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Heavy Water:

A School of Romanian Scientific and Technological Research, a Paradigm in Kuhn's Sense

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Abstract

From the position of a simple employee of the Drobeta Turnu Severin Heavy Water Plant, as a quality assurance inspector, the head of the destructive and non-destructive control laboratories, and finally the head of the quality assurance service, I had the honor to participate, between 1983 and 1993, in the largest technical-scientific project in Romania at that time, which involved universities, countless research institutes, design institutes, factories and construction-assembly companies, which, forced to use exclusively Romanian materials and solutions, had to research, innovate and implement, on a daily basis, unique technologies for Romania, and specific solutions for their improvement.

In this paper I highlight the close collaboration between all these entities, which allowed the development of an important component of the Romanian nuclear program, and laid the foundations of scientific and technological knowledge for the entire further evolution of activities in the nuclear field, and not only. Although there are many books and articles on the history of heavy water in Romania, in this paper I approach this subject from a new point of view, emphasizing the close collaboration between universities, scientific and technological research institutes, design institutes, production factories of machinery and equipment, construction-assembly enterprises, and heavy water plant specialists, thus creating an informal community, even a school within which an unprecedented scientific and technological discipline was developed, and a special emulation for research and innovation . For this purpose, I also analyzed documents that have not been used in such studies until now. And all these aspects are discussed through the lens of a direct and active participant in the construction, putting into operation, and operation of the heavy water plant.

In the case of heavy water produced in Romania, I will demonstrate in this paper that it corresponds to a paradigm in the sense of Thomas Kuhn from *The Structure of Scientific Revolutions*, having the specific characteristics and passing through all the phases specified by him in the case of a paradigm.

Contents

Introduction

Heavy water

Heavy water, or deuterium oxide, with the chemical symbol ^2H_2O or D_2O, is a type of water (H_2O) whose molecules are made up of hydrogen and oxygen. (IUPAC 2005, 306) Hydrogen naturally has three types of isotopes: ^1H, also called protium, with the nucleus consisting of only one proton (the most widespread isotope in nature), ^2H (or D), also called deuterium, with the nucleus consisting of one proton and one neutron, and ^3H (or T), also called tritium, with its nucleus consisting of one proton and two neutrons. The hydrogen in heavy water contains a much higher percentage of deuterium than that in ordinary water. (PubChem 2022)

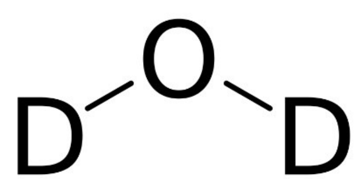

Fig. 1. Chemical diagram of a heavy water molecule, with related chemical bonds.

Main properties of heavy water *: (PubChem 2022)

- Chemical formula: D_2O
- Molar mass: 20.0276 g mol^{-1}
- Appearance: Colorless liquid
- Odor: Odorless
- Density: 1.107 g mL^{-1}
- Melting point: 3.82 °C
- Boiling point: 101.4 °C
- Solubility in water: Miscible
- log P: −1.38
- Refractive index (n_D): 1.328
- Viscosity: 1.25 mPa·s (at 20 °C)
- Dipole moment: 1.87 D

* Unless otherwise stated, data are given for materials in their standard condition (at 25 °C, 100 kPa).

Physical properties of heavy water (with deuterium) compared to light water (with protium): (Chaplin 2014)

Property	D_2O (Heavy water)	H_2O (Light water)
Melting point (standard pressure)	3.82 °C	0.0 °C
Boiling point	101.4 °C	100.0 °C
Density at STP (g/mL)	1.1056	0.9982
Temp. of maximum density	11.6 °C	3.98 °C [13]
Dynamic viscosity (at 20 °C, mPa·s)	1.2467	1.0016
Surface tension (at 25 °C, N/m)	0.07187	0.07198
Heat of fusion (kJ/mol)	6.132	6.00678
Heat of vaporisation (kJ/mol)	41.521	40.657
pH (at 25 °C) [14]	7.44 ("pD")	7.0
pK_b (at 25 °C) [14]	7.44 ("pK_b D_2O")	7.0
Refractive index (at 20 °C, 0.5893 μm) [15]	1.32844	1.33335

Table 1. Physical properties of heavy water

Uses

Heavy water has many and various uses, of which I mention the most important:

In nuclear magnetic resonance, heavy water is used as a solvent in spectroscopy when the nuclide of interest is hydrogen, due to the different magnetic moment of the two types of water.

In organic chemistry, it is used as a source of deuterium.

In infrared spectroscopy, heavy water is used in the collection of FTIR spectra of proteins in solution, improving the resolution over light water.

In neutrino detection systems, heavy water is used as a solvent for the neutrino absorbing medium and for the detection of exotic neutrinos.

In medicine, heavy water is used mixed with $H_2{}^{18}O$ to test average metabolic rate.

In self-powered lighting and controlled nuclear fusion, and other uses that use tritium, it is obtained in some cases in moderated heavy water reactors, or by methods in which deuterium captures a neutron and transforms into tritium.

In certain types of nuclear reactors, especially CANDU-type nuclear reactors, heavy water is used as a neutron moderator to slow down the neutrons and thus increase the effective cross-section of the fissile uranium-235, also contributing to great stability within the chain reaction. Heavy water is also used as a cooling agent in the heat transfer system due to its specific physical properties.

CANDU (CANada Deuterium Uranium) nuclear reactors use pressurized heavy water (Wang 2012) and (originally, natural) uranium fuel. In October 2011, the Canadian federal government licensed the CANDU project to Candu Energy (a wholly owned subsidiary of SNC-Lavalin), which provides support services for the existing sites and also handled the previously blocked facilities in Romania and Argentina through a partnership with the China National Nuclear Corporation.

The heavy water used as a moderator in CANDU nuclear reactors helps to separate neutrons and uranium because ^{238}U has a high affinity for neutrons of intermediate energy ("resonance" absorption), but is easy to fission (has a better cross section) only for the few energetic neutrons above ≈1.5–2 MeV. (Rouben 2011) By moderating, most neutrons will reach a lower energy and be more likely to cause fission, resulting in better "burning" of natural uranium, and thus greater efficiency[1]. Also, heavy water allows for greater stability of the chain reaction.

[1] The moderator slows down the fast neutrons, ideally without capturing them, bringing them into the state of thermal neutrons with minimal kinetic energy. The natural uranium used as fuel is introduced, in the form of beams, into a vessel (calandria) containing the heavy water.

Obtaining

Deuterated water (semiheavy water), HDO, occurs naturally in normal water in a ratio of about 1 molecule to 3,200 molecules of light water (H_2O). Deuterated water can be separated from normal water by distillation, electrolysis, or by various chemical exchange processes, by isotopic exchange. The difference in mass between the two hydrogen isotopes translates into a slight difference in the rate of the reaction. Producing pure heavy water by distillation or electrolysis requires a large cascade of alembics or electrolysis chambers and consumes large amounts of energy, so chemical methods are generally preferred. The most cost-effective process for producing heavy water is the dual-temperature sulphide exchange process (known as the Girdler sulphide process) developed in parallel by Karl-Hermann Geib and Jerome S. Spevack in 1943. (Waltham 2011) Heavy water obtained can have varying degrees of purity, from 98% to 99.75–99.98% for use in nuclear reactors, and occasionally higher isotopic purity.

Marius Peculea, in *Apa grea, procese industriale de separare* (*Heavy water, industrial processes of separation*), (Peculea 1984) summarizes the main technologies for obtaining heavy water:

Process	**Capacity**	**Separation factor**	**Mass transfer rate**	**Energy needed**	**Raw material**	**Complexity of the equipment**
Water distillation	Unlimited	1.015 – 1.055	Moderated	Very high	Water	Average
Distillation of liquid H_2	Limited	~ 1.5	Small	Moderated	Very pure hydrogenr	Average
Electrolysis of water	Unlimited	5 - 10	High	Very high	Water	Average
Isotopic exchange water - H_2S	Unlimited	1.8 – 2.3	High	High	Water	Average

Isotopic exchange NH_3 - H_2S	Limited	2.8 – 6.0	Small - A catalyst is required	Moderated	Hydrogen	High
Isotopic exchange H_2O - H_2	Unlimited	2.0 – 3.8	Very small - A catalyst is required	Moderated	Water	High

Table 2: The main technologies for obtaining heavy water. Source: (Peculea 1984)

