	17
1. Applications of Heavy Water in Nuclear and Non-Nuclear Fields	17
2. Radiation Processing Technologies.....	17
3. Ionising Radiation Metrology.....	18
4. Nuclear Forensics.....	19
5. Experimental Pilot Facility for Tritium and Deuterium Separation (PESTD)	20
6. National Centre for Hydrogen and Fuel Cells	20
7. Medical Applications	21
8. Agricultural and Food Applications.....	21
Food Treatment and Preservation	21
Food Quarantine and Export	22
Insect Control.....	22
9. Environment	22
10. Cultural Heritage Conservation	23

11. Industrial Applications	23
Gamma Radiography	23
Industrial Measurements and Analyses.....	24
Miniature Power Sources	24
Manufacture of Iridium-192 Sources for Industrial Non-Destructive Testing	24
E. ACTION PLAN FOR ACHIEVING THE MEDIUM- AND LONG-TERM STRATEGIC OBJECTIVES	24
OS 1 Maintain a High Level of Operational Performance while Increasing the Number of CANDU Nuclear Power Units	26
OS 2 – Construction of New-Type Power Plants, in a Phased Approach, Over Time and by Technology Line (Small Modular Reactors – SMR – and Innovative Gen IV Reactors)	31
OS 3 – Development of an Integrated Fuel Cycle Ensuring the Sustainability and Efficiency of Nuclear Power Generation	32
OS 4 – Safe Management of Spent Nuclear Fuel and Radioactive Waste in Support of the Development of Nuclear Power, Including the Closure and Institutional Control of Radioactive Waste Disposal Facilities	35
OS 5 – Strengthening Scientific and Technical Support Capacity and Enhancing the Role of Research and Innovation in the Nuclear Sector	38
OS 6 – Ensuring Highly Qualified Human Resources Required for the Successful Achievement of the Strategic Objectives.....	40
OS 7 – Capitalizing on the Advantages of Non-Energy Applications in Medicine, Industry, Agriculture, Space Technologies, Hydrogen Production and Other Fields	44

A. OVERVIEW OF THE NUCLEAR SECTOR COVERED BY THE NATIONAL NUCLEAR PROGRAMME

A.1 Nuclear Power Sector

Nuclear power represents a sustainable option for the development of Romania's national energy sector, taking into account the limited availability of primary energy resources and the need to generate electricity without greenhouse gas emissions. Its role has become increasingly important in achieving ambitious greenhouse gas emission reduction targets while making an effective contribution to energy security, maintaining affordable electricity prices for final consumers, and strengthening the country's energy independence.

Romania's Energy Strategy 2025–2035, with a 2050 Outlook, establishes concrete objectives, defines clear strategic directions and provides the framework through which Romania will maintain its position as an energy producer in the region and as an active and significant contributor to addressing regional energy security challenges.

Accordingly, the development of the energy sector is closely linked to the implementation of the national strategic investment projects identified in the National Strategy for the Development of the Nuclear Sector (SNDDN).

The completion of Cernavodă Nuclear Power Plant Units 3 and 4, designated as a strategic investment project of national importance, aims to capitalise on valuable existing assets, including heavy water and uranium octoxide held as public assets, together with land, buildings, equipment and other tangible assets owned by National Company Nuclearelectrica S.A. (SNN), as well as intangible assets owned by EnergoNuclear S.A., in accordance with the applicable legal framework.

In order to ensure the supply of CANDU nuclear fuel required for the future operation of Units 3 and 4, SNN also plans to expand the production capacity of the Nuclear Fuel Plant (FCN Pitești).

Romania's Energy Strategy 2025–2035, with a 2050 Outlook also provides for strengthening the existing nuclear fuel cycle while improving the security and efficiency of the supply of raw materials required for nuclear fuel manufacturing at FCN Pitești. To achieve this objective, SNN has assumed responsibility for nuclear raw material processing through the establishment of Feldioara Uranium Concentrate Processing Plant S.R.L. (FPCU Feldioara).

The National Integrated Energy and Climate Plan (NECP) 2021–2030 provides for the establishment of a Contracts for Difference (CfD) support mechanism designed to stimulate investment in new low-carbon electricity generation capacity, including nuclear power and renewable energy sources. The objective is to facilitate the development of additional low-carbon generation capacity while ensuring diversification of energy sources and increasing the flexibility of the national power system.

In view of projected electricity demand up to 2050 and the ongoing decarbonisation of the energy sector, SNN has identified as a strategic objective the diversification and expansion of its portfolio of activities through the deployment of Small Modular Reactors (SMRs). The SMR programme represents the first initiative of its kind in Romania. To support its implementation, SNN signed a Memorandum of Understanding with NuScale Power, the developer of the first

pressurised water reactor (PWR)-based SMR technology to receive design approval from a nuclear regulatory authority, namely the United States Nuclear Regulatory Commission (U.S. NRC), with respect to the safety aspects of its standard reactor design.

Following the successful industrial and commercial demonstration of advanced nuclear technologies, Generation IV reactors are expected to play an increasingly significant role in nuclear electricity production during the second half of the twenty-first century. Their advanced characteristics are designed to meet enhanced requirements in the areas of nuclear safety, sustainability, economic competitiveness and nuclear non-proliferation.

Generation IV reactor concepts are currently under intensive development worldwide. These efforts are supported internationally through the Generation IV International Forum (GIF) and, at the European level, through the European Sustainable Nuclear Industrial Initiative (ESNII) under the Sustainable Nuclear Energy Technology Platform (SNETP).

Romania is actively engaged in research related to Generation IV reactor systems and contributes to the development of Lead-cooled Fast Reactor (LFR) technology. As part of these efforts, Romania will host and construct the ALFRED (Advanced Lead Fast Reactor European Demonstrator) together with the experimental research infrastructure required for the testing, demonstration, qualification, validation and verification activities necessary to support the licensing of the demonstrator.

Maintaining the current pace of technological development and demonstration requires the long-term availability of adequate financial resources, funding instruments, qualified personnel, international cooperation and sustained political commitment throughout the entire project lifecycle. This includes the construction of the experimental support facilities and of the ALFRED reactor itself, followed by the provision of the resources required for their long-term operation.

The successful demonstration of the technical and commercial viability of LFR technology is expected to pave the way for the commercial deployment of LFR-based Small Modular Reactors, beginning around 2040.

Generation IV nuclear systems also offer the potential to significantly reduce both the volume and the radiotoxicity of radioactive waste. Fast reactor technologies are expected to reduce radioactive waste volumes by approximately one order of magnitude. In parallel, partitioning and transmutation technologies continue to be developed, with the European Union playing a leading role through the MYRRHA (Multi-purpose Hybrid Research Reactor for High-tech Application). These technologies make it possible to transmute long-lived radionuclides, thereby substantially reducing the period during which radioactive waste remains hazardous within a geological repository and further enhancing environmental protection in nuclear energy production.

For the final disposal of high-level radioactive waste, deep geological disposal has become the internationally preferred solution. Significant progress in demonstrating the long-term safety of deep geological repositories has already been achieved in countries such as Finland, Sweden, France and Canada. The technological solutions developed to date have gained broad acceptance among stakeholders and the general public in countries with advanced geological disposal programmes. As a result of sustained efforts in Finland and Sweden, including cooperation under the Swedish KBS-3 disposal concept, Finland became the first country in the

world to obtain a construction licence for a deep geological repository at Olkiluoto. In addition, at the end of January 2022, the Swedish Government approved the construction of a final repository and a spent nuclear fuel encapsulation facility for Sweden's national programme. The experience gained by countries with advanced geological disposal programmes will facilitate the implementation of similar programmes in other nuclear countries, while providing regulators and technical experts with sufficient time to evaluate and authorise these solutions in accordance with internationally accepted safety standards.

Romania's current National Strategy for the Safe Management of Spent Nuclear Fuel and Radioactive Waste provides for the development of a Deep Geological Repository (DGR), scheduled to become operational around 2055, for the final disposal of spent nuclear fuel generated by the Cernavodă Nuclear Power Plant. The Deep Geological Repository is also planned to accommodate long-lived low- and intermediate-level radioactive waste (LILW-LL). By contrast, short-lived low- and intermediate-level radioactive waste (LILW-SL) will be disposed of in the Final Disposal Facility for Low- and Intermediate-Level Radioactive Waste (DFDSMA). The selected site for this near-surface disposal facility is located within the exclusion zone of the Cernavodă Nuclear Power Plant and is scheduled to become operational by 2032.

Future revisions of the National Strategy for the Safe Management of Spent Nuclear Fuel and Radioactive Waste will take into account the latest available technical data and programme developments in order to assess and incorporate appropriate concepts, implementation plans and technical solutions for the management of spent nuclear fuel and radioactive waste arising from future nuclear energy facilities.

A.2 Non-Power Applications

The non-power applications of nuclear and radiation technologies, beyond the civil generation of electricity, are generally less visible to the public. Nevertheless, they make an essential contribution to improving quality of life, creating high-value employment, supporting economic growth and maintaining a high level of radiation protection and safety. For decades, scientists have continuously expanded the peaceful applications of ionising radiation for the benefit of society. Ionising radiation has become an indispensable tool across numerous sectors, including consumer products, food production and agriculture, industry, medicine, scientific research, transport, water resources and environmental protection.

Its benefits extend across multiple areas, including: improving human health through disease diagnosis, treatment and the control of communicable and non-communicable diseases; strengthening food security through safer food and improved agricultural production; supporting environmental protection and climate resilience through freshwater resource management; enabling the manufacture of advanced industrial and consumer products; enhancing public safety through radiological detection technologies.

Nuclear medicine relies on radiopharmaceuticals produced using radioisotopes generated in nuclear reactors, cyclotrons and linear accelerators. Both diagnostic imaging and therapeutic applications including theranostics, which integrates diagnosis and treatment—form the foundation of personalised medicine, particularly in oncology. In addition to oncology, cardiology and neurology benefit from state-of-the-art functional imaging techniques based on radioactive tracers, providing highly accurate diagnostic capabilities. Tumour cells are particularly sensitive to ionising radiation because their ability to repair radiation-induced

damage is significantly lower than that of healthy cells. This biological characteristic underpins the use of radiation in cancer therapy through a range of treatment modalities employing externally generated beams of charged particles, X-rays or gamma rays, as well as internally administered radioactive isotopes in the form of radiopharmaceuticals. At the same time, radiation-based medical imaging technologies continue to evolve in support of increasingly effective treatments. Advanced imaging modalities such as PET-CT, SPECT-CT and PET-MRI play an essential role in treatment planning, therapeutic monitoring and precision medicine.

The peaceful non-power applications of nuclear science encompass medicine, nuclear physics, radiochemistry and radiopharmacy, all of which play a central role in advancing diagnostic and therapeutic practices. These disciplines contribute directly to expanding access to personalised healthcare while improving patient outcomes and overall quality of life.

Through advanced analytical methods capable of determining the origin, history, trafficking routes, intended use and illicit movement of nuclear and radioactive materials, as well as identifying links between individuals, materials and locations involved in criminal investigations, nuclear forensics has become an essential component of investigations involving illicit trafficking in nuclear and other radioactive materials.

B. OVERVIEW OF THE STRATEGIC OBJECTIVES

In accordance with the National Strategy for the Development of the Nuclear Sector, the following strategic objectives have been established to guide the medium- and long-term development of Romania's nuclear power programme and non-power nuclear applications:

Strategic Objective 1 – Maintain a high level of operational performance while increasing the number of CANDU nuclear power units.