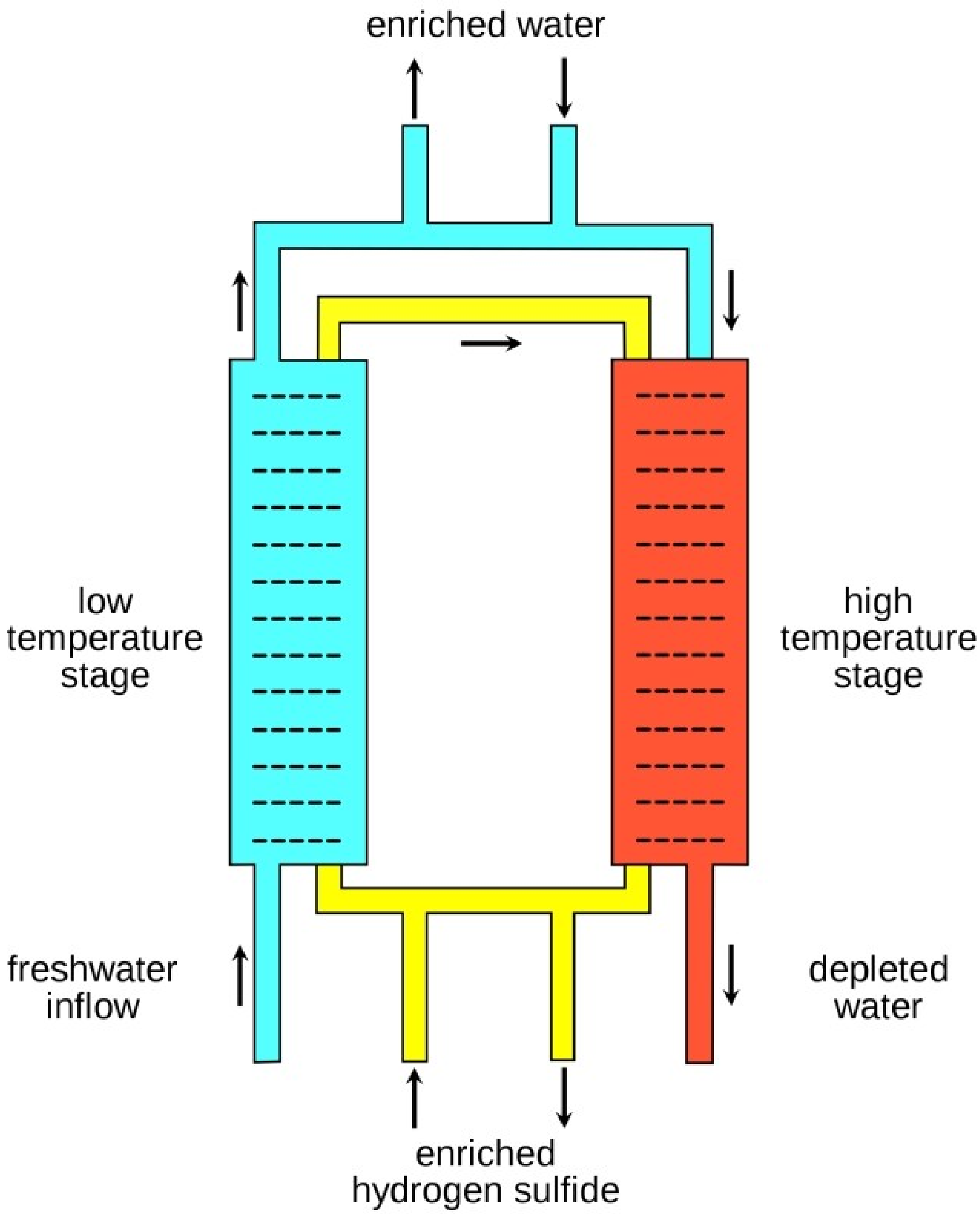

Fig. 2. Girdler sulphide process (Geib-Spevack, GS) simplified. Credit Roland Mattern, Wikipedia CC BY 3.0 license.

By the process known as the Girdler sulfide process, or Geib-Spevack (GS), (Keyser, Mader, and O'Neill 1986) invented by Karl-Hermann Geib and Jerome S. Spevack independently and in parallel in 1943, (Castell and Ischebeck 2013) heavy water is produced industrially from natural water. The method uses isotopic exchange between H2S and H2O, in several steps (stages). One stage consists of two towers with sieve trays, one maintained at about 30 °C (cold tower) and the other at 130 °C (hot tower). The enrichment process is based on the separation difference between 30 °C and 130 °C, with the equilibrium reaction:

$$H_2O + HDS \longleftrightarrow HDO + H_2S$$

Hydrogen sulfide gas is circulated in a closed loop between the cold tower and the hot tower. In both towers, water enters from top to bottom and hydrogen sulfide circulates from bottom to top. The isotopic exchange actually takes place on the plates with holes. In the cold tower, deuterium migrates from gaseous hydrogen sulfide to liquid water. In the warm tower, the transfer of deuterium takes place from water to hydrogen sulfide gas. In a cascaded (multi-stage) system the enriched water from the first stage is fed to the next stage and further enriched. Through this process, the water is enriched to 15-20% D_2O. Further enrichment into heavy water, above 99% D_2O, is done in another process, usually by distillation. (Rae 1978)

Hydrogen sulfide (H_2S) used in the isotopic exchange to obtain heavy water is a colorless, poisonous, corrosive and flammable gas, with traces in the ambient atmosphere having a characteristic foul smell of old eggs. (Greenwood and Earnshaw 1997) Hydrogen sulfide is obtained by separating it from more complex gas mixtures with a high H_2S content, by treating hydrogen with elemental sulfur, or from hydrocarbons. (Faraji et al. 1998)

History

In 1934, Norsk Hydro built the first heavy water plant at Vemork, Tinn, producing 4 kilograms per day. (Feilberg 2018) From 1940 and throughout World War II, the plant was under German control. In 1943, through Operation Gunnerside, Norwegian commandos managed to partially destroy the plant and heavy water reserves. (Gallagher 2002) Air raids in 1943 led the Nazi government to move all heavy water to Germany, an operation foiled in 1944 by a Norwegian partisan.

In the United States, the Manhattan Project built three heavy water plants as part of Project P-9, and other quantities were purchased from Canada. The domestic production plants were closed in 1945. The United States developed the chemical shift manufacturing process at the Dana, Indiana plant in 1945, and then at the Savannah River, South Carolina plant in 1952.

Canada built and operated an electrolytic heavy water plant at Trail, British Columbia in 1943. (US Dep. of Energy 1947) The Atomic Energy of Canada Limited (AECL) project built two heavy water plants with design issues, then Bruce, Ontario heavy water plant (Canadian Nuclear Safety Commission 2018) with a maximum effective capacity of 1600 tons per year. Ontario Hydro built, from 1971, a plant with design capacity reached in April 1974, and then three additional heavy water plants for the Bruce site, commissioned in 1979. By 1993, Ontario Hydro had produced sufficient heavy water, closing the plants for good in 1997. (Davidson 1978, 27–39)

In the Soviet Union, by 1943 there was only 2-3 kg of heavy water in the whole country, obtaining by import from the USA another 1 kg of heavy water in 1939 and 100 kg in February 1945. After winning the Second World War with the other Allies, the Russians deported to the Soviet Union, from Germany, German scientists who had worked on the production of heavy water, including Karl-Hermann Geib, the inventor of the Girdler sulphide process, (Sadovsky

2016) building a plant with which they produced large quantities of heavy water until 1948. (Waltham 2011)

Sweden produced 2,300 liters per year of WW2 heavy water, which was then sold to Germany, and to the US Manhattan Project. (Edfast 15:16:00Z)

There was a small heavy water plant in France in the 1950s and 1960s.

Israel operates a heavy water reactor purchased from Norway in 1959.

Since 1996, a heavy water production plant has been built in Iran at Khondab near Arak, (GlobalSecurity 2011) expanded in 2006. Iran exports excess production according to the agreements.

Argentina uses an ammonia/hydrogen exchange-based plant for heavy water production, approx. 180 tons of heavy water per year. (Ecabert 1984)

In India, the produced heavy water is exported to countries such as the Republic of Korea, China and the United States. (Laxman 2007)

In Pakistan there is a 50 MWth natural uranium heavy water research reactor at Khushab in Punjab province for the production of plutonium, deuterium and tritium. (Fas.org 2000)

The structure of scientific (and technological!) revolutions

Kuhn's theory of the structure of scientific revolutions (Kuhn 1996) focuses on conceptual issues such as the practice of normal science, the influence of historical events, and progress through scientific (and technological) revolutions. In this approach, Kuhn recommends taking into account the intellectual, scientific (and technological) options and strategies available to communities in a certain period prior to the development of the paradigm. The evolution of scientific theories (and technological innovations) does not result from the simple accumulation of facts, but rather from a changing set of intellectual, (scientific and technological) circumstances and possibilities.

For Kuhn this evolution is not independent of the social, political and economic reality of the time, it is guided by the paradigm: " Science does not deal in all possible laboratory manipulations. Instead, it selects those relevant to the juxtaposition of a paradigm with the immediate experience that that paradigm has partially determined." (Kuhn 1996, 216) A paradigm shift is a mixture of sociology, excitement and scientific promise.

Scientists spend most of their careers solving problems within the paradigm in which they live during normal science, building on previous successes of the paradigm that generate confidence that the approach is the right one. When a paradigm reaches its limits, anomalies — failures of the current paradigm — accumulate, the significance of which is judged by practitioners, some anomalies being dismissed as procedural errors, while for others small adjustments to the current paradigm are attempted without lose faith in the established paradigm.

In the analysis of anomalies, some scientists or specialists appear who, considering that there is actually a crisis, embark on a new revolution exploring alternatives to the current paradigm - the candidate paradigm, itself with numerous problems and anomalies due to its incompleteness. Most of the community will oppose these conceptual changes. There usually follows a period in which there are adherents to both paradigms while the candidate paradigm develops and resolves its own early anomalies. In time, the new paradigm will replace the old.

Kuhn lists several phases in the evolution of a paradigm: 1) Pre-paradigm, in which there is no consensus on a certain theory, characterized by several incompatible and incomplete theories and ideas, from which the paradigm that is supported by a consensus coagulates more broadly that imposes its methods, terminology and types of technologies likely to contribute to a better perspective; 2) The period of normal science (and technology), in which solutions are put into the context of the dominant paradigm; over time, progress may reveal anomalies and problems of the existing paradigm, which may accumulate to the point where normal science (and technology) becomes difficult and where vulnerabilities of the old paradigm are exposed; 3) If the paradigm can no longer resolve the anomalies that have appeared and they become critical, the community enters a period of crisis; if that crisis is not resolved within the paradigm, the evolution enters the next phase; 4) The paradigm shift, or scientific (and technological) revolution occurs, in which basic principles are reexamined and a new paradigm is established; 5) The dominance of the new paradigm is established and returns to normal science (and technology) based on new concepts and methodologies.

According to Kuhn, in times of normality, scientists tend to subscribe to a large body of interconnected knowledge, methods, and assumptions that make up the dominant paradigm. Normal science (and technology) presents a series of problems that are solved as scientists discover them, the solutions becoming well known and exemplified by the field (in the case of technology innovations, leading to patents).

In the first edition of *The Structure of Scientific Revolutions*, in the last chapter entitled "Progress through Revolutions" Kuhn states that problem solving is a central element of science (and technology): "First, the new candidate must seem to resolve some outstanding and generally recognized problem that can be met in no other way." (Kuhn 1996, 168) In the second edition of the book, Kuhn says that the more recent a theory is, the better it will be as a tool for solving the kinds of problems scientists set out to solve: “That is not a relativist's position, and it displays the sense in which I am a convinced believer in scientific progress." (Kuhn 1996, 206)

Kuhn's paradigm concept, exemplified in this work by the development of a school of Romanian scientific and technological research from that period, was also confirmed by Stephen Toulmin, who defined the paradigm as "the set of common beliefs and agreements shared between scientists about how problems should be understood and addressed”. (Toulmin 1972)

It should be noted that the methodology of the scientific research programs developed by Imre Lakatos (Lakatos 1980) can be very well applied to the history of heavy water production in Romania, explaining very correctly the evolution of the idea of heavy water production in Romania and the way in which it followed to be produced[2]. But the basic idea of this paper is to highlight the formation of a Romanian school of research around this idea, and not the idea itself.

I equated Kuhn's idea of a scientific revolution with that of a technological revolution, since in this context I believe that science and technology follow the same path, in contrast to Henryk Skolimowski who states that, in philosophy, technology is something completely different from science (Skolimowski 1966). Skolimowski believes that science is concerned with what is, while technology is concerned with what will be, an idea confirmed by Herbert Simon in the book *The Sciences of the Artificial*. (Simon 1996) In defense of my point, I argue with Mario Bunge's thesis, (Bunge 1966, 329–347) that technology is applied science, but in a subtle way that does justice to the differences between science and technology, arguing that technology is about action, supported by theory, which puts it on a par with science. The distinction is between "knowing that" and "knowing how"; "knowing how" was taken up by Michael Polanyi as tacit knowledge and became a central feature of technology, (Polanyi 1962) an important theme for Thomas Kuhn as

[2] Lakatos' methodology has been seen as an attempt to reconcile Popper's falsifiability with the views of Thomas Kuhn. Lakatos proposed a middle way, in which Kuhn's socio-psychological tools were replaced by logical-methodological ones. (Sfetcu 2019)

well. (Kuhn 1996). Likewise, the design process, a structured goal-directed process, is seen by (Franssen, Lokhorst, and van de Poel 2018) as forming the heart of technological practice.

National Nuclear Program

After the Second World War, Romania felt the need to develop its own energy system, of much greater power, and as independent as possible from the influence of the Soviet Union. This is the first phase (pre-paradigm) of Kuhn's theory, (Kuhn 1996) in which the future direction of Romania's evolution in the energy field is foreshadowed. The preceding theories and ideas will coagulate in the future National Nuclear Program (Programul Nuclear Național)[3].

The Romanian nuclear program actually began in the 1950s, when a joint Soviet-Romanian company, named "SovRom - Quarţit", started operations in the Bihor project, in Băiţa, where uranium was extracted, then exported to the USSR below the market price , a total of approx. 18,000 tons of uranium. (Bădileanu 2019)

Since the founding of the Institute of Atomic Physics (Institutul de Fizică Atomică - IFA) in 1956, the research of this institute has been directed towards the technologies of reactors with natural uranium and heavy water, (Glodeanu 2007) through research at the IFA Cluj Branch for heavy water and graphite, and at IFA Măgurele for uranium dioxide technology. (Bădileanu 2019) During the years 1964-1966, there were numerous comparative studies at the IFA and the Institute of Energy Studies and Design (Institutul de Studii și Proiectări Energetice - ISPE), including power plants from England, France, Sweden and the USSR. The conclusions led to the reactor with natural uranium and heavy water, highlighting as arguments the fact that the entire fuel cycle can be carried out in the country, as well as heavy water, no heavy boiler facilities are required, small sizes and costs of reactors, strict standards of security, the in-process accumulation of plutonium

[3] Although the social and political context was important in the evolution of the nuclear strategy and the history of heavy water in Romania and in the development of the scientific and technological research community, I avoided addressing these aspects by focusing on the economic and, in particular, on the scientific and technological aspects.

for future fast neutron reactors. Relatively small unit powers were considered a disadvantage. (Glodeanu 2007)

In 1957, Romania put into operation the first research reactor in the countries of Eastern Europe. (Bădileanu 2019)

In 1967, commercial negotiations began with AECL Canada for a 600 MW CANDU unit, with Siemens (RFG) for a 340 MW reactor, and with ASEA-ATOM Sweden for a 400 MW Markiven unit. (Glodeanu 2007)

According to (Bădileanu 2019), the reactor with natural uranium, moderated and cooled with heavy water (CANDU type PHWR) was preferred, as enriched uranium was too expensive, in reactors with natural uranium the fuel cycle is simpler, there were already researches in Romania for the industrial units related to the fuel cycle and special materials that could be obtained in the country, the PHWR-CANDU branch allowed for refinement, it was safer from a nuclear point of view, and the reactor can be adapted to various nuclear fuel cycles.

The Design Institute for the Petroleum Industry (Institutul de Proiectări pentru Industria Petrolului - IPIP) in Ploiești drew up the project for a heavy water separation and production facility, on the basis of which the National Nuclear Program (Programul Nuclear Național – PNN) was drawn up based on three criteria: the independence of nuclear energy production, the participation of the Romanian industry in the program, and the development of indigenous technological research. (Proca 2015)

In order to achieve Romania's energy independence with the help of nuclear energy, in 1969 the first National Nuclear Program was approved. It provided for the construction, until 1980, of nuclear units of 1000 MWe, and the further development of this sector based on technological research, under the coordination of the State Committee for Nuclear Energy (Comitetul de Stat pentru Energia Nucleară – CSEN) established by State Council Decree no. 870 of December 30, 1969, (Consiliul de Stat 1969) simultaneously with the decision to build a pilot plant for the production of heavy water (Uzina G), with Prof. Marius Sabin Peculea as General Director, for the development of a water production and separation technology heavy. According to Marius Peculea,

> "Since the end of 1968, at the Institute of Atomic Physics (IFA) in Cluj there were three pilot plants in operation for the manufacture of deuterium or, in a broader sense, for the separation of heavy water; two of the installations were based on water-hydrogen isotopic exchange, the third was a vacuum isotopic distillation of water. The water-hydrogen isotopic exchange pilot plant operated at two temperatures (bitherm) and two pressures (bibar) represented the set of technological knowledge accumulated over years of activity by the staff of the Cluj Institute, knowledge confirmed by exceptional experimental results, unique at that time, worldwide". (Proca 2015)

In this context, although a contract with the USSR for VVER 440 reactors had already been signed in 1970, Romania began negotiations for the development of nuclear reactors with both Canada and the Soviet Union. For independence from the Soviet Union, the CANDU type of nuclear reactor from the Canadians was preferred, taking into account the difficulty of enriching natural uranium for Soviet reactors, but also the previous results of Romanian research. (Camera deputaților 2000) The State Committee for Nuclear Energy (CSEN), led by Professor Ioan Ursu, coordinates research and development work in the nuclear field. (Glodeanu 2007)