Strategic Objective 2 – Develop new nuclear power plants through a phased deployment of Small Modular Reactors (SMRs) and Generation IV innovative reactor technologies.

Strategic Objective 3 – Develop an integrated nuclear fuel cycle that ensures the sustainability and efficiency of Romania's nuclear power programme.

Strategic Objective 4 – Ensure the safe management of spent nuclear fuel and radioactive waste, including the closure of radioactive waste disposal facilities and the implementation of institutional control following their closure.

Strategic Objective 5 – Strengthen scientific and technical support capabilities and enhance the role of research, development and innovation in the nuclear sector.

Strategic Objective 6 – Ensure the availability of highly qualified human resources required for the successful implementation of Romania's nuclear programme.

Strategic Objective 7 – Maximise the benefits derived from the peaceful non-power applications of nuclear science and technology in medicine, industry, agriculture, the space sector, hydrogen production and other fields.

C. OVERVIEW OF THE MEDIUM- AND LONG-TERM PROJECTS OF THE NATIONAL NUCLEAR PROGRAMME IN THE NUCLEAR POWER SECTOR

The National Strategy for the Development of the Nuclear Sector identifies a number of strategic investments of national importance, including:

1. Completion of **Cernavodă Nuclear Power Plant Units 3 and 4**;
2. Refurbishment of **Cernavodă Unit 1 and Unit 2**;
3. Expansion of the **Spent Fuel Interim Storage Facility (DICA)** at Cernavodă Nuclear Power Plant through additional **MACSTOR 400** storage modules;
4. Licensing, construction and commissioning of the **Final Disposal Facility for Low- and Intermediate-Level Radioactive Waste (DFDSMA)**;
5. Licensing, construction and commissioning of the **Deep Geological Repository (DGR)**;
6. Construction of the **Heavy Water Detritiation Facility (CTRF)** at the Cernavodă Nuclear Power Plant site;
7. Construction of a nuclear power plant based on **Small Modular Reactor (SMR)** technology;
8. Construction of the experimental support facilities for the **ALFRED** demonstrator;
9. Construction of the **ALFRED** demonstrator to validate **Lead-cooled Fast Reactor (LFR)** technology;
10. Construction of a research infrastructure for the production of radioactive ion beams and medical radioisotopes;
11. Production of medical isotopes at the **Cernavodă Nuclear Power Plant**;
12. Development of technologies for fundamental and applied nuclear physics research using the high-power laser systems at **ELI-NP**.

The successful implementation of these strategic projects requires the development of dedicated sectoral programmes, institutional development strategies and coordinated activities covering research, engineering, licensing, design, construction and commissioning.

1. Completion of Cernavodă Nuclear Power Plant Units 3 and 4

The Cernavodă Units 3 and 4 Project consists of completing and commissioning two CANDU 6 nuclear power units at the Cernavodă Nuclear Power Plant site, each with a minimum gross installed electrical capacity of 724 MWe. Existing structures specifically designed for CANDU 6 technology—including the reactor buildings, turbine-generator buildings and hydraulic structures—have already been partially completed and will continue to be utilised for the completion of the project.

The project will be implemented in full compliance with the Romanian and European Union nuclear regulatory framework, ensuring that all applicable requirements relating to nuclear safety, radiation protection, protection of workers, the public, the environment and property are met. Implementation will also comply with the international nuclear agreements and conventions to which Romania is a Party.

International experience demonstrates that the implementation of nuclear new-build projects requires the allocation of substantial high-risk capital during the preparatory phase. This early

investment is essential to adequately define the project and provide the technical, financial and regulatory basis necessary for taking a Final Investment Decision (FID).

Accordingly, the National Strategy adopts a phased implementation approach, consistent with international best practice, under which the project is divided into three successive stages:

- Stage 1 – Preparatory Phase (Preliminary Notice to Proceed – Pre-LNTP)

This phase includes all preparatory activities required to establish the technical, financial, commercial and regulatory foundations of the project prior to authorising preliminary works.

- Stage 2 – Preliminary Works (Limited Notice to Proceed – LNTP)

This stage comprises the execution of preliminary engineering and construction activities necessary to prepare the project for full-scale implementation.

- Stage 3 – Construction Phase (Final Notice to Proceed – FNTP)

This stage begins with the issuance of the Final Notice to Proceed (FNTP) and covers the full construction, installation, testing and commissioning of Units 3 and 4 until their entry into commercial operation.

2. Refurbishment of Cernavodă Unit 1 and Refurbishment of Unit 2

The Refurbishment of Cernavodă Unit 1 represents the largest investment project undertaken exclusively by National Company Nuclearelectrica S.A. (SNN).

Like all nuclear power reactors, CANDU units have a finite design life. For CANDU technology, the design lifetime corresponds to approximately 210,000 equivalent full-power operating hours, which, assuming an average capacity factor of approximately 80%, translates into an economic operating life of roughly 30 years. The principal life-limiting components are the fuel channels, feeder pipes and the reactor containment system.

Given the significant capital investment required to construct new large-scale nuclear generating units, refurbishment offers an economically attractive alternative. Upon completion, the refurbished unit is capable of operating for an additional design life of approximately 30 years, while requiring investment costs estimated at around 40% of those associated with constructing a comparable new nuclear unit. An additional advantage of refurbishment is the considerably shorter implementation schedule. Based on current experience, the outage required for the refurbishment works is estimated at 24 to 30 months, substantially less than the time required for constructing a new nuclear power plant.

The refurbishment of Cernavodă Unit 1 was approved by the shareholders of SNN through Shareholders' Resolution No. 27 of 23 December 2013.

According to the study defining the optimal project organisation, the refurbishment programme is structured into three phases:

- Phase 1 – Project Definition;
- Phase 2 – Implementation Preparation;
- Phase 3 – Unit Shutdown and Execution of the Refurbishment Works.

On 23 February 2022, the shareholders of SNN approved the investment decision for the refurbishment of Unit 1 based on the Feasibility Study and the Enhanced Safety Scenario (Scenario 2), identified by SNN as the preferred option. Compared with the reference scenario, the approved option incorporates additional design modifications intended to increase nuclear safety margins while reflecting the latest international developments aimed at improving plant robustness and resilience. Following the approval of the investment decision, the Unit 1 Refurbishment Project entered Phase 2 – Implementation Preparation.

With regard to the Refurbishment of Cernavodă Unit 2, the project is expected to follow an implementation approach broadly similar to that adopted for Unit 1, while incorporating the lessons learned and best practices derived both from the Unit 1 project and from comparable refurbishment programmes carried out in countries operating PHWR/CANDU nuclear power plants.

3. Licensing, Construction and Commissioning of the Final Disposal Facility for Low- and Intermediate-Level Radioactive Waste (DFDSMA)

Pursuant to Article 3(1)(e) of Annex No. 1 to Government Decision No. 1437/2009 approving the Regulation on the Organisation, Functioning and Organisational Structure of the Nuclear and Radioactive Waste Agency (ANDR), the Agency is responsible for ensuring the safe disposal of radioactive waste arising from the nuclear fuel cycle through the development of new radioactive waste disposal facilities.

In accordance with the objectives established by the National Strategy for the Safe Management of Spent Nuclear Fuel and Radioactive Waste, approved by Government Decision No. 102/2022, ANDR is responsible for the licensing, construction, commissioning and operation of a near-surface disposal facility for low- and intermediate-level radioactive waste, designated as the Final Disposal Facility for Low- and Intermediate-Level Radioactive Waste (DFDSMA).

The purpose of DFDSMA is to ensure the safe and permanent disposal of low- and intermediate-level radioactive waste containing short-lived radionuclides together with limited quantities of long-lived radionuclides.

The DFDSMA near-surface disposal facility is designed to provide a maximum disposal capacity of approximately 122,000 cubic metres of conditioned low- and intermediate-level radioactive waste generated by authorised nuclear licence holders. The facility will ultimately comprise up to 64 disposal vaults, to be constructed progressively in eight development stages. The initial investment phase covers the construction of the first eight disposal vaults.

The implementation stages of this project are described in detail in the National Strategy for the Safe Management of Spent Nuclear Fuel and Radioactive Waste, which serves as Romania's principal strategic policy document in the field of radioactive waste management and was approved by the Government through Government Decision No. 102/2022

4. Licensing, Construction and Commissioning of the Deep Geological Repository (DGR)

In accordance with Article 3 of Government Ordinance No. 11/2003 on the Safe Management of Radioactive Waste and Spent Nuclear Fuel, republished, the Nuclear and Radioactive Waste Agency (ANDR) is responsible for ensuring the safe final disposal of radioactive waste generated throughout the nuclear fuel cycle, including waste arising from the decommissioning of nuclear and radiological installations, as well as radioactive waste generated through the application of nuclear technologies in industry, medicine, agriculture, scientific research and other socio-economic sectors.

Romania currently follows an open nuclear fuel cycle policy, under which spent nuclear fuel is classified as high-level radioactive waste intended for direct disposal in a deep geological repository without subsequent recovery.

The repository will provide for the final disposal of: spent nuclear fuel; high-level radioactive waste (HLW); and long-lived low- and intermediate-level radioactive waste (LILW-LL), within a dedicated deep geological facility relying on a system of engineered and natural barriers designed to prevent the migration of radionuclides into the biosphere.

The implementation of a Deep Geological Repository (DGR) constitutes the long-term solution for the safe disposal of spent nuclear fuel, high-level radioactive waste and long-lived low- and intermediate-level radioactive waste.

The project is founded upon the fundamental principle governing radioactive waste management established by Government Ordinance No. 11/2003, namely: „the application of the best available techniques and technologies without imposing unjustified burdens on future generations, while taking into account potential transboundary effects”.

As in many countries with relatively recent nuclear power programmes, Romania's geological disposal programme is currently at an early stage of development. The planned implementation strategy comprises the following sequential phases:

- Selection of the disposal concept;
- Development of the site selection strategy;
- Preparation of the research and development programme supporting geological disposal;
- Selection of the host rock;
- Site characterisation;
- Site licensing;
- Construction of the repository;
- Operating licence;
- Post-closure institutional control period.

ANDR is responsible for the licensing, construction, commissioning and operation of the Deep Geological Repository, with the objective of bringing the facility into operation by **2055**. The implementation stages of the project are also described in the above-mentioned National Strategy for the Safe Management of Spent Nuclear Fuel and Radioactive Waste.

Under the present National Nuclear Programme (NNP) and following a joint initiative of the Ministry of Energy (ME), ANDR and SNN, Romania commits to ensuring that the next revision of the National Programme/National Strategy for the Safe Management of Spent Nuclear Fuel and Radioactive Waste will include a detailed action plan aimed at commissioning the Deep Geological Repository by 2050. The repository will provide disposal capacity for spent nuclear fuel and long-lived low- and intermediate-level radioactive waste (LILW-LL) generated by the four Cernavodă nuclear power units. The update of the National Programme constitutes one of the actions included under Strategic Objective 4 of the present Action Plan, with a target completion date of 2028.

ANDR, in cooperation with SNN and with the support of the Ministry of Energy, will ensure the preparation and assessment of the studies and technical reports required to substantiate the updated implementation plan for the Deep Geological Repository.