According to Mircea Turtureanu, the project director of the heavy water plant, at the beginning of his career at CSEN, all kinds of fanciful programs were discussed regarding the construction of the heavy water plant, which was called „Programul Dunărea" ("Danube Program"). (Turtureanu 2016)

The original plan was to build four nuclear reactors, three of the natural uranium and heavy water type of 600 MWe each and the fourth based on enriched uranium and normal water with a power of 400 MWe. Initially, the reactors with natural uranium and heavy water were proposed, in 1970 to be built on a site in Hârşova. The expected capacity of the heavy water plant was 360 t/year, with the obtaining of heavy water through isotopic exchange in the H_2S-H_2O system, which forms the basis of Lummus' offer for Romania. For the heavy water plant, the location in Malaia, Vâlcea county, on the Lotru river was initially considered. (Turtureanu 2016)

According to (Gheorghe 2013), in the 1960s and 1970s, Romania "successfully sold its image as an 'independent maverick' to the Western world in an effort to secure nuclear technology assistance… U.S. can improve its tactics by drawing a few lessons from the U.S.-Romanian NCA negotiations" Documents from archives in Bucharest, Ottawa and Washington on Romania's efforts to obtain nuclear assistance in the 1960s and 1970s suggest that Romania managed to attract to its side much more powerful players in international politics. (Fuhrmann 2009)

As early as 1964, American analysts identified Romania's potential to become nuclear. (Murray 1964) The US signed a nuclear cooperation agreement with Romania in 1969 for a research reactor, highly enriched uranium fuel, a heavy water plant and scholarships for Romanian scientists in the US, and approval for a heavy water reactor from Canada[4]. Romania's attitude towards the Soviet Union increased its chances of obtaining a CANDU heavy water reactor. In November 1966, the Canadian Ambassador to Belgrade, Bruce Williams, reported in Canada that "Romania's overtures to us in the nuclear field [are] a similar manifestation of a desire to establish economic independence of Mcow [Moscow]." (Gheorghe 2013) Bruce Williams was one of the main supporters of the sale of Canadian nuclear technology to Romania[5].

[4] Minutes of conversation between Emil Bodnăraş and the Ambassador of the People's Republic of China to Bucharest Liu Phan, January 28th, 1965, Bucharest, Romanian National Historical Central Archives (ANIC), Central Committee of the Romanian Communist Party (CC RCP), Foreign Relations Section (FRS), folder 4/1965; Minutes of conversation between Emil Bodnăraş and the Ambassador of the People's Republic of China to Bucharest Liu Phan, July 20th, 1965, Bucharest, ANIC, CC RCP, FRS, folder 4/1965. (Gheorghe 2013)

[5] Telegram from the Canadian Ambassador to Belgrade, Bruce Williams, to the Ministry for External Affairs, March 18, 1968, NCA, RG 20, Vol. 1644, 20-68-Ra Pt. 2

The US Secretary of State, Dean Rusk, pleaded for the application of a "policy of differentiation" in Romania. Washington's support was necessary for Romania to overcome the obstacles imposed by the Coordinating Committee for Multilateral Export Controls (CoCom), which regulated East-West trade, and the Mutual Defense Assistance Control Act (Battle Act) of 1954. In 1968, Rusk gave the Canadians the green light for the nuclear agreement with Romania: "if Canada and Romania could agree on something, there would be no squawk out of the USA administration". (Gheorghe 2013

In 1970, negotiations were held with the Lummus-USA company for the construction of a heavy water plant with a capacity of 400 tons/year and with AECL for a 600 MW reactor, but in the end the transaction was completed by the Romanian side. Instead, by Decision of the Council of Ministers (HCM) 148 of 17.02.1970 (Consiliul de Miniştri 1970), the State Committee for Nuclear Energy (CSEN) was established, and approved the construction of the heavy water pilot plant (Uzina G, with the name „Instalație pilot experimentală de fabricare a hidrogenului sulfurat" ("Pilot facility hydrogen sulphide manufacturing experimental plant"), establishing its location in Govora by HCM 197 of 02.03.1970; the creation of the Institute of Nuclear Energetic Reactors IRNE in Pitești (Mioveni), and the ore concentration and carbon dioxide manufacturing plant natural uranium in Feldioara.

Discussions with the Canadians resumed in 1974, with a license agreement for the construction of CANDU-type units being finalized in 1976. In 1978, three contracts were signed with AECL: license, engineering, and technical assistance for a 700 MW nuclear power plant in Cernavodă.

On August 9, 1976, the first quantity of heavy water with a concentration of 99.9% was produced at "Uzina G". (C.N.M.A.G. 2018)

In 1977, when an agreement was signed between Romania and Canada, Romania expressed its desire to buy 20 CANDU reactors, then reducing their number to four, with the option for Romania to build other reactors on its own under the license agreement with Atomic Energy of Canada Limited (AECL), the number of reactors being later reduced to two. The license contract was finalized in December 1978. In February 1981, Romania signed contracts with the Italian firm ANSALDO for the conventional components of the nuclear power plant and with the American firm General Electric for the plant's turbogenerator. (Bădileanu 2019)

Within RENEL, by Romanian Government Ordinance no. 15 of 1993, the Nuclear Energy Group was formed, which included the Cernavodă Nuclear Power Plant, the Pitești Nuclear Fuel Plant, the ROMAG Drobeta Turnu-Severin Heavy Water Plant, the Bucharest Nuclear Engineering and Objectives Center, and the Pitesti Nuclear Research Institute.

Research and design

The National Nuclear Plan, the studies of specialized institutes and trade negotiations with other countries based on the existing social, the economic and political conditions in Romania, and the geopolitical circumstances, led to the creation of national institutes oriented towards the development of a national nuclear system in which heavy water will play an important role. Next comes phase 2 of Kuhn's theory of scientific structure, of normal science (and technology), within which the solution of the highlighted problems takes shape.

In Romania, there were numerous institutions in the nuclear field with scientific and technological research activity in this field, including educational units with faculties and sections specially dedicated to the nuclear field, such as the Politehnica University of Bucharest (Ghizdeanu et al. 2004) and the Faculty of Physics from the University of Bucharest with the Technological Physics section. (Glodeanu 2007)

In 1968, after the retirement of Professor Horia Hulubei from the management of IFA, the position was taken over by Professor Ioan Ursu, who continued and developed the concepts of his predecessor for the development of nuclear energy, and created the Institute of Nuclear Technologies (ITN) from Pitesti, which it was later transformed into the Institute of Energetic Nuclear Reactors. At Uzina G in Râmnicu Vâlcea, Marius Peculea established the pilot station for the development of heavy water production technologies based on the results obtained at IFA in Cluj. (Frangopol 2008)

The Bucharest pump company, in the period 1965-1989, was involved in applied research in the field of deformable solid mechanics to solve specific problems, through static and dynamic strain measurements, and photoelastic research to determine the state of tension in structures or resistance elements . Thus, measurements of vibrations and frequencies, accelerations, speeds and displacements were carried out in soils, constructions and machine foundations, produced by controlled explosions, forge hammers, compressors and pumps, in order to locate the heavy water plant. Many of these studies were carried out by the materials resistance departments in collaboration with laboratories from research institutes, and with the support of departmental research institutes and the Romanian Academy. (Spinei 2019)

In the research activity, the Research Institute for Electronic Components (ICCE) carried out research contracts through the microproduction of some components under special regime ("G") for the electronic components needed for the heavy water plant, with the support of teaching staff from the Faculty of Automation. (Spinei 2018)

Marius Peculea, in the *Interfață între știință și tehnologie - Un exemplu de caz* (*Interface between science and technology - A case example*), (Peculea 2010) highlighted the close connection and complementarity between scientific and technological research in the specific case of heavy water production through H_2S-H_2O isotopic exchange using GS towers:

- isotopic exchange space (sieve tray):
    - in scientific research, it is defined as an isotopic balancing element
    - in technological research, it represents a well-defined element with the aim of achieving a contact surface as large as possible between liquid and gas
- mathematical modeling:
    - in scientific research the intimacy of the phenomenon is pursued
    - in technological research only the flow of the two fluids is of interest
- behavior of the exchange space:
    - in scientific research, the number of theoretical sieve trays can be determined through iteration
    - in technological research, the performance of the separation tower is determined from the characteristic diagram
- specific loading of the exchange space:
    - in scientific research, the behavior of the process is monitored through pilot laboratory installations
    - in technological research is concerned with obtaining the performance of isotopic separation towers

Peculea completes this research with an equally important stage, the design of the heavy water plant, which deals with the technical documentation of execution and costs, naming the three institutions with a major role in these three stages in the construction and operation of the heavy water plant:

Scientific research	Technological research	Design
Process study	Facility study	Industrial plant project
Laboratory pilot	Industrial pilot	Assistance during construction
IFA – Cluj	Uzina G Râmnicu Vâlcea	IITPIC București

Table 3. Correlation between scientific research, technological research, and design (Source: (Peculea 2010)*, modified)*

According to (Nică 2016), the main designers involved in the construction of the heavy water plant were:

- I.I.T.P.I.C. Bucharest (Institute of Technological Engineering and Design in the Chemical Industry), as a general designer
- I.P.A. Bucharest (Design Institute for Automation)
- I.S.L.G.C. Bucharest for process water
- I.C.S.I.T.E.E. Bucharest (centrifugal compressors for hydrogen sulphide)
- I.C.S.I.T. Faur Bucharest (piston compressors for hydrogen sulphide liquefaction)
- C.C.I.T.P.V. Bucharest (special hydrogen sulphide water pumps and fans)
- Designers of the plants supplying machinery, assembly materials, electrical and automation equipment.
- Designers of the builders and installers.