With regard to Small Modular Reactors (SMRs), ANDR will coordinate the integration into the updated National Programme of the analyses and studies required to define appropriate solutions for the final disposal of radioactive waste generated by these future facilities. The corresponding disposal solutions will be developed by ANDR on the basis of supporting documentation provided progressively by SNN and/or the relevant project companies, including inventories of radioactive waste and strategies for pre-disposal management, in accordance with the successive stages of project development and implementation. Through these actions, Romania commits to meeting the technical criterion established by Commission Delegated Regulation (EU) 2022/1214, namely the existence of a documented plan providing for the commissioning, by 2050, of a disposal facility for high-level radioactive waste, in accordance with the requirements of the EU Taxonomy framework for sustainable economic activities.

5. Construction of the Heavy Water Detritiation Facility (CTRF) at the Cernavodă Nuclear Power Plant Site

In CANDU reactors, heavy water is used both as a neutron moderator and as the primary heat transport coolant. During reactor operation, deuterium the hydrogen isotope contained in heavy water—is exposed to neutron irradiation and is gradually converted into tritium, resulting in the formation of tritiated heavy water (DTO). Under normal operating conditions, the tritium concentration in the heavy water inventory progressively increases until a steady-state equilibrium is reached, at which the rate of tritium production is balanced by its radioactive decay.

The implementation of the Heavy Water Detritiation Facility (CTRF) will have a significant positive impact by substantially reducing the total tritium inventory of the CANDU nuclear power plant. The facility will alternately process and detritiate the heavy water used in the nuclear systems of Cernavodă Units 1 and 2.

The CTRF project represents a major environmental improvement initiative undertaken by the Cernavodă Nuclear Power Plant. By reducing tritium discharges in liquid and gaseous effluents, the facility will enhance the protection of both the public and the environment. At the same time, the reduction of tritium concentrations within plant systems will significantly decrease occupational exposure of plant personnel, thereby further strengthening radiation protection and occupational health.

The implementation of the project will also prevent tritiated heavy water from becoming radioactive waste at the end of reactor operation. Consequently, it will eliminate the need to include the management of this waste stream within the decommissioning programmes for Cernavodă Units 1 and 2, thereby avoiding the generation and ultimate disposal of substantially larger volumes of radioactive waste.

The CTRF facility has also been designed to provide detritiation services for the heavy water inventories of the future Cernavodă Units 3 and 4. Should these units enter operation, the target tritium concentration for each reactor moderator system will be established accordingly, together with the infrastructure required to transfer heavy water from Units 3 and 4 to the CTRF facility.

6. Construction of the First Small Modular Reactor (SMR) Nuclear Power Plant

The new generation of nuclear energy systems is based on Small Modular Reactor (SMR) concepts designed to provide increased flexibility and, where appropriate, support cogeneration, enabling the simultaneous production of electricity and process heat for industrial applications.

The deployment of SMR technology forms an integral part of the Intergovernmental Agreement between Romania and the United States of America on Cooperation Related to Romania's Civil Nuclear Programme. The project represents a key component of Romania's strategy for achieving its decarbonisation and energy security objectives through the deployment of advanced nuclear technologies.

In 2021, National Company Nuclearelectrica S.A. (SNN) and NuScale Power signed a Teaming Agreement, establishing the initial roadmap for the implementation of NuScale Small Modular Reactor technology in Romania.

The purpose of the agreement is to develop a preliminary implementation plan and an overall project roadmap for Romania's first SMR nuclear power plant.

Within this framework, SNN is carrying out the preparatory activities required for the deployment of Romania's first SMR-based nuclear power plant during the current decade.

In parallel, long-term considerations regarding the siting and deployment of SMR technology are being addressed. The Action Plan of the National Nuclear Programme promotes extensive regional, European and international cooperation in nuclear research, development, demonstration and innovation, including participation in international initiatives dedicated to advanced SMR technologies. Accordingly, Romania intends to continue its active involvement in the European Industrial Alliance on Small Modular Reactors, established by the European Commission in 2023, whose objective is to accelerate the deployment of Small Modular Reactors (SMRs) and Advanced Modular Reactors (AMRs) throughout the European Union.

7. Construction of the Experimental Support Facilities for the ALFRED Demonstrator

Lead-cooled Fast Reactor (LFR) technology offers significant advantages in terms of nuclear safety, fuel resource utilisation, minimisation of high-level radioactive waste and proliferation resistance. In addition, its modular design provides important opportunities for improving the economic competitiveness of future nuclear energy systems.

The development of LFR technology is supported by the European Union through the Sustainable Nuclear Energy Technology Platform (SNETP) and the European Sustainable Nuclear Industrial Initiative (ESNII), the industrial pillar dedicated to the development of Generation IV nuclear energy systems.

The ALFRED (Advanced Lead Fast Reactor European Demonstrator) project is a strategic European research initiative aimed at constructing in Romania a demonstration reactor based on Lead-cooled Fast Reactor technology together with the experimental infrastructure required to support its licensing.

In 2011, taking advantage of the opportunities offered by the EURATOM Research Framework Programme, the Romanian Government committed, through the Institute for Nuclear Research (RATEN-ICN), to participate in the European research programme dedicated to Lead-cooled Fast Reactor technology, which includes the construction of the ALFRED demonstrator in Romania.

Subsequently, under a Government Memorandum adopted in 2014, the Mioveni Nuclear Platform (Argeş County) was designated as the reference site for both the ALFRED demonstrator and the associated experimental support infrastructure.

The ALFRED project is included in: Romania's National Roadmap for Research Infrastructures, adopted under the National Strategy for Research, Development and Innovation; the updated 2017 National Research Infrastructure Roadmap; and the Smart Specialisation Strategy of the South-Muntenia Development Region.

The demonstration of the technical and economic feasibility of LFR technology requires the construction of a demonstration reactor prior to commercial deployment. Before licensing can be granted, the ALFRED project must demonstrate, through comprehensive testing programmes, the qualification of materials, components and systems, together with the verification and validation of the engineering codes, standards and safety assessment methodologies used in the reactor design.

For this purpose, a comprehensive experimental research infrastructure is being developed, consisting of:

- **ATHENA** — pool-type thermal-hydraulic testing facility;
- **CHEMLAB** — lead chemistry laboratory;
- **HELENA-2** — fuel assembly testing loop;
- **ELF** — endurance testing facility;
- **HANDS-ON** — fuel handling testing facility;
- **MELTIN POT** — accident fuel behaviour investigation facility;
- **Lead School Centre of Excellence and Project Coordination Hub.**

Significant progress has already been achieved through preparatory activities for the construction of the experimental infrastructure, the implementation of associated research and development programmes, and specialised education and training activities supporting testing, demonstration, verification and validation.

Construction of the ATHENA and CHEMLAB facilities is already under way, while the remaining experimental facilities (HELENA-2, ELF, HANDS-ON and MELTIN POT) have been contracted and financed under the POCIDIF 4 ALFRED Project, together with the associated research and demonstration activities.

8. Construction of the ALFRED Demonstrator for the Validation of Lead-cooled Fast Reactor (LFR) Technology

Romania is pursuing research associated with Generation IV reactors and contributes to the development of Lead-cooled Fast Reactor (LFR) technology through its commitment to host and construct the ALFRED Demonstrator.

Lead-cooled Fast Reactor technology is particularly attractive due to its nuclear safety characteristics, the efficient utilisation of nuclear fuel (through integration with the current reactor fleet, a fully closed fuel cycle with complete recycling can be achieved), the significant reduction in both the volume and radioactivity of radioactive waste, and its enhanced proliferation resistance.

The ALFRED Demonstrator is a lead-cooled fast reactor designed as a Small Modular Reactor (SMR), with a maximum electrical output of 125 MWe, to be constructed on the Mioveni Nuclear Platform. The demonstrator will be operated in a phased manner, through three successive power and temperature levels.

The LFR Demonstrator is intended to test all systems under representative operating conditions with regard to operation, inspection and maintenance procedures, and to demonstrate the viability of LFR technology. It supports the further development of LFR technology and the LFR-SMR concept by:

- demonstrating the viability of the LFR technology concept, taking into account its potential applications, feasibility and performance;
- supporting the safe and sustainable operation of the envisaged fleet of industrial LFR systems;
- strengthening the contribution of nuclear energy to sustainable development and climate change mitigation; and
- contributing to the enhancement of Romania's nuclear research capabilities.

Provided that the necessary human and financial resources are made available in due time, LFR technology could become commercially available from 2040 onwards.

The integrated platform established through the research, design, construction, commissioning and operation of the ALFRED reactor will support the development of advanced technologies, the training and specialisation of the human resources required for the national nuclear power programme, as well as the maintenance and further development of the domestic nuclear industry through the participation of Romanian suppliers and specialists.

The project is included in the portfolio of the FALCON (Fostering ALFRED CONstruction) international consortium, established in 2013 by the Autonomous Administration for Nuclear Energy Technologies (RATEN), Ansaldo Nucleare and ENEA. It is also among the first nine projects selected in 2024 by the European Industrial Alliance on Small Modular Reactors (SMRs) and is included in the roadmap of the EAGLES Consortium, established by FALCON and SCK CEN, for the development of a commercial Lead-cooled Fast Reactor Small Modular Reactor (LFR-SMR).

9. Construction of a Research Infrastructure for the Production of Radioactive Ion Beams and Medical Radioisotopes

The production of radioactive ion beams and the study of isotopes far from the valley of stability represent a leading field of contemporary nuclear physics and one of the main directions for the development of experimental fundamental research in this field.

It is proposed to establish at the Horia Hulubei National Institute for Research and Development in Physics and Nuclear Engineering (IFIN-HH) a research infrastructure (RI) dedicated to the production of radioactive ion beams through photonuclear reactions. This infrastructure will open up new opportunities for research in nuclear physics and its applications.

The Radioactive Ion Facility at IFIN-HH (RIF@IFIN) will provide beams of exotic radioactive nuclei produced through the photofission of uranium or thorium induced by bremsstrahlung radiation generated by an intense high-energy electron beam. In parallel, an irradiation station will be dedicated to the production, through photonuclear reactions, of radioactive isotopes with theranostic potential for the development of new radiopharmaceutical products.

The worldwide uniqueness of the RIF@IFIN infrastructure will consist in the use of state-of-the-art technologies for the separation and extraction of fission products (cryogenic gas cells and radio-frequency carpets) in order to optimise the intensity of radioactive ion beams, particularly those of refractory element isotopes.

RIF@IFIN will contribute to the development of new techniques, technologies and advanced equipment, leading to an increased innovation potential in the field of nuclear physics applications, particularly in the fields of advanced materials and health. It will also contribute to a better understanding of the nuclear fission process and to the development of expertise in this field, which represents one of the main options for energy production without greenhouse gas emissions.

10. Development of Technologies for Fundamental and Applied Nuclear Physics Research Using the High-Power Laser Systems at ELI-NP

Extreme Light Infrastructure – Nuclear Physics (ELI-NP) is a world-leading research infrastructure dedicated primarily to studies in the field of Nuclear Photonics. Nuclear Photonics is an interdisciplinary field in which nuclear physics, laser physics, materials science, accelerator science and life sciences contribute synergistically to the establishment of new directions in both fundamental and applied research, providing unique benefits for society.

The main research equipment consists of a system of two 10 PW ultra-short pulse high-power lasers based on the Chirped Pulse Amplification (CPA) technique.

At maximum power, the ELI-NP lasers will, for the first time worldwide, achieve intensities of up to 10^{23} W/cm², making it possible to explore heavy-ion acceleration regimes with remarkable characteristics. One such characteristic is the exceptionally high ion beam density (solid-state density of approximately 10^{22} atoms/cm³), which is several orders of magnitude higher than that of ion beams produced by conventional particle accelerators. Such ultra-intense laser pulses have the potential to fundamentally change the paradigm of particle accelerators in the future.

A comprehensive biomedical research programme, building on the unique capabilities of ELI-NP, is currently under development and addresses topics such as: the production of radiation beams relevant to radiotherapy; the radiobiological effects of radiation beams generated by high-power lasers; phase-contrast X-ray medical imaging; and the investigation of the feasibility of producing radioisotopes of medical interest using radiation beams generated by high-power lasers.

The intense secondary radiation beams generated by 0.1 PW and 1 PW laser pulses (electrons, protons, neutrons and gamma rays) will be used to characterise the behaviour of materials under extreme radiation fields, with applications in the selection and development of materials for nuclear fusion devices, nuclear fission reactors and the space industry.

D. OVERVIEW OF NON-POWER NUCLEAR FACILITIES, ACTIVITIES AND PROJECTS

1. Applications of Heavy Water in Nuclear and Non-Nuclear Fields

Heavy water is used primarily as a moderator in pressurised heavy water reactors (PHWRs), including CANDU reactors.

Other applications of heavy water include its use in neutrino detectors, tritium production, nuclear magnetic resonance (NMR) spectroscopy, infrared spectroscopy, and in organic chemistry for the preparation and labelling of specific isotopes. It is also used in physiology and biology for metabolic rate testing, in the semiconductor industry, in the manufacture of optical fibres and OLED displays, in medicine for routine and advanced diagnostic testing, and in pharmacology for the development of medicinal products with fewer adverse effects through the use of deuterated compounds.

In this context, Societatea Națională Nuclearelectrică S.A. (SNN) is undertaking activities to assess the feasibility of recommissioning the Heavy Water Plant in Drobeta-Turnu Severin.

2. Radiation Processing Technologies

IFIN-HH has developed a wide range of applications, including the sterilisation/decontamination of medical and pharmaceutical products for human and veterinary

use, raw materials for cosmetics and food supplements, materials for biotechnology, as well as radioresistance studies of microorganisms, materials and devices.

A distinct application, to the development of which Romania has made a significant contribution at the international level, is disinfection treatment for the preservation of cultural heritage.

The Horia Hulubei National Institute for Research and Development in Physics and Nuclear Engineering (IFIN-HH) operates the only industrial-scale gamma irradiation facility (Cobalt-60) in Romania. In addition to the multi-purpose industrial irradiator, the IRASM Technological Irradiation Department of IFIN-HH also operates a research gamma irradiator, a microbiology laboratory, and a physico-chemical testing laboratory, carrying out activities both under direct contracts with industrial operators and within publicly funded research, development and innovation (RDI) projects.

The IRASM irradiator is the only third-party sterilisation facility available in Romania, accessible to all interested economic operators. Practically, all small and medium-sized enterprises manufacturing sterile products or requiring microbial load reduction treatments make use of IRASM's services.

Through its technological irradiation activities and laboratory analyses (microbiological and physico-chemical), IRASM has contributed to the placing on the market or the continued marketing of numerous Romanian products (up to 5,000 m³/year) in compliance with CE marking requirements and Good Manufacturing Practice (GMP) authorisation requirements. It has also contributed to the development and promotion of new technologies through the implementation of more than 25 research, development and innovation (RDI) projects carried out in partnership with companies and research organisations under all major national research programmes implemented over the past twenty years (ORIZONT 2000, PNCDI I–III and POC).

IFIN-HH aims to maintain and further strengthen its existing technological irradiation capacity based on gamma irradiation, while also developing new applications specific to electron accelerator technologies.

3. Ionising Radiation Metrology

Since the beginning of the 21st century, as a result of the rapid advances in electronics and computer science, information technology (IT) and digitalisation have gradually become integrated into almost every sector of society. As a consequence of this "symbiosis", a new innovative concept the Internet of Things (IoT) has emerged. This concept describes an interconnected system of computing devices, mechanical and digital machines, objects and other entities capable of transferring data over a network without requiring human-to-human or human-to-computer interaction.

As a result, the Fourth Industrial Revolution (Industry 4.0) has become increasingly evident across all its subsectors and related fields. Metrology, as a specialised discipline closely linked to most industrial sectors, must also advance towards digitalisation in order to meet these new requirements.

Accordingly, a new innovative concept the Digital Calibration Certificate (DCC) needs to be developed, validated and implemented. The DCC will enable metrology service providers to

deliver their services in a simpler, faster, safer, more cost-effective and more environmentally friendly manner (Metrology 4.0), thereby contributing to the implementation of the European Union's Green Deal concept of the Smart City, which is strongly supported by the European Commission.

Through the implementation of this project, IFIN-HH intends to contribute to the digitalisation of metrology, taking into account its status as the National Measurement Standard for Ionising Radiation Metrology.

The radiation protection aspects and the risks associated with the field of ionising radiation place ionising radiation metrology among the branches of metrology for which digitalisation (Metrology 4.0) is of particular importance.

The National Standard for Radioactivity must be maintained and further developed in the coming years. This requires the modernisation of existing equipment, annual participation in international comparisons of radioactivity measurements organised by the International Bureau of Weights and Measures (BIPM) or the European Association of National Metrology Institutes (EURAMET) in order to maintain metrological traceability and international equivalence, as well as ensuring the availability of the necessary personnel within the IFIN-HH Ionising Radiation Metrology Laboratory (LMRI).

This requires highly specialised personnel whose competencies are continuously maintained and enhanced through participation in national and international conferences, workshops and training courses, as well as through scientific placements at leading National Metrology Institutes (NMIs) and Designated Institutes (DIs) abroad.

4. Nuclear Forensics

Nuclear Forensics is a relatively new multidisciplinary scientific field. Its primary area of activity is the analysis of nuclear materials and other radioactive materials through the determination of their physical and chemical characteristics using advanced technologies and techniques from disciplines such as nuclear physics, chemistry and materials science.

The NFL-RO Laboratory within the Horia Hulubei National Institute for Research and Development in Physics and Nuclear Engineering (IFIN-HH) focuses on effectively supporting judicial authorities in criminal investigations, ensuring the sustainability of the laboratory and its human resources, and maintaining the most appropriate balance between cost and efficiency with regard to the analytical services it provides.

The nuclear forensics capabilities developed by Romania through the NFL-RO Laboratory are intended to support national investigative authorities by carrying out analyses of evidential materials that exhibit radioactivity. These capabilities can also be successfully used to provide technical support to the nuclear regulatory authorities, as well as to authorities in other fields.

The examinations performed by nuclear forensics specialists support the identification of nuclear and other radioactive materials found outside regulatory control and may therefore provide evidence of violations of the law or breaches of nuclear security, including information on potential vulnerabilities in the physical protection systems of facilities possessing such materials.

Depending on the national legal framework and the provisions governing the national judicial system, nuclear forensics may also assist in determining the legal classification of offences where it is necessary to distinguish between different levels of criminal severity based on the nature of the materials involved or their potential use.

5. Experimental Pilot Facility for Tritium and Deuterium Separation (PESTD)

The Experimental Pilot Plant for Tritium and Deuterium Separation (PESTD), operated by the National Research and Development Institute for Cryogenic and Isotopic Technologies (ICSI Râmnicu Vâlcea), has the mission of validating the technological parameters and the operational characteristics of equipment specifically designed for operation in a tritiated environment and under cryogenic conditions, with a view to implementing a Heavy Water Detritiation Facility at the Cernavodă Nuclear Power Plant (NPP) for the detritiation of heavy water used in CANDU reactors.

The Experimental Pilot Plant (PESTD) is one of the few experimental tritium and deuterium separation facilities in the world and the only semi-industrial-scale pilot facility of its kind in Europe. The cryogenic distillation system, which forms an integral part of the pilot plant, is a high-capacity cryogenic installation in terms of refrigeration performance.

This experimental facility makes it possible to develop representative experiments for the recovery of tritium from liquid and gaseous effluents specific both to CANDU-type fission reactors and to fusion reactors (within the framework of the ITER Project), thereby creating the conditions for investigating tritium recovery and storage processes within the Tritium Cycle System.

6. National Centre for Hydrogen and Fuel Cells

The National Centre for Hydrogen and Fuel Cells (CNH), within the National Research and Development Institute for Cryogenic and Isotopic Technologies – ICSI Râmnicu Vâlcea, has identified the development of energy systems based on hydrogen and fuel cell technologies as one of its key priorities. It is a research and development facility whose mission is to implement, develop and disseminate hydrogen-based energy technologies in Romania, while supporting national priority policies in the fields of energy and environmental protection.

The CNH has an outstanding research infrastructure covering the entire hydrogen value chain (Production → Storage/Transport → Utilisation). Its human resources are focused on the development of technologies, products and services that contribute to the establishment of a genuine **hydrogen economy** in Romania.

The Low-Temperature Laboratory dedicated to liquefied hydrogen storage applications and superconducting energy storage technologies (CRYO-HY), together with the Energy Storage Laboratory (ROM-EST) and the ICSI-4EE (ICSI for Energy and Environment) research programme, have been designed to ensure continuity and promote innovation through applied and technological research capable of generating human and technological capabilities, as well as new knowledge in strategic areas for Romania's development, namely:

- (i) isotopic technologies supporting the nuclear power sector;
- (ii) hydrogen energy technologies and energy storage technologies;

(iii) waste valorisation; and

(iv) advanced assessment of the anthropogenic impact on the environment and quality of life through the development and implementation of advanced analytical methods and appropriate indicators.

7. Medical Applications

Nuclear techniques provide accurate diagnostic information that is of vital importance for the detection and treatment of both infectious and non-communicable diseases, such as cancer. Radiopharmaceuticals are used for the treatment of diseases and for diagnostic imaging. Radiotherapy also employs targeted radiation beams that are essential for the treatment of a wide range of medical conditions.

The safe and well-coordinated use of nuclear techniques for the detection, diagnosis and treatment of diseases, as well as for combating malnutrition, contributes to improving public health and social well-being worldwide.

In this context, the Horia Hulubei National Institute for Research and Development in Physics and Nuclear Engineering (IFIN-HH), Măgurele, which has departments equipped with modern, state-of-the-art research and production facilities for a wide range of radiotracers used in cancer diagnosis, as well as for curative and palliative treatment, is carrying out extensive research on the production of medical radioisotopes for nuclear medicine applications, as well as on the development of new radiopharmaceuticals and innovative diagnostic and therapeutic techniques.

The projects developed by IFIN-HH in this field will lead to the implementation and development of diagnostic and treatment methods that are currently either not available in Romania or are insufficiently developed due to inadequate medical infrastructure and the lack of appropriately trained specialised personnel.

Consequently, the results of these projects will contribute to improving the quality of healthcare services and enhancing patient safety.

8. Agricultural and Food Applications

Food Treatment and Preservation

Ionising radiation provides an alternative to chemical products for the treatment and preservation of food. It can be used to extend the shelf life of food products.

In meat and other foods of animal origin, irradiation destroys bacteria responsible for spoilage as well as pathogens that cause diseases, such as *Salmonella* food poisoning. This makes it possible to provide safe food products that can be stored for extended periods.

Irradiation also inhibits sprouting in fruits and vegetables and delays the ripening process. As a result, fresh fruits and vegetables can be stored for longer periods before reaching full maturity.

Food irradiation is particularly important for the export of food products to countries with tropical climates, where high temperatures may accelerate food spoilage.