IFA Cluj

In 1949, the Physics Department of the Romanian Academy was established in Bucharest.

In 1950, the Physics Department of the Romanian Academy Branch was born in Cluj-Napoca.

In 1956, the Institute of Atomic Physics (IFA) is established in Bucharest, Măgurele, and the Cluj Physics Department of the Academy becomes a subsidiary of IFA Bucharest. (INCDTIM 2022)

Research on heavy water began in 1958.

The pilot laboratory for the experimental research of isotopic separation was built here under the coordination of Marius Peculea who arrived at the institute in 1959, it is the first installation for the separation of heavy water made in Romania, in a separation process at two temperatures (bitherm). The original idea was to complete the "bitherm process" with a process at two pressures, a process named by its inventor the "bitherm-bibar" process, with superior performance compared to the "bitherm" system of two temperatures, a world premiere in 1968 (Tãnãsescu 2007)

In 1970, the IFA Section in Cluj became a unit with its own economic management under the name of the Institute of Stable Isotopes, having as its object of activity the carrying out of research and the development of technologies regarding the production of heavy water, stable isotopes, the design and production of scientific equipment for applications of stable isotopes. (INCDTIM 2022)

In the first stage, the research had as its object the prospecting of deuterium sources, the development of deuterium analysis methods, and the development of a deuterium separation method. For the analysis of deuterium, the following were developed: densimetric methods for the total isotopic analysis of water (D/H) using a variant of the droplet method with superior performance to those obtained worldwide, optical methods with a Fabry-Perot spectrometer with magnetostrictive scanning and by pressure variation, and gas chromatography. Research started at IFA Bucharest in 1958 was improved by chromatography. For the isotopic separation, experimented on a laboratory pilot, the isotopic exchange method between water and hydrogen was chosen, developing in parallel research related to the use of hydrogen as an energy source. The institute was the only manufacturer of mass spectrometers in the country, used for measurements of deuterium concentrations in the field of natural concentrations, in dynamic mode, the study of ion-molecule reactions, and isotopic and chemical analyzes in gaseous and liquid samples. (Văsaru 2011)

All these researches from Cluj were classified as strictly secret.

In 1977, the Institute of Stable Isotopes changed its name to the Institute of Isotopic and Molecular Technology ITIM Cluj-Napoca, under the State Committee for Nuclear Energy.

In 1999, through the reorganization of ITIM Cluj-Napoca, the National Research and Development Institute for Isotopic and Molecular Technologies INCDTIM Cluj-Napoca was created (HG 408/1999). (INCDTIM 2022)

The research carried out here in the first years of activity decisively influenced the choice of the natural uranium - heavy water chain in the National Nuclear Program (PNN), (Peculea 2002) materializing in two pilot installations, one monothermal with phase conversion by electrolysis and one free bitherm, operated at two temperatures and two pressures, the achievement being successfully tested also for ammonia-hydrogen isotopic exchange. (Hodor, Peculea, and Străulea 1973) They were completed by patenting the heavy water production technology and capitalizing on it in the design and construction of the heavy water plant, attesting to the importance of oriented fundamental research. (Peculea 2002)

Uzina G Râmnicu Vâlcea

Following the research at IFA Cluj regarding the isotopic separation of heavy water on the two pilot installations of the institute, in 1969 a commission was set up to analyze the possibility of industrialization of the heavy water separation technology. The Director of the Design Institute for the Petroleum Industry (IPIP) Ploiești has committed to the realization of the pilot plant at Uzina Gin Râmnicu Vâlcea. Initially, only the vacuum isotopic distillation of water was adopted, at that time the isotopic exchange method of water - water vapor - hydrogen was considered uncompetitive. In the end, a primary separation stage was adopted through isotopic exchange at two temperatures (bitherm) between water and hydrogen sulphide, and a final stage through isotopic distillation of water under vacuum. (Glodeanu 2007)

On March 1, 1970, with the establishment of the State Committee for Nuclear Energy (CSEN) as the coordinator of the National Nuclear Program (PNN), the establishment of Uzina Gin Râmnicu Vâlcea was also approved. The pilot plant consisted of four facilities: sodium sulfide production, hydrogen sulfide production, vacuum isotopic distillation of water, and water-hydrogen sulfide isotopic exchange at two temperatures. The facilities were approved on December 3, 1974 and the first heavy water of nuclear quality from Uzina Gwas produced on August 9, 1976. After the first production from Uzina G, it was decided to fully use Romanian technology. (Glodeanu 2007)

Research in Uzina Gdeveloped in four main directions: technology, calculation, laboratory, engineering and verification on the experimental plant, (Ioniţă 2018) with an emphasis on:

- gas separation processes, advanced purification and recovery technologies;
- apparatus, methods and equipment for controlling isotopic separation processes;
- techniques, command and control methods of complex installations with increased risk, having as its main purpose within the National Nuclear Program the technologies for the

production, separation and reconcentration of heavy water, analysis equipment, technical assistance and expertise, monitoring and environmental analyses. (Ștefănescu 2017)

Uzina Ghas provided innovative solutions, new improved materials and the development of specific equipment, mainly through the balance tower, the study of hydrodynamic flow on sieve trays, the passivation technology of carbon steel alloy, the passivation technology using pyrite (Patent No. 90 3821 /1986), (Peculea, Beca, and Ștefănescu 1998) the hydrogen sulphide compressor. (Ioniţă 2018)

Marius Peculea appreciates the fact that CSEN, MICh and CNST (National Council of Science and Technology), contrary to a normative act from 1979, maintained the independence in activity of Uzina Gunder the coordination of CSEN. (Glodeanu 2007)

After 1979, through technological research at the Plant G, many solutions were found to the problems posed by the construction and operation of the heavy water plant, such as the passivation by pyritization of the carbon steel G52/28 of the GS towers, the stability in operation of the sieve trays of the isotopic exchange, separation technology by isotopic exchange at two temperatures (bitherm) by introducing an isotopic balancing tower (a global innovation), etc. (Glodeanu 2007) And research on the hydrodynamics of the isotopic separation interface increased the performance of the real sieve trays so that the heavy water produced at Drobeta Turnu Severin is considered to be the purest heavy water, both isotopically and chemically. (Peculea 2019)

In 1988, the technological patent for heavy water was issued, based on the application submitted in 1976, and it was used for the design and construction of the heavy water installation at Drobeta-Turnu Severin. (ICSI Râmnicu Vâlcea 2020)

In the book *În sfârșit, Adevărul* (*Finally, the Truth*) of gen. Victor Atanasie Stănculescu, he states that "The foundations of the pilot station for obtaining heavy water from Vâlcea were laid in the 60s under the guidance of the Directorate of Foreign Intelligence, as soon as the agent of the Special Brigade TS Polihroniade, code name "Poly", managed to bring heavy water manufacturing technology from a plant somewhere in the Savannah River — United States. The TS Special Brigade (later SD) was a compartment specialized in economic espionage, within the

Foreign Intelligence Directorate." (Stănculescu 2009) Mircea Turtureanu, the former director of IITPIC Bucharest, states that, although he searched for additional data, he did not find additional confirmations regarding this aspect. (Turtureanu 2016)

The technology resulting from the research at Uzina G differs substantially from that used at the Savannah River Plant, among improvements Peculea enumerating: modification of the connections between the floors of the plant increasing the stability in operation and a simple and safe adjustment, perforated sieve trays much simpler than those with bells, humidification and dehumidification of hydrogen sulphide directly at the base of the towers, isotopic distillation towers equipped with B7 packing reducing the volume of the plant without further processing. (Peculea 2019)

The mixed filling from the distillation plant is protected by patent No. 113218.C1(1999). (Peculea 2002) The installation for the production of the heavy water standard developed at Plant G, with an isotopic concentration of 99.995% ±0.002% D/(H + D), is protected by 4 invention patents, allowing the plant to receive authorization for the production and marketing of heavy water standard. (Peculea 2019)

Among the patents obtained in Plant G in research on obtaining heavy water, are(ICSI Râmnicu Vâlcea 2020)

- 62367 "Process and installation for continuous flow production of high purity hydrogen sulfide"
- 62368 "Procedure for cleaning a bithermal H2S-H2O isotopic exchange installation"
- 62370 "Heavy water manufacturing process by H2S-H2O bitherm exchange"
- 62374 "Quasi-adiabatic isotopic distillation tower"
- 62375 "Method and reflux control device for distillation towers"
- 62377 "Sodium sulphide manufacturing process"
- 62378 "Procedure for the production of hydrogen sulphide in a discontinuous system"
- 62379 "Process and plant for the production of heavy water by H2S-H2O bithermal isotopic exchange"
- 69866 "Procedure of surface oxidation of metal products"