Food Quarantine and Export

Ionising radiation is used to eliminate parasites and insects that may be present in goods intended for export. Irradiation destroys pests that could pose significant quarantine risks in the importing countries.

Food irradiation is applied both to extend shelf life and reduce losses resulting from spoilage, and as a preventive measure to control specific foodborne pathogens (such as *Salmonella* and *Escherichia coli* (*E. coli*)), or as a quarantine treatment for intercontinental food exports.

Although food irradiation has a lower level of public acceptance in Europe than in other parts of the world, it remains an effective tool for ensuring food safety.

Insect Control

Worldwide, approximately 10% of agricultural crops are destroyed by insects. To control this threat, insects sterilised in laboratories using ionising radiation are released into the environment during their specific mating periods. Female insects that mate with sterile males are unable to reproduce.

As a result, populations of harmful insects can be rapidly reduced. This method of releasing sterile insects into the environment is known as the Sterile Insect Technique (SIT).

9. Environment

Nuclear science plays a valuable role in helping us understand the history of our environment, the way environmental systems function and interact, the factors that may influence the spatial and temporal distribution of the hydrological balance, as well as the impact of human activities on the environment.

At present, among emerging applications, environmental applications based on electron accelerator technologies have the potential to become viable alternatives for reducing the effects of air pollution through radiation treatment of flue gases from thermal power plants and marine engines as well as water pollution, through the treatment of sewage sludge and industrial wastewater. Water treatment applications include both microbial decontamination and the degradation of persistent organic pollutants (POPs).

Environmental tracers provide an important tool for understanding the origin, flow and dynamics of water resource systems, soil erosion, changes occurring in coastal areas, the effects of ocean acidification on marine chemistry and marine life, and other environmental processes.

There is a continuing need to promote the use of environmental tracers for the development of sustainable management policies aimed at protecting water resources and the terrestrial and aquatic environments.

Natural and artificial radioactive tracers may also be used to contribute to the improvement of human health through:

(i) studies of palaeoclimate variability over millions of years in order to achieve a better understanding of the interactions between the oceans, the land surface and the atmosphere within the climate system;

(ii) the study and monitoring of pollution sources; and

(iii) the study of the transport and dispersion of pollutants in the lower atmosphere.

IFIN-HH focuses on ensuring the robustness and fitness for purpose of the application and use of environmental tracers in addressing scientific challenges and opportunities, promoting their wider use, and tackling fundamental issues related to the vulnerability, sustainability and uncertainty of surface water and groundwater resources, water resource systems and their management.

Technologies for the neutralisation of pollutants contained in flue gases, wastewater and municipal sludge are currently under experimental development. In addition, irradiation is already routinely used as a technological process in the manufacture of motor vehicle tyres and in other industrial processes involving polymer cross-linking and graft polymerisation.

10. Cultural Heritage Conservation

Treatment with ionising radiation for the preservation of cultural heritage represents a significant societal contribution of the nuclear sector. The high penetrating capability of gamma radiation ensures the effectiveness of the biocidal treatment while allowing the rapid processing of large quantities of cultural heritage objects.

This treatment can be applied to objects made of wood, paper, textiles, photographic film, leather and parchment. Accidents and/or inadequate storage conditions may lead to extensive biological infestations in museums, archives and libraries, which are difficult to eliminate because of the large number of contaminated objects. Radiation treatment offers a major advantage: the high penetration capability of ionising radiation ensures the effectiveness of the biocidal treatment throughout the entire volume of the treated objects.

In order to fully exploit the potential of technological irradiation, IFIN-HH is pursuing the development of new electron accelerator-based irradiation facilities, promoting the development of new technological irradiation applications, and preparing feasibility studies for emerging technological irradiation applications, including those involving the installation of electron accelerators.

11. Industrial Applications

A wide range of industries, from agriculture to manufacturing, use radionuclides to evaluate materials, products and industrial processes.

Gamma Radiography

Just as a medical X-ray enables a physician to obtain a detailed image of a bone fracture, industrial X-ray or gamma radiography provides a detailed image of internal defects, such as cracks in metal castings, welds and other industrial components.

Industrial Measurements and Analyses

Radioisotopes are widely used in industrial processes for measuring viscosity, density and thickness, particularly where other measurement methods would be difficult or impossible to apply.

The intensity of radiation decreases as it passes through different materials. Accordingly, the ratio between the emitted radiation intensity and the intensity measured after passing through a material, in accordance with the absorption law specific to that material, provides information on the characteristics of the material or layer through which the radiation has passed.

Radioisotopes are also used to determine the efficiency of industrial mixing processes, assess the wear of blast furnace linings, detect leaks and other defects in cooling towers and heat exchangers at power plants. Instruments using radioactive sources are also widely employed in grinding and flotation operations. These devices provide the advantage of reliable non-contact measurements.

In the mining industry, radionuclides are used to locate and quantify mineral deposits, map geological formations through exploratory boreholes and mining drill holes, and determine the presence of hydrocarbons.

Miniature Power Sources

Radioisotopes are widely used in applications requiring autonomous power sources, such as meteorological stations, weather balloons, navigation equipment (including lighthouses and buoys), cardiac pacemakers, and other similar applications.

Manufacture of Iridium-192 Sources for Industrial Non-Destructive Testing

The assessment of the structural integrity of industrial components manufactured by casting, forging or welding requires the use of sealed radiation sources for the detection of manufacturing defects by means of gamma radiography. Iridium-192 (Ir-192) is one of the radioisotopes most commonly used for industrial non-destructive testing (NDT).

E. ACTION PLAN FOR ACHIEVING THE MEDIUM- AND LONG-TERM STRATEGIC OBJECTIVES

In order to support the actions required for the successful development and implementation of the objectives set out in this Strategy and presented above, a number of action and measures have been identified to facilitate their effective implementation.

Accordingly, the Action Plan for achieving the medium- and long-term strategic objectives provides a framework for monitoring the proposed objectives through the use of performance indicators, with the purpose of assessing the progress made towards their achievement in a manner that is meaningful for all stakeholders, reviewing the key aspects of implementation, and measuring the results of the implementation of the Strategy.

OS 1 Maintain a High Level of Operational Performance while Increasing the Number of CANDU Nuclear Power Units

Direction of Action / Project	Key Measures in Developing the Direction of Action / Project Stages	Responsible	Timeline	Performance Indicator
(Project) Completion of construction and commissioning of Units 3 and 4 at Cernavodă NPP	Stage 1 – Preparatory Stage – Preliminary Notice to Proceed (Pre-LNTP)	SNN Ministry of Energy	12-18 months	✓ Re-operationalization of the EN project company ✓ Pre-project studies and activities necessary to revise the technical requirements needed to contract the EPC ✓ Undertaking actions to support project financing ✓ Implementation of the project re-operationalization and development strategy
	Stage 2 – Preliminary Works (Limited Notice to Proceed – LNTP) – Phase 1 of the EPC (Engineering, Procurement and Construction) Contract		18-24 months	✓ Development of the Project's critical engineering component, nuclear safety documentation, and analyses of the local market of equipment and service suppliers needed for construction works ✓ Project notification to the European Commission under Article 41 of the EURATOM Treaty ✓ Re-assessment of the Project's feasibility based on the new techno-economic indicators, and the Final Investment Decision, which will allow the Project to move to Stage 3
	Stage 3 – Construction (Issuance of the Final Order to Begin Works / Final Notice to Proceed) – Phase 2 of the EPC Contract		68-78 months	✓ Effective start of construction, assembly and commissioning works (Estimated timelines: U3 - 2031; U4 - 2032)
(Project) Refurbishment of the operating units at Cernavodă NPP. Refurbishment of Unit 1 at Cernavodă NPP	Phase 1 – Preliminary studies	SNN Ministry of Energy	2018-2022	✓ Demonstration of the current capability of Unit 1 reactor components to operate beyond 210,000 hours at rated power, at least until the end of 2026 ✓ Finalization of the scope of the Refurbishment Project

				works, and demonstration of the Refurbishment Project's feasibility ✓ Approval of the Feasibility Study <i>Note: On 23.02.2022 the SNN shareholders approved the investment decision for the Cernavodă Unit 1 Refurbishment Project, based on the Feasibility Study. The Project moved to Phase 2.</i>
	Phase 2 – Preparation for implementation		2022-2026	✓ Development of the engineering package related to project modifications ✓ Procurement of equipment and components with a long manufacturing lead time ✓ Award of the Engineering, Procurement and Construction (EPC) contract
	Phase 3 – Unit shutdown and effective execution of the Refurbishment Project		2026-2029	✓ Unit shutdown and effective execution of the Cernavodă Unit 1 Refurbishment Project ✓ Continuation of Cernavodă Unit 1 operation: 2029 <i>Note: The Agreement between the Government of Romania and the Government of the United States on cooperation regarding nuclear-energy projects at Cernavodă and Romania's civil nuclear energy sector ("IGA"), ratified by Law no. 200/16.07.2021, takes into account the Unit 1 refurbishment project.</i>
(Project) Refurbishment of the operating units at Cernavodă NPP. Refurbishment of Unit 2 at Cernavodă NPP	Similar planning scenario for the preparation and execution phases and activities of the project, taking into account the good practices and lessons learned from the Unit 1 Refurbishment project.	SNN Ministry of Energy	2037-2039	✓ Performance indicators similar to those implemented for the Unit 1 Refurbishment project are considered.

(Project) Construction works for the Heavy Water Detritiation Facility (CTRF), on the Cernavodă NPP platform	Stage 1 – including completion of investment preparations. Finalization of the detailed design for the contractor to begin procurement of components with a long manufacturing lead time ("long lead items")	SNN Ministry of Energy ICSI Râmnicu Vâlcea	2022-2023	✓ Award of the "Engineering, Procurement, Construction" execution contract ✓ Securing of financing ✓ Initiation of procurement of components with a long manufacturing lead time ("long lead items") ✓ Obtaining the permits, approvals and the decision issuing the environmental agreement, etc., required as a basis for the construction approval
	Stage 2 – including construction activities: assembly, technological tests / commissioning. Start of construction and installation works. Commissioning (PIF) of the facility		2023-2025	✓ Obtaining the construction permit for the project and the commissioning (PIF) permit ✓ Carrying out construction and installation works
	Stage 3 – including completion of construction activities and preparation for entry into operation. Trial operation. Transfer to operation		2025-2026	✓ Obtaining the operating license ✓ Ensuring the conditions for entering into operation
Maintaining and increasing nationally acquired design and research capabilities for the CANDU line	Ensuring continuity of expertise in carrying out safety analyses	SNN RATEN M Energy CNCAN	Permanent	✓ Obtaining and maintaining nuclear safety licenses at Cernavodă NPP ✓ Safety analyses carried out by nationally recognized organizations, for R&D, design and engineering activities in the field of safety analyses for nuclear power units
	Study of structural materials and advanced nuclear fuels	SNN RATEN M Energy Mec CNCAN	Permanent	✓ Results from experiments, data and information credited as support for the safety analyses underlying the supporting documents describing structural-material performance and the decision-making process for developing advanced fuel solutions
	Study of the possibilities for	SNN RATEN	Permanent	✓ Development of capabilities to focus