- 76953 "Asymmetric control device for anti-pumping protection of a centrifugal compressor"
- 78668 "Procedure and installation for the purification of waste water from the production of hydrogen sulphide"
- 83372 "Float for transducer measuring the level of corrosive liquid at high pressure and temperature"
- 90073 "Device for reducing the whine effect of multi-spill sieve trays"
- 90131 "Ion analyzer for hydrogen isotopic analysis"
- 90382 "Process and installation for the formation of a protective deposit with a high pyrite content in bithermal isotopic exchange installations"
- 90566 "Orderly filling for equipping isotope separation towers"
- 90567 "Orderly filling for equipping isotope separation towers"
- 93471 "Procedure for rapid recovery of hydrogen sulphide in industrial installations"
- 95871 "Method and apparatus for measuring the liquid content in foam"
- 96678 "Liquid Film Gland and Floating Bushing"
- 101759 "Procedure for the protection of carbon steel surfaces in heavy water manufacturing plants"
- 107558 C1 "Catalytic filling for the combustion of stoichiometric mixtures of hydrogen and oxygen"
- 107842 C1 "Process for the preparation of hydrophobic platinum catalysts"
- 11 3386 C1 "Mechanical sealing device for hydrogen sulfide-carrying turbofans"
- 113401 C1 "Device for cooling specimens for resilience tests"
- 114911 C1 "Process of chemical cleaning of steel pipes"
- 115129 C "Procedure for obtaining a selective adsorbent"
- 115367 C "Conservation method of anti-corrosion protections formed by iron sulphides"

"The pilot plant has been operating for more than 10 years. During all this time, it was a source of scientific, technological and thermo-energetic knowledge, which allowed the training of Romanian experts in the field of heavy water." (Peculea 2007)

Marius Peculea

Marius-Sabin Peculea was born on April 13, 1926, in Cluj. Between 1944 and 1949 he attended the engineering courses of the Faculty of Electromechanics of the Polytechnic School of Timișoara. In 1966 he received his doctorate in thermodynamics, with the doctoral thesis "Thermodynamic study of separation towers, in continuous flow, with three fluids and different reaction temperatures".

Positions held: (Conphys 2022)

- Until 1959: Tehnofrig Cluj Plant - Head of the Studies and Designs Service, established by him in 1952
- 1959 - 1963: ITIM Cluj-Napoca - Principal Researcher II
- 1963 - 1970: ITIM Cluj-Napoca - Laboratory Head
- 1970 - 1994: Plant "G" (INC-DTCI-ICSI) Rm. Vâlcea: Director
- 1994 - 1999: Romanian Academy - General Secretary

Scientific titles, professional degrees:

- Doctor in thermodynamics (1966)
- Teaching doctor (1974)
- Corresponding member of the Romanian Academy (1991)
- Full member of the Romanian Academy (1993)
- Doctor Honoris Causa of the Cluj-Napoca Technical University (1995)
- Doctor Honoris Causa of the Technical University of Construction Bucharest (1996)
- Doctor Honoris Causa of the University of Craiova (1996)
- Member of the "Academia Scientiarum at Artium Europaea" Salzburg (1996)
- Founding member of the Romanian Academy of Technical Sciences (1998)
- Doctor Honoris Causa of the University of Oradea (1998)
- Doctor Honoris Causa of the Ovidius University of Constanta (2000)
- Doctor Honoris Causa of the Polytechnic University of Timișoara (2002)

Professional achievements:

- Scientific and technical publications: his works mainly address topics related to isotopic separations (heavy water, tritium) and thermodynamics (cryogenics, gas separations), including 6 books, 90 academic papers, 30 invention patents, 88 scientific reports, and 126 scientific conferences.
- Developed 4 technologies for heavy water separation
- 12 invention patents awarded at international invention salons (Conphys 2022)

Global priorities: (Ratcu 2017)

- Deuterium separation process, through successive water-hydrogen isotopic exchange, in the "bitherm-bibar" system (at two temperatures and two pressures) (1966)
- Heavy water separation process, by water-hydrogen sulphide isotopic exchange, in a bithermic system (at two temperatures), with the isotopic balancing tower (1985).

Scientific priorities:

- Modeling of isotopic separation processes in bitherm system and distillation.

- Exergetic analysis of isotopic separation processes.
- Introduction of the technological function to the comparative analysis of isotopic separation processes.
- Defining actual versus design capacity for an isotope separation facility.
- Introduction of the t-T diagram (of temperatures) for the calculation of heat exchangers and humidifiers (heat and mass exchange).
- Definition of the isotopic exchange plate with successive reactions.
- Introduction of the figure "We" (Weber) in the performance representation of the separation plates. (Ratcu 2017)

Expert of the International Atomic Energy Agency (IAEA), and specialist invited to conferences in the field of heavy water in Germany, India, USA, Canada, USSR, Libya, China, Pakistan

Teaching activity: (Conphys 2022)

- Polytechnic Institute of Cluj - Department of Thermal Engines: university trainer (1949 - 1950)
- Babeș Bolyai University in Cluj: university assistant (1950 - 1952; 1954 - 1958)
- Bucharest Construction Institute: university lecturer (1968 - 1971), university professor at the Department of Thermodynamics, disciplines of Technical Thermodynamics and Heat Transfer (1971- 1989), associate university professor (1989), doctoral supervisor in the discipline of Thermodynamics, specialty separation of isotopes (1969)

Professional awards and distinctions:

- Award of the Romanian Academy "Dragomir Hurmuzescu" (1981);
- Order of Scientific Merit Cl. II (1974);
- Order of Scientific Merit Cl. III (1981);
- Scientific Merit Medal (1969 and 1979);
- "Ionel Purica" Award for contributions in Nuclear Energy (1993);
- Special Award for the contribution to the development of Romanian Thermotechnics (1995);
- Diploma for special contributions in energy research-development activity (1995);
- Honorary Citizen of the Municipality of Cluj-Napoca (1996);
- Order "For Merit" in the rank of Grand Officer (2000)
- Honorary Citizen of the Municipality of Rm. Vâlcea (2008) (Conphys 2022)

According to (Tãnãsescu 2007),

"What characterizes Marius Peculea in all these searches in a scientific field not accessible to many, was his eternal spirit to ask himself questions, to answer the criticisms brought to a process, most of which, however, were not of "others", but his own."

In Marius Peculea's own words:

"I sought to find the relationship between the separation factor that characterizes a process and the cost price of the product. Specifically for heavy water, we were able to find this relationship by introducing the notion of technological function, which quantitatively represents the quality (intelligence) of the given technological solution for the industrialization of a process". (Tãnãsescu 2007)

IITPIC Bucharest

In 1977, the chemical and petrochemical industry design institutes were unified into a single institute - the Institute of Technological Engineering and Design for the Chemical Industry (IITPIC)

IITPIC Bucharest took care of the design part of the heavy water plant, as the general designer, under the aspects of plant feasibility, design and installation schemes, calculation methodology and procedures, how to equip the exchange towers with sieve trays, etc., taking over the technology already existing developed within the Uzina G.

According to Mircea Turtureanu, the former project director, (Turtureanu 2016) the basic conditions of the project were that the technology should be the one developed at Uzina G, and that all materials, machinery and equipment should be made in the country, except for the purchased nitrogen plant from the former DR Germany. Three aspects had to be decided before starting the actual design: the scheme of the isotopic exchange plant (Patent no. 74088/29.03.1980 entitled "Plant for the separation of deuterium by isotopic exchange"), the number of production lines (in finally, four production lines / modules were decided) and the way of coupling the towers, and the problem of the corrosion of the isotopic exchange towers by hydrogen sulphide (the solution of this problem being through pyritization and special characteristics of the steel used). (Turtureanu 2016)

The geotechnical studies were carried out with the help of a specialized institute for land surveys and improvements, ISPIF Bucharest, and for solutions regarding the elimination of organic substances from the process water, the Institute of Hydrotechnical Studies and Designs (ISPH) was consulted. The automation project was carried out by the Automation Design Institute (IPA). In order to prevent incidents of accidents due to uncontrollable releases of hydrogen sulphide into the atmosphere, specific studies were carried out with the help of the Institute of Meteorology and Hydrology (IMH). (Turtureanu 2016)

In 1991, based on Law no. 15/1990 on the reorganization of state economic units as autonomous administrations and commercial companies, by H.G. no. 156/07.03.1991, the commercial company IPROCHIM S.A. Bucharest is established, by fully taking over the assets and liabilities of the Institute of Technological Engineering and Design for the Chemical Industry - IITPIC - Bucharest.