	improving design, testing, operation, maintenance, licensing and modernization performance of instrumentation and control systems, and for carrying out equipment and process analyses	Men		knowledge and expertise on enabling improvement of instrumentation and control system performance and of equipment and process analysis results ✓ Contribution to improving overall plant performance and, consequently, to the economics and safety of present and future nuclear power plants
	Continuous development and improvement of radioactive waste management and radiological protection	SNN ANDR RATEN IFIN CNCAN MEd M Energy MC	Permanent	✓ Identification and demonstration of technically and technologically licensable, economically feasible solutions for managing certain categories of radioactive waste “cradle to grave”, within sectoral and national R&D programs ✓ Maintaining competencies and lessons learned regarding ALARA implementation for reducing doses to personnel and the public ✓ Long-term planning of preventive measures for maintaining and, respectively, adequately developing radiological-protection knowledge and competencies, correlated with the need to ensure the safety levels of future nuclear projects
	Ensuring a high level of operating performance through the use of appropriately qualified equipment and personnel, meeting requirements related to the continuous increase in nuclear-safety levels for normal and accident conditions	SNN M Energy CNCAN	Permanent	✓ Preventive and corrective maintenance programs, inspections, mandatory testing during planned outages, implementation of design modifications ✓ Recruitment and retention programs for competent personnel to meet increased nuclear-safety requirements, appropriate for new

				generations of specialists
Studying accident scenarios and fuel strategies	Study of accident-tolerant fuel (ATF) (correlated with a similar measure under OS 3)	SNN RATEN M Energy M Research CNCAN	2025-2030	✓ Technological feasibility study ✓ Decision on implementing an ATF fuel solution applicable to CANDU technology that could be manufactured at FCN Pitești and used at Cernavodă NPP ✓ Contribution to fulfilling the supporting conditions for obtaining financing agreements from investors that impose taxonomy conditions to demonstrate sustainability in terms of environmental and social aspects
	Studies on advanced CANDU fuel	RATEN SNN M Energy CNCAN ANDR	2035	✓ Studies/reports on the feasibility of implementing alternative advanced CANDU fuel solutions, taking into account the most recent developments in international experience in the field
	Investigating the possibility of using other types of fuel, in compliance with international treaties and conventions to which Romania is a party, and taking into account the types of nuclear reactors introduced into operation	SNN RATEN M Energy CNCAN ANDR	2025-2035	✓ Studies/reports on analyzing and documenting strategic-approach processes regarding the possibility of using other types of nuclear fuel, based on the types of nuclear reactors introduced into operation
Ensuring material resources for the nuclear energy programme	Analysis of the possibilities of meeting material-resource requirements, taking into account future projects	SNN RATEN M Energy Authorities and organizations operating within the scope of action and responsibility of ME; ANRM, M Research, Romanian Academy, etc.	Permanent	✓ Own investment programs and/or sectoral or national investment programs
	Capitalizing on the heavy water reserve built up in previous years for the operation of Cernavodă NPP,	CNMAG M Energy Authorities and organizations operating within the scope of action and	Permanent	✓ Ensuring the planning and implementation of activities enabling the preservation of the quality and quantity of

	including ensuring the estimated annual technological top-up requirements and operation of Units 3 and 4 at Cernavodă NPP over their entire operating life, and resuming heavy water production	responsibility of the heavy-water management field, Government Secretariat, ANRSPS, CNCAN RATEN, SNN, etc.		heavy water, over the medium and long term, for CANDU-line nuclear reactors ✓ Analysis of the feasibility of the project to re-operationalize the Heavy Water Plant
Maintaining national technological competence	Correlating national education and training systems with the needs of the nuclear programme Specific preparation within research and design institutes, within SNN and through international cooperation	SNN RATEN M Energy Authorities and organizations operating within the scope of action and responsibility of MEC; MEd, M Research, Romanian Academy, etc.	Permanent	✓ Social-responsibility programs in the fields of education, health and the environment ✓ Succession plans and plans for attracting highly qualified personnel

OS 2 – Construction of New-Type Power Plants, in a Phased Approach, Over Time and by Technology Line (Small Modular Reactors – SMR – and Innovative Gen IV Reactors)

Direction of Action / Project	Key Measures in Developing the Direction of Action / Project Stages	Responsible	Timeline	Performance Indicator
(Project) Construction of Romania's first nuclear power plant based on SMR modules, with PWR technology	Preliminary activities	SNN Ministry of Energy	2021-2022	✓ Technical support studies for identifying possible SMR sites ✓ Selection of the preferred candidate site ✓ Establishment of the project company
	Site selection and initiation of pre-project activities needed for the Final Investment Decision		2022-2026	✓ Obtaining the environmental agreement ✓ Obtaining the siting permit ✓ Securing financing sources ✓ Placing orders and manufacturing equipment with long manufacturing lead times
	Initiation of engineering, procurement and construction activities		2026-2029	✓ Obtaining the construction permit
	Module installation and commissioning		2029-2030	✓ Installation, testing and commissioning ✓ Obtaining the operating license
Establishing a regional hub for	Exchange of experience in promoting and	SNN RATEN	2027-2030	✓ Development of capabilities to

promoting and sharing know-how in the operation and production of small modular reactors	implementing small modular reactor projects Improving the transfer of knowledge from the developer to the operator	M Energy CNCAN Authorities and organizations operating within the scope of action and responsibility of the education and training field; MEC; MEd, M Research, IFIN HH, Romanian Academy, etc.		concentrate expertise and resources for training in the operation and production of small modular reactors ✓ Social-responsibility programs in the field of education, appropriate for the expansion of new reactor types under the nuclear energy programme
(Project) Construction of experimental facilities supporting the ALFRED demonstrator	Completion of the ATHENA and CHEMLAB facilities Construction of the HELENA2 and ELF facilities Construction of the MELTIN POT facility Construction of the HANDS ON facility Construction of the HUB and Lead School	M Energy ANC RATEN	2025-2030	✓ Experimental data on testing, demonstration and qualification of materials, components and sub-assemblies of the ALFRED reactor, for licensing purposes ✓ Verification and validation of calculation standards and codes used in the design of the ALFRED reactor, for demonstrator licensing purposes ✓ Preparation of the human resources required for construction and operation of the ALFRED demonstrator ✓ Involvement of the domestic nuclear industry in the supply chain specific to LFR technology
(Project) Construction of the ALFRED demonstrator	Preliminary pre-licensing activities Facility licensing activities Facility construction activities Operation and commercialization of the developed SMR LFR technology	M Energy ANC RATEN CNCAN	2025-2045	✓ Obtaining the license for the ALFRED reactor's conceptual design ✓ Obtaining the siting permit ✓ Obtaining the construction permit ✓ Demonstrating the viability of LFR technology

OS 3 – Development of an Integrated Fuel Cycle Ensuring the Sustainability and Efficiency of Nuclear Power Generation

Direction of Action / Project	Key Measures in Developing the Direction of Action / Project Stages	Responsible	Timeline	Performance Indicator
Development of accident-tolerant fuel (ATF)	Development of technical concepts for the ATF fuel bundle, compatible with the CANDU6 reactor Testing of ATF fuel performance outside the reactor Manufacturing of experimental elements for demonstration irradiation Development of technologies and facilities for manufacturing an ATF fuel-bundle prototype Qualification/licensing of the new fuel type	M Energy RATEN Other authorities involved	2022-2032	✓ Production of an experimental ATF fuel element ✓ Demonstration of ATF fuel performance under irradiation ✓ ATF fuel bundle ✓ Obtaining licensing of the ATF fuel concept
Ensuring nuclear fuel in an integrated system at national level, taking into account the types of nuclear reactors introduced into operation	Diversification of raw-material supply sources needed for nuclear fuel production and for SNN's future development regarding the front end of the nuclear fuel cycle Preserving production capacity and profitable activity on national territory in the fields of uranium ore mining, processing, and nuclear fuel production	SNN M Energy Authorities and organizations operating within the scope of action and responsibility of the mining sector and associated activities (MEC, ANRM, etc.)	2026-2035	✓ Development of feasible scenarios for ensuring nuclear fuel in an integrated national system ✓ Sustainable development of the front end of the nuclear fuel cycle, taking into account strategic options for the back end of the fuel cycle ✓ Modernization and, as appropriate, expansion of uranium-ore preparation, raw-material processing and CANDU nuclear-fuel production capacities
	Key measures in developing this direction, correlated with measures presented under the direction "Studying accident scenarios and fuel strategies"			
Integration of fuel cycles for CANDU-type and new-generation power plants	Analysis of the possibilities for integrating the fuel cycles used at existing and future NPPs Analysis and documentation of the possibilities for recycling spent nuclear fuel Analysis of documented alternative scenarios considering the possibility of implementing a DUPIC (Direct Use of Spent PWR Fuel in CANDU) cycle in Romania Analysis of the possibility of using spent CANDU fuel within the ALFRED project	M Energy SNN RATEN CNCAN	2023-2030	✓ Studies on economically feasible solutions for integrating the fuel cycles of CANDU-type plants with those of the new generation ✓ Definition of strategic options for approaching spent-fuel recycling alternatives ✓ Studies on the conditions for implementing the DUPIC cycle in Romania, taking into account the most recent national and international experience regarding the technical progress of R&D results on advanced CANDU fuel use

				✓ Studies on closing the fuel cycle through implementation of LFR technology
Managing radioactive waste, including spent fuel, through the provision of interim storage	Promotion of radioactive-waste management facilities ensuring safe pre-disposal management (including interim storage) of all radioactive waste generated from the operation of Cernavodă NPP units	SNN ANDR CNCAN Authorities and organizations operating within the scope of action and responsibility of MEC; MMAP, MS, etc.	2022-2032	✓ Radioactive-waste management strategy/plan for waste generated at Cernavodă NPP, in agreement with the DFDSMA and DGA programs ✓ Investment programs for future projects ✓ Proper compliance with license conditions for radioactive-waste management activities at nuclear and radiological facilities ✓ Strategic approach to technical radioactive-waste management solutions on the Cernavodă NPP platform, in synergy for Units 1 and 2, and Units 3 and 4
Ensuring treatment-conditioning solutions for radioactive waste, and conditioning of spent nuclear fuel, to meet acceptance requirements at final repositories	Establishing and implementing an integrated concept of technical/technological solutions for treating and conditioning radioactive waste generated at Cernavodă NPP and its acceptance at the DFDSMA Identifying and demonstrating technical and technological solutions for treating/conditioning LL-LILW waste for final disposal purposes Study of the encapsulation concept for spent nuclear fuel, taking into account the deep-geological-disposal concept chosen for the DGR Study of radioactive-waste management from the decommissioning of nuclear power units	SNN RATEN ANDR CNCAN M Energy IFIN-HH Authorities and organizations operating within the scope related to MEC; ANRM, M Research, Romanian Academy, etc.	2023-2028	✓ R&D study on an integrated concept of technically/technologically and economically feasible solutions for treatment-conditioning, appropriate for final disposal at the DFDSMA of radioactive waste from Cernavodă NPP ✓ Decision and implementation plan for the project of a radioactive-waste treatment station for waste disposed of at the DFDSMA Saligny facility ✓ Implementation of an integrated technological solution for the deep-geological-disposal concept – transport container and final disposal station for spent-nuclear-fuel encapsulation ✓ Updating of decommissioning studies/reports and associated cost estimates, integrating the results of studies describing economically feasible technological disposal solutions for all waste categories (VLLW, SL-LILW and LL-LILW)
Implementing applications that increase plant	Study of the manufacturing of various radioisotopes that can be	SNN M Energy ANC	2027-2030	✓ Studies on the artificial production of radioisotopes in nuclear reactors and, as

efficiency and economic utilization	used in the medical industry and for various medical treatments, such as Cobalt, Molybdenum, Lutetium, etc.	CNCAN		applicable, substantiation of the decision-making process for implementing economically feasible solutions, taking into account the potential for utilization at national and international level
--	---	-------	--	---

OS 4 – Safe Management of Spent Nuclear Fuel and Radioactive Waste in Support of the Development of Nuclear Power, Including the Closure and Institutional Control of Radioactive Waste Disposal Facilities

Direction of Action / Project	Key Measures in Developing the Direction of Action / Project Stages	Responsible	Timeline	Performance Indicator
Updating the National Programme for the Management of Spent Nuclear Fuel and Radioactive Waste (correlated with the directions of action and indicators presented under OS 3)	Integration into the National Programme of flow diagrams on management from generation to disposal of spent nuclear fuel and radioactive waste resulting from the development of future nuclear activities envisaged under the SNDDN	ANDR Main waste generators Interinstitutional Working Group	2025-2028	✓ Updated National Programme for the Management of Spent Nuclear Fuel and Radioactive Waste ✓ Studies estimating the inventory of radioactive waste and spent fuel for new nuclear energy projects ✓ Generators' own strategies regarding the stages of pre-disposal and management of radioactive waste and spent fuel ✓ Studies documenting the planning of DGA commissioning stages in 2050
Defining, finalizing and implementing final-disposal solutions	Promotion of final disposal of very-low-level radioactive waste (VLLW)	ANDR SNN		✓ Development plan for an operational concept for geological disposal of LL-LILW
	Study of geological disposal of LL-LILW waste, with alternative solutions in the spent-nuclear-fuel repository	RATEN CNCAN M Energy IFIN-HH Authorities and organizations operating within the scope related to MEC; MEd, M Research, Romanian Academy, etc.		✓ Studies for defining and developing conceptual solutions for the final disposal of all categories of radioactive waste and spent fuel, over the medium and long term
Establishing appropriate national measures for the responsible management of spent nuclear fuel and radioactive		ANDR – Interinstitutional Working Group SNN M Energy CNCAN RATEN IFIN	Permanent	✓ Management plan for radioactive waste resulting from radiological emergency situations or potentially radioactive material, including identification, segregation and minimization of waste that

waste, including that resulting from potential radiological emergency situations, bankruptcy or judicial liquidation and/or falling under State responsibility, in order to comply with the nuclear and radiological safety and security requirements established under the legislative and regulatory framework in the nuclear field, and to ensure protection of the population and the environment		Authorities and organizations operating within the scope related to MEC; INSP, MS, MICD, MMed, MAPN, IGSU, MAI, etc.		also presents other non-radiological hazardous characteristics, such as toxicity and biological hazard; the plan will also address issues related to human and animal remains ✓ Solutions for integrated national-level management of radioactive waste resulting from potential emergency situations, bankruptcy or judicial liquidation and/or falling under State responsibility ✓ Solutions for integrated national-level management of potentially contaminated materials / radioactive waste resulting from other activities not covered by a CNCAN registration or license
Developing pre-disposal and disposal solutions for radioactive waste resulting from non-nuclear activities	Development of pre-disposal solutions for LL radioactive waste and spent nuclear fuel resulting from non-energy applications	RATEN IFIN-HH ANDR M Energy MICD INCDMRR	2023-2035	✓ Ensuring dry interim-storage capacity at the RATEN ICN site for spent fuel generated by TRIGA operation ✓ Ensuring interim-storage capacity at the RATEN ICN and IFIN-HH sites for long-lived radioactive waste destined for final disposal at the DGA
	Support for research-innovation activities under national research programmes enabling the provision of efficient, economically feasible technologies and solutions for the treatment, conditioning and interim storage of radioactive waste in preparation for final disposal, and for the decommissioning of nuclear and radiological facilities	Min Energy MICD RATEN IFIN-HH ANDR	Permanent	✓ Identification and demonstration of technical and technological solutions for treatment-conditioning of LL-LILW waste in preparation for final disposal at the DGA ✓ Analysis of the impact of operating Gen IV and SMR nuclear plants on radioactive-waste disposal ✓ Development of treatment and conditioning technologies for waste considered difficult, generated from decommissioning of the VVR-S reactor, operation/decommissioning of TRIGA, operation/decommissioning of ALFRED (irradiated graphite, aluminium, beryllium, boron carbide,

				lead-containing waste, etc.) and other research-development activities
Promoting optimization of radioactive-waste management in a manner that ensures reuse and recycling of materials and radioactive sources, in the context of the transition to a circular economy		ANDR Min Energy CNCAN SNN RATEN	Permanent	✓ Optimization of design solutions for final disposal, correlated with reuse and recycling activities promoted at the pre-disposal stage ✓ Analyses of solutions for minimizing the volume of radioactive waste and spent nuclear fuel intended for final disposal (correlated with the indicators presented under OS 3)
(Project) Licensing, construction and commissioning of the National Repository for Low- and Intermediate-Level Radioactive Waste (DFDSMA)	Preliminary activities regarding obtaining the Site and Design Permit	ANDR Min Energy CNCAN	2024-2025	✓ Steps necessary for procuring the engineering services needed to obtain the siting permit ✓ PUZ (Zonal Urban Plan) authorization, Environmental Agreement and DFDSMA siting permit
	Preliminary activities regarding obtaining the Construction Permit (first 8 cells)		2025-2028	✓ Steps necessary for preparing the procurement documentation for selecting a contractor, for obtaining the construction permit, and for the stages of building the DFDSMA repository ✓ Construction of the first 8 cells of the DFDSMA repository
	Activities regarding obtaining the Operating Permit (first 8 cells)		From 2028	✓ Selection by ANDR of a DFDSMA operating organization, in accordance with applicable legislation ✓ Obtaining the DFDSMA operating license
(Project) Licensing, construction and commissioning of the Deep Geological Repository (DGA)	Establishing the site-selection strategy and the geological-repository concept	ANDR Min Energy CNCAN	2022-2025	✓ Action Plan for implementing a Deep Geological Repository in Romania, for spent nuclear fuel and for high-level and long-lived low- and intermediate-level radioactive waste ✓ Studies to identify potentially favorable host-rock formations and to establish site-selection criteria
	R&D support plan for implementation of the geological repository	ANDR Min Energy CNCAN RATEN	2025-2028	✓ Preparation of at least 2 R&D support studies for the site-selection process and characterization methods, by 31 December 2025
	Activities regarding selection of the host rock	ANDR RATEN Min Energy	2028-2030	✓ Carrying out a study on the selection of the host rock for potential Deep

		CNCAN		Geological Repository sites, based on selection criteria established by CNCAN, in accordance with IAEA recommendations, by 31 December 2028
	Activities necessary for site research/characterization	ANDR RATEN Min Energy CNCAN	2030	✓ Carrying out studies to establish potential Deep Geological Repository sites, by 31 December 2030
	Activities necessary for obtaining the repository Construction Permit	ANDR CNCAN	2045	✓ Obtaining the Environmental Agreement and other approvals/permits by 2043. Obtaining the Siting Permit by 2044, and the Construction Permit by 2045
	Activities for construction and operation of the geological repository	ANDR Min Energy CNCAN	2045-2055	✓ Steps necessary for contracting the repository construction works ✓ Obtaining the operating license by 31 December 2055

OS 5 – Strengthening Scientific and Technical Support Capacity and Enhancing the Role of Research and Innovation in the Nuclear Sector

Direction of Action / Project	Key Measures in Developing the Direction of Action / Project Stages	Responsible	Timeline	Performance Indicator
Supporting the research-development-innovation programme underpinning the national nuclear programme and its associated infrastructure	Supporting research centres directly involved in developing innovative solutions Ensuring high-performance infrastructure Ensuring the necessary funding	ME MCDI RATEN	Permanent	✓ Research programmes adapted to the implementation stage of strategic projects and objectives ✓ Research and infrastructure projects proposed and funded ✓ Adequate funding mechanisms
Increasing R&D allocations for the nuclear field from the public and private sectors	Gradual increase of the percentage of GDP allocated to research, development and innovation expenditure	ANC RATEN	Permanent	✓ Number of R&D programmes/projects funded in the nuclear field ✓ Supporting nuclear R&D programmes through appropriate budget allocations ✓ Gradually reaching a 1% of GDP target by 2030
	Engaging the private sector in funding nuclear research	ANC	Permanent	✓ Promotion of fiscal approaches to encourage the private sector, through fiscal facilities for investment in research, innovation and demonstration
	Improving research-management	ANC	Permanent	✓ Continuous staff-training projects

	capacity in the nuclear field	Research organizations		✓ Measures to encourage top specialists and their teams
Developing excellence in RDI in the nuclear field	Improving personnel qualification in the nuclear field Support for maintaining highly qualified human resources and promoting specialists and their teams Capitalizing on the potential of talent and promoting access to excellent research	ANC Organizations conducting research	Permanent	✓ Grants awarded to early-career researchers, in the consolidation stage, confirmed for training and mobility
	World-class, integrated and interconnected research infrastructures	ANC Organizations conducting research	Permanent	✓ Participation in the creation of new international-level research infrastructures ✓ Synergy grants
Development of research-development-innovation programmes/projects on hydrogen production that harness the electrical and thermal energy produced in nuclear reactors (correlated with the directions of action, measures, etc. of the hydrogen strategy)	Gradual increase of allocations for research, development and innovation in this field	ANC Organizations conducting research CNHPC	Permanent	✓ Number of R&D projects ensuring the technical maturity of the developed research-development solutions ✓ Pilot/demonstration facilities
Capitalizing on the results of research, development and innovation, with particular focus on mobilizing private investment and developing field-specific policies	Creating synergies between research-innovation policy and industrial policy	Organizations conducting research ANC M Energy M Ec		✓ Stimulating innovation ecosystems
	Creating a framework for capitalizing on knowledge and assimilating research results Improving competencies and managing intellectual assets			✓ Stimulating innovation ecosystems ✓ Stimulating innovation and technology-transfer activity ✓ Addressing EU policy priorities and global challenges through RD&I ✓ Supporting national and EU policies for the continuous improvement of security, safeguards and nuclear safety
Strengthening international cooperation	Continuing and intensifying international cooperation in research-development and	ANC M Energy ANDR RATEN IFIN-HH	Permanent	✓ Research and technical-assistance programmes with international organizations

	technological-engineering activities	Organizations conducting research		✓ Bilateral and cross-sectoral cooperation programmes
	Improving participation in regional, European and NEA/OECD cooperation on research-development in the nuclear field	Authorities and organizations operating within the scope of action and responsibility related to the nuclear field	Permanent	✓ Creating the national legislative framework enabling access to and participation in regional, European and international cooperation ✓ Legislative amendments ✓ Access to, and participation in, partnerships/consortia, programmes, projects, initiative groups, working groups, training networks, etc., at regional, European and international level, in accordance with the projects and actions under the PNN
	Collective approach to global societal challenges	ANC		✓ Extended possibilities for association ✓ Access to the best talent, knowledge, specialized skills and resources ✓ Increasing the supply of, and demand for, innovative solutions

OS 6 – Ensuring Highly Qualified Human Resources Required for the Successful Achievement of the Strategic Objectives

Direction of Action / Project	Key Measures in Developing the Direction of Action / Project Stages	Responsible	Timeline	Performance Indicator
Ensuring the human resources needed for commissioning new nuclear facilities and for retaining existing staff	Attracting new generations to the nuclear field through actions adapted to new generations and their particularities	SNN ANDR RATEN IFIN CNCAN Authorities and organizations operating within the scope of action and responsibility related to ensuring highly qualified human resources for the nuclear field, Ministry of Energy, Ministry of Education and Research, National Authority for Research, etc.	Permanent	✓ National Human Resources Strategy for the nuclear field ✓ Increase in the number of students and graduates of nuclear-energy faculties ✓ Increase in the number of graduates employed in the nuclear field