Heavy Water Plant

The location of the heavy water factory was originally thought of in Malaia on the Lotru Valley, the water of the Lotru River being considered very pure. After checking this location, Turtureanu concluded that a well-ventilated area is needed and, based on the Canadian standard IAEA-SM-188.4, about means by which a plant is integrated into a Canadian community, developed by Atomic Energy Control Board of Canada, which mentioned the specific conditions for the siting of heavy water plants (low population density, special geographical and meteorological conditions, etc.). A second area near Francești, also in Vâlcea county, was considered, then an area in Bărăgan. Mircea Turtureanu proposed the location in Cernavodă but, although approved by Decree no. 419/25 October 1978, in the end it was decided to build the factory near the hydroelectric power plant Iron Gates 2. After a proposal for the exact location in Rogova in Mehedinți county, and another in Cerneți, on the outskirts of Drobeta Turnu Severin, the final location was decided to be in Răscolești, at approx. 6 kilometers from Drobeta Turnu Severin. (Turtureanu 2016)

The heavy water factory was established under the name of Combinatul Chimic Drobeta (Chemical Plant Drobeta), by Decree 400/16.11.1979, under the Inorganic Products Industrial Center (CIPA) Râmnicu Vâlcea. The thermo-electric plant for supplying the heavy water factory with steam was decided to be located in Halânga village, three kilometers from the factory.

Later, the name of the factory was changed over time as Regia Autonomă ROMAG (until 1992), ROMAG (until 1998) and ROMAG Prod (until 2015, when it was closed).

The process water required for the factory was brought from the Danube, with a content of approx. 144 ppm D_2, being subjected to a purification treatment process before being used. The hydrogen sulfide used in the process, since it is not consumed during the process (it circulates in a closed loop, having rather the role of a "carrier", taking the light hydrogen (protium) from the process water and giving it deuterium), was produced in the plant, through a specific technology, being then compressed, liquefied, and stored in special tanks.

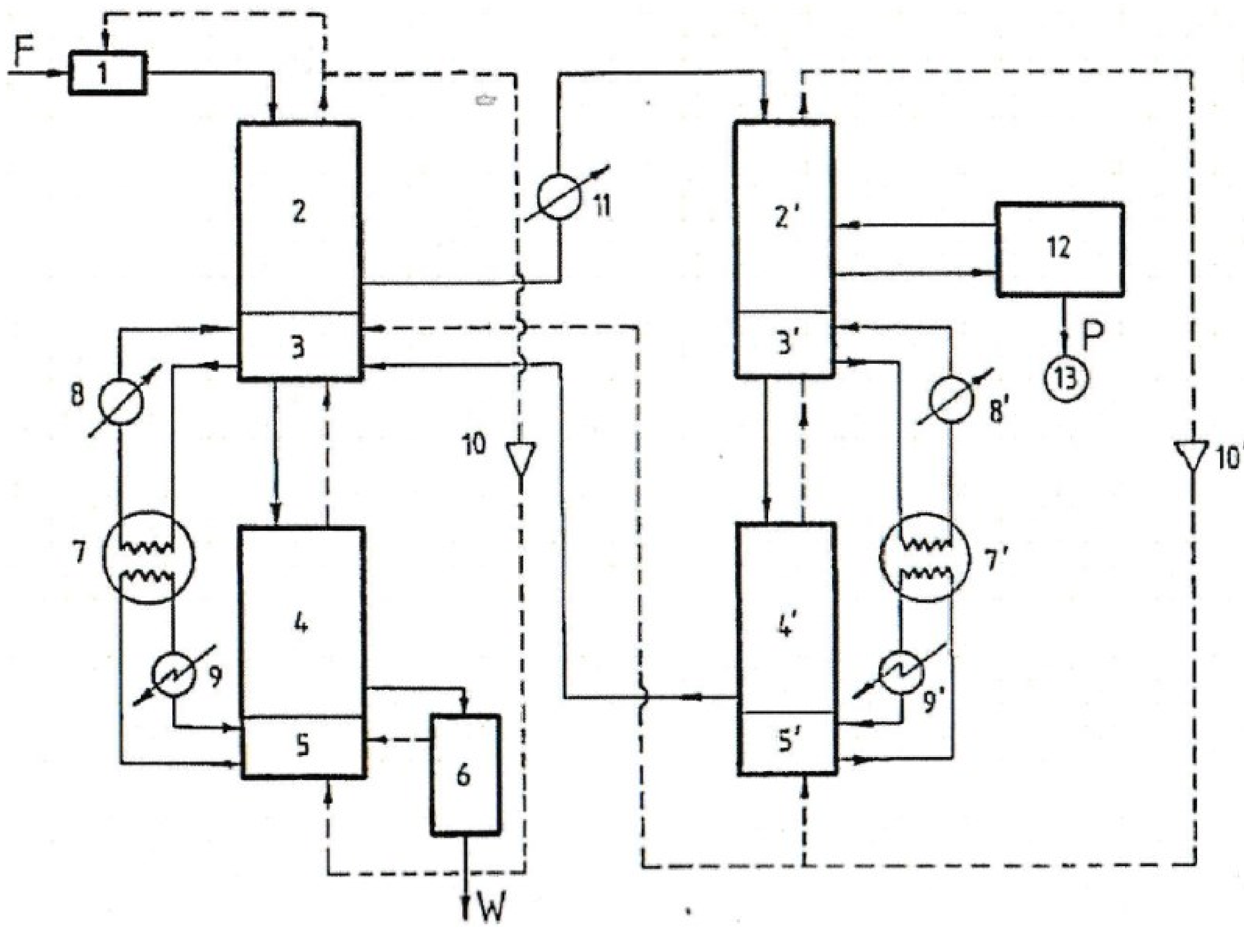

Figure 2. Scheme of the isotopic separation module according to patent 74088/1980
1 = absorber, 2, 2' = cold towers, 3, 3' = dehumidifier, 4, 4' = warm towers, 5, 5' = humidifier, 6 - striper, 7, 7' = heat recovery, 8, 8 ', 11 = cooler, 9, 9' = heater, 10, 10' = compressor, 12 = distillation, 13 = storage of finished product
_______ = H2O, _ _ _ _ _ = H2S
Source: (Turtureanu 2016)

The water was enriched in deuterium in two steps: by isotopic exchange, and finally by distillation. Four manufacturing lines (modules) were planned for the isotopic exchange, which were to operate in parallel. Each module included four sets of towers (bitherms), each with one hot and one cold tower, the first three using a G52/28 special steel with diameters greater than 5.3 m and height of 60 m forming Floor 1, and the fourth set (Floor 2) which took the enriched water from the 1st floor consisting of a hot tower and a cold tower, with a diameter of 2.8 m and a height of 80 m. The distillation towers contained phosphor bronze filling made at Uzina G The final product was stored in special barrels under a nitrogen cushion. (Turtureanu 2016)

All equipment was manufactured in the country, in the best and most efficient specialized factories.

Heavy water for nuclear use must have a concentration of min. 99.75 D_2O. During the exploitation of the heavy water plant, it was found that there is an oversizing of the distillation plant which allowed to obtain a more concentrated heavy water than necessary (super heavy water). Also, during the production of heavy water, a secondary product was obtained, water depleted in deuterium, with values of the percentage of deuterium much lower than in normal water, with uses in the field of health. (Turtureanu 2016)

Construction

The works at the heavy water plant at Drobeta Turnu Severin, subordinated to MICh (Ministry of Chemical Industry), began in 1979, based on a derogatory HCM. (Glodeanu 2007)

The equipment for the heavy water plant was purchased through the Industrial Center for Chemical and Refinery Equipment (CIUTCR). The main suppliers were: (Turtureanu 2016)

- Întreprinderea de Mașini Grele Bucharest (IMGB): sections of G52/28 steel towers from Combinatul Siderurgic Galați developed in the 80s at the Uzina de Oțel Galați based on the National Technical Normative NTR 440/83, installed by the Trustul de Montaj Utilaj Chimic (TMUCB), and centrifugal compressors for the recirculation of hydrogen sulphide (ICSITEE Bucharest);
- Uzina Grivița Roșie in Bucharest: the isotopic exchange towers on the 2nd Floor and part of the heat exchangers;
- IUC Ploiești: part of the heat exchangers in the isotopic exchange plant, the plates for the isotopic exchange towers and all the equipment in the distillation plant;
- Enterprise 23 August Bucharest: piston compressors for hydrogen sulfide designed by ICSIT FAUR Bucharest, spherical tanks for air and propane, and Diesel groups for isotopic exchange installations, all designed in the Plant's own design center;

- Aversa pump factory Bucharest: special pumps for hydrogen sulphide water designed by the design center within the factory (CCITPV Bucharest designer);
- Întreprinderea de Utilaj Petrolier Târgovişte: special fittings from the exchange facility;
- Electroputere Craiova: Diesel group;
- Unio Satu Mare: spirometallic gaskets;
- Uzina G: phosphor bronze fillers for distillation towers

Other providers: (Nica 2016)

- IAIFO Zalău: fittings;
- IMF Odorheiul Secuiesc: special faucets;
- Întreprinderea Mecanică Fină Sinaia: Norton mechanisms, reducers;
- Enterprise 1 Mai Ploiesti;
- Pipe factory Republica Bucharest;

The assembly works, with Trustul de Construcții Industriale (TCInd) Bucharest (TCInd Craiova and TCInd Drobeta Turnu Severin sites) as general contractor, were executed by: (Turtureanu 2016)

- Trustul de Montaj Utilaj Chimic (TMUCB) Bucharest through branches in Pitesti, Bacău, Craiova, Arad and Iași: installation of equipment and pipelines;
- IAMSAT Bucharest through the Turnu Severin construction site: automation works;
- TIEA Bucharest: electrical installations;
- TIAB Bucharest: high voltage electrical installations;
- TLSIT Bucharest: thermal insulation and waterproofing.