Revitalizing the national education system to address the need for qualified human resources in the nuclear field	Stimulating cooperation among research, industry and universities Adapting the educational programme to the requirements of Romania's nuclear-energy sector	SNN RATEN IFIN ANDR CNCAN Authorities and organizations operating within the scope of action and responsibility related to ensuring highly qualified human resources for the nuclear field (Ministry of Education and Research, Ministry of Energy, etc.)	Permanent	✓ Collaborations and partnerships among entities interested in the nuclear field ✓ Establishing educational requirements at national level ✓ Periodic updating of university educational programmes for the fields and specializations needed for nuclear energy
	Increasing educational-system performance			✓ Plan of measures to increase requirements in the education field (equipment, fellowships, etc.)
Maintaining and continuously developing expertise and competence in the nuclear field within the community	Attractive careers for researchers and facilitating links with higher education	IFIN-HH SNN RATEN ANDR CNCAN Authorities and organizations operating within the scope of action and responsibility related to ensuring highly qualified human resources for the nuclear field	Permanent	✓ Supporting faculties with a tradition specialized in the nuclear field ✓ Developing an internal research market offering improved framework conditions for research careers, both within and outside academia
	Developing training capacities in the nuclear field		Permanent	✓ Establishing a regional training centre in Romania ✓ Specialization of personnel in nuclear science and technology fields ✓ Qualification and certification of specialized personnel
Supporting the complementarity of educational and training programme providers and facilitating their collaboration	Creating a national network for education and training in the nuclear field, and communities of practice	(Ministry of Education and Research, Ministry of Energy, etc.)	Permanent	✓ Creation of national hubs to facilitate education specific to the nuclear field
Establishing a national and international personnel-training centre using specialized platforms for NuScale SMR reactors	Creating an E2 Centre (NuScale Energy Exploration Center)	NUSCALE-UPB Partnership	2022-2023	✓ Installation of the NuScale Simulator for small modular reactors ("SMR") at the Politehnica University of Bucharest by the end of 2023, funded by the U.S. Department of

				State, under the FIRST programme (Foundational Infrastructure for Responsible Use of Small Modular Reactor Technology)
ENEN2plus	UPB participates in creating education and training programmes funded by the European Union/EURATOM, as well as in a personnel mobility programme for training purposes	ENEN-52 partner organizations (including UPB)	2022-2026	✓ Analysis of the human-resource needs of the European nuclear industry, supplemented with the human-resource needs of research centres ✓ Development of a “HUB” that can serve as a single public entry point for information about existing courses, internships, theses, jobs and other opportunities in the nuclear industry, healthcare, research and government institutions ✓ Organizing at least 3 career events to attract young people to the nuclear field ✓ Awards for outstanding work in the nuclear field (for undergraduate, master's and PhD students, based on final theses) ✓ Programmes rewarding teachers for outstanding results in promoting nuclear science, STEM, and nuclear-in-STEM, as well as communication about nuclear topics ✓ Creation of a European online network for teachers ✓ 3 summer schools, 2 nuclear-science camps and 2 workshops for young people ✓ 2 interdisciplinary “science dating” events ✓ Strengthening competencies in the nuclear field ✓ Comparative analysis and evaluation of current university education-and-training programmes

				✓ Educational materials (new technologies in medical physics; radiation protection – including in space; decontamination and decommissioning; nuclear systems) ✓ Webinars for specialists on developments in the nuclear industry ✓ 6 summer schools on various classic nuclear topics ✓ 2 workshops for PhD candidates ✓ 1 winter school for master's students ✓ Regular PhD competitions ✓ Expansion of the mentoring network ✓ Development of an EU strategy for higher education in the nuclear field ✓ Creation of a VET (Vocational Education and Training) learning community ✓ Implementation of a VET platform with dedicated courses ✓ Creation of a generous mobility programme worth over EUR 2.5 million, for attracting, retaining and developing new and existing human resources in the nuclear field ✓ International cooperation ✓ Development and implementation of education-and-training actions together with international organizations such as the JRC, OECD/NEA, and partners from the USA, China, Canada, South Korea and Japan
--	--	--	--	---

OS 7 – Capitalizing on the Advantages of Non-Energy Applications in Medicine, Industry, Agriculture, Space Technologies, Hydrogen Production and Other Fields

Direction of Action / Project	Key Measures in Developing the Direction of Action / Project Stages	Responsible	Timeline	Performance Indicator
Developing ionizing-radiation metrology	Developing radon (^{222}Rn) metrology to provide new services to beneficiaries in Romania	ANC IFIN-HH	2022-2027	✓ Calibration of equipment measuring radon activity concentration in air, water and soil, and calibration with the provision of radon reference standard sources
	Calibration in-service of new radionuclides with applications in medicine, industry and other fields	mANC IFIN-HH	2022-2027	✓ Primary activity standards
	Improving and expanding the performance of calibration services	ANC IFIN-HH	Permanent	✓ Ensuring metrological traceability for dose measurements ✓ Participation in new international comparisons or proficiency testing
	Extending dose-rate measurement ranges	ANC IFIN-HH	Permanent	✓ Ensuring metrological traceability for dosimetry applied to the radiological protection of occupationally exposed personnel
Developing high-value-added technological irradiation applications in industry	Installation of new ^{60}Co sources up to 1,000,000 Ci	ANC IFIN-HH	2022-2035	✓ 300% increase in IRASM irradiation capacity
	Installation of an electron accelerator to develop new applications and meet industry requirements	ANC IFIN-HH	2022-2030	✓ Irradiation technologies with applications in plastic-waste recycling ✓ Improving sterilization methods for medical-pharmaceutical products ✓ Biotechnologies based on technological irradiation
	Maintaining and increasing Romania's participation in IAEA regional and inter-regional projects in the field of technological irradiation	IFIN-HH	Permanent	✓ IAEA regional and inter-regional projects
Initiating steps to develop hydrogen production capacities that will use electric and thermal energy produced by nuclear	Technical-economic analyses and business plan on the potential for applying research-development technological solutions	CNHPC ANC M Energy RATEN	In correlation with the investment decision-making process in the	✓ Capitalizing on research-development and innovation results, through technology transfer, in order to achieve the climate-

reactors (correlated with the directions of action, measures, etc. of the hydrogen strategy)	regarding hydrogen production capacities		national energy sector	neutrality performance targets
Developing revolutionary medical applications	Development and implementation of new irradiation technologies for the production and extraction of radioisotopes and the preparation of radiopharmaceutical compounds	RATEN Ministry of Energy IFIN-HH ANC	2022-2030	✓ Production and extraction of radioisotopes and preparation of radiopharmaceutical compounds ✓ Treatment methods for various conditions, especially oncological ones
	Development of diagnostic and therapy imaging techniques	ANC IFIN-HH Other institutions in the medical field	2022-2035	✓ Early-diagnosis imaging techniques ✓ Irradiation-therapy protocols
	Development of innovative solutions for combating cancer: early detection, treatment and care	ANC IFIN-HH Other institutions in the medical field	2022-2035	✓ Widely accessible cancer hadron therapy ✓ Phase-contrast X-ray imaging for early tumour detection
Developing nuclear forensics with the aim of reducing threats to nuclear security	Implementation of traditional forensic methods in the NNFL-RO laboratory	IFIN-HH CNCAN	2022-2027	✓ Methods for analysing radionuclide-contaminated samples under safe conditions
	Digitalization of nuclear-safeguards data	IFIN-HH CNCAN	2022-2030	✓ Implementation of a digital nuclear-forensics library as an accounting and control system for materials of interest to nuclear safeguards
	Developing on-scene response capabilities in accordance with the Code of Criminal Procedure	IFIN-HH CNCAN	2022-2028	✓ Procedures compliant with current criminal legislation, developed within the SMC (Quality Management System) implemented in the laboratory
	Strengthening the nuclear-safeguards system for the WRMA balance area	IFIN-HH CNCAN	2022-2030	✓ Updating working procedures on nuclear safeguards in accordance with Euratom Regulation 302, the Additional Protocol and NGN-01
Assessing the impact of ionizing radiation on the environment and biological systems, to ensure radiation protection and radiological safety in nuclear-field practices	Estimation of the radiological risk of radionuclides, especially tritium and carbon-14, in the environment	ANC IFIN-HH RATEN	Permanent	✓ Prospective and retrospective mathematical models ✓ Software products ✓ Preventive measures
	Development of advanced dynamic models for the transfer of tritium and carbon-14 in the atmosphere-soil-plant-animal-human chain; human	ANC IFIN-HH	Permanent	✓ Prospective and retrospective mathematical models ✓ Software products ✓ Corrective/preventive measures

	tritium dosimetry (occupationally exposed personnel and the public), aquatic food chain			
	Development and implementation of nuclear methods and technologies for complex environmental determinations and monitoring	RATEN IFIN-HH CNCAN ANPM	2022-2030	✓ Corrective measures
	Assessment of the ecological and radiological impact of nuclear activities, of nuclear-accident response, and of radiological emergencies	IFIN-HH CNCAN ANPM	Permanent	✓ Software products ✓ Corrective measures
Developing research in national smart-specialization fields: research to obtain new materials, methods, techniques, technologies and advanced equipment to stimulate economic growth	Development of advanced detection and data-acquisition systems	ANC IFIN-HH RATEN	2022-2030	✓ Realization of specialized small-size detectors
	Development of quantum technologies in Romania	ANC IFIN-HH	Permanent	✓ Development of a new generation of detectors, front-end electronics, processing and data acquisition ✓ Development of fast, high-granularity, radiation-resistant detectors for measuring electrons and identifying hadrons ✓ Construction of secure quantum-communication infrastructure ✓ Protecting sensitive data and critical infrastructure by integrating quantum systems into existing communication infrastructure, providing an additional level of security based on quantum communication
	Development of major industrial applications and critical security applications	ANC IFIN-HH	2022-2040	✓ Development of compact and efficient particle accelerators with extreme particle densities, up to TeV energies ✓ Equipment for remote detection of sensitive nuclear materials ✓ Development of ultra-fast non-destructive

				inspection using gamma rays and neutrons
	Development of methods for measuring ultra-low background radioactivity	ANC IFIN-HH	2022-2030	✓ New, as-precise-as-possible techniques and methods for measuring radioactivity ✓ Specific methods for environmental protection and conservation, in the current and future context
	Obtaining, characterizing and/or modifying material properties	ANC IFIN-HH	2022-2030	✓ Production of new materials of technological interest, with applications in biology, geology, archaeology, etc. ✓ Production of radioactive tracers with applicability in medicine, industry, agriculture, the environment and research
	Carrying out facilities, instrumentation and procedures dedicated to elemental analyses based on nuclear methods	RATEN	2022-2035	
	Development of methods and instruments for measuring and monitoring radioactive effluents released from nuclear activities	RATEN	2022-2030	
Development and implementation of new irradiation technologies for the production and extraction of radioisotopes and the preparation of radiopharmaceutical compounds	Assimilation of fission Mo-99 production technology Cyclotron production of Mo-99 Production of radioisotopes for therapy	RATEN IFIN-HH	2022-2030	✓ Fission Mo-99 production technology