Other construction-assembly enterprises: (Nică 2016)

- Teleconstrucţia Bucharest (Drobeta Turnu Severin construction site): installation of low current installations;
- Hidroconstrucția Drobeta Turnu Severin.
- TCMRIC (Trustul de Construcții Montaj şi Reparații în Industria Chimică) Bucharest.

Since all equipment and facilities that transported hydrogen sulphide had to comply with strict quality assurance conditions, IITPIC developed its own Quality Assurance Manual and General Standards for Quality Assurance Manual on the basis of which all enterprises had to develop their own quality assurance manuals, with execution procedures and mandatory inspection and testing points attended by representatives of the beneficiary (future heavy water plant). The experience of the quality assurance system obtained for the heavy water plant helped equipment factories and builders when they moved on to the execution of nuclear equipment and the construction of the Cernavodă nuclear power plant. Overall, the introduction of the Quality Assurance System led to an unprecedented technological discipline and to the qualitative increase in the level of execution in the Romanian industry, thus becoming competitive on the international market.

During the construction of the heavy water factory, at the national level it was decided to double the number of CANDU type reactors, requiring double the amount of heavy water. Consequently, it was planned to expand the plant from its current designed stage (Stage 1) with a new adjoining plant (Stage 2). The design was the same, and some units (such as sheds, part of the installations, etc.) were to be shared. Orders for Stage 2 have begun, however, considered by the designers as a big mistake. (Turtureanu 2016)

In 1979, by Decree 400/16.11.1979, it was decided to establish the "Drobeta" Chemical Plant for the production of heavy water, located in the village of Răscolești. M.E.E., as the plan holder, will ensure, until June 30, 1982, the steam and electricity requirements and divert the high voltage lines until March 30, 1980. (Fako et al. 2019)

The first employees of the factory were eight people, led by the first director, the chemist Gheorghe Florea. The foundations for the isotopic exchange towers, the water adduction works from the Danube have started to be poured. (Nică 2016)

In the spring of 1983, facility trials began and process water quality testing was completed.

The construction-assembly works started at the beginning of 1985.

In 1986 CET Halânga can supply steam. It is decided to expand Stage 2 with three isotopic exchange modules.

In May 1987, the first pyritization begins in the first module for the protection of carbon steel from the corrosive attack of hydrogen sulfide, by forming a micron layer of pyrite on the surface, finishing it in the autumn of the same year.

In September 1987, the first loading with hydrogen sulfide is done at Module 1.

Functioning

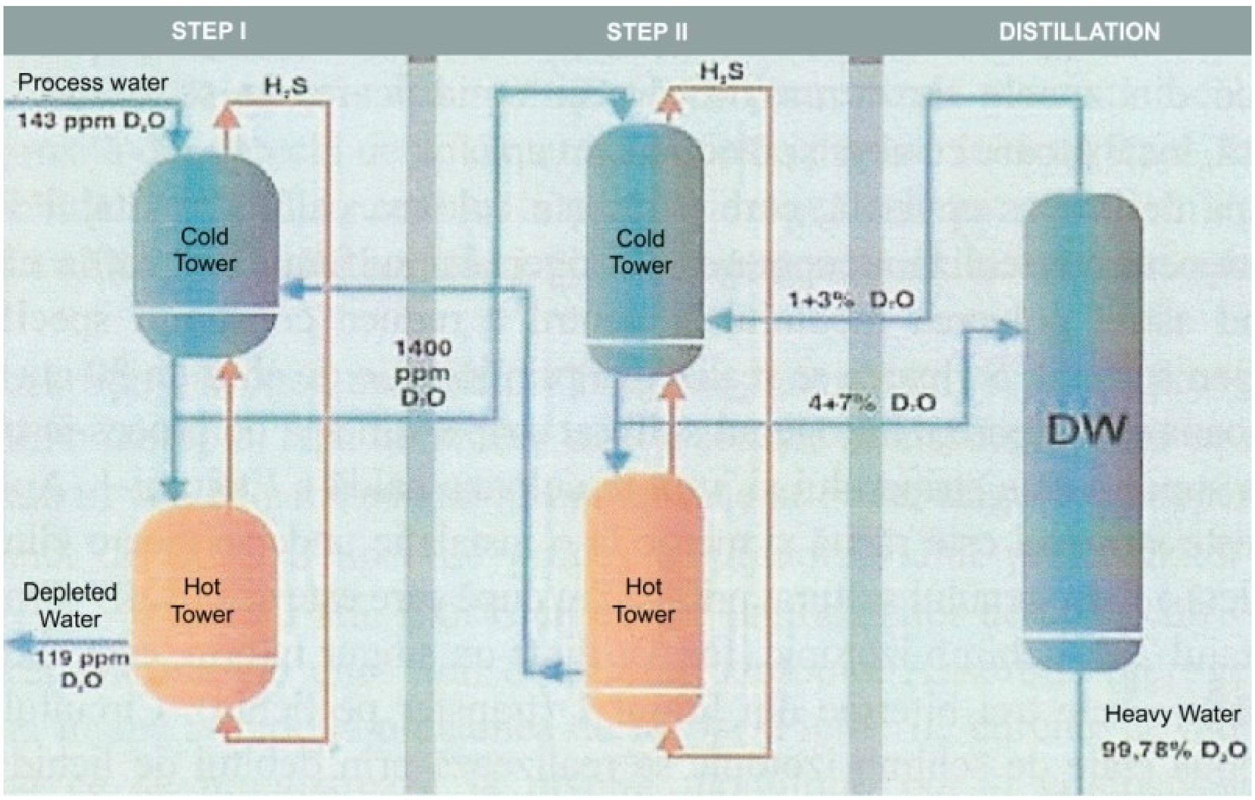

Figure 3. Isotope exchange plant with water distillation. Source: Magazine, no. 7/2008

With the help of the previously prepared sodium sulfide, it was proceeded to the preparation of hydrogen sulfide used in the isotopic exchange with water. The hydrogen sulfide produced was liquefied and stored, followed by pyritization and nitrogen tightness tests, and finally the start-up of the plant. From the beginning, there were a lot of problems (with interruptions in the supply of steam, for example, or problems with the sieve trays in the isotope exchange towers), which were solved every time by a very close collaboration between the specialists of the heavy water plant and designers (especially IITPIC), and sometimes also scientific and technological research institutes (especially Uzina G). (Turtureanu 2016) There were also differences of opinion between various institutes, such as the large entrainment of liquid at the sieve trays of the cold tower on second step, where Uzina G considered the cause to be the variation of the surface tension of water saturated with hydrogen sulfide, which influenced the hydrodynamics of the sieve trays, (Peculea 2007) while the IITPIC designers considered that the problem was an operation at a pressure lower than the intended one, which influenced the hydrodynamics of the sieve trays. (Turtureanu 2016) Several tests contributed to solving the problem, through collaboration, including the specialists of the heavy water factory (the director at that time was a former colleague of the IITPIC designers).

Due to the special working conditions in the heavy water plant, an extensive research has been developed for the operational safety of the installations, based on specific action methodologies and in situ experimental programs for the evaluation of the long-term behavior of materials and installations.

During the construction of the plant, all the welds of the machines and pipelines working in a hydrogen sulfide environment were 100% controlled, and spirometallic gaskets were used at the joints. The walls of the machines and pipes were permanently controlled by the inspectors of the quality assurance service, in a very large number of predetermined points.

All machinery and equipment manufacturers, and all builders, worked in a quality assurance system based on Canadian and American quality assurance standards, with permanent verification by the beneficiary at inspection and testing points, according to decree 159/1982. The beneficiary itself (the heavy water plant), has developed its own quality assurance system, with a quality assurance manual, execution procedures and its own inspection and testing points, with permanent checks using non-destructive testing laboratory equipment and service inspectors of quality assurance. The development of these documents was a complex and lengthy process, taking into account the complexity of the processes and installations, the increased safety in operation and the high risk for employees and the surrounding population due to the circulation of very large quantities of hydrogen sulfide.

Production of heavy water, in tons per year: (Nică 2016)

- July 17, 1988: the first amount of heavy water: 8,8 tons
- 1989: 22,084 tons
- 1990: 1,266 tons
- 1992: 7,602 tons
- 1993: 40,906 tons
- 1994: 85,217 tons
- 1995: 103, 716 tons
- 1996: 110,2 tons
- 1997: 144,243 tons
- 1998: 146,38 tons
- 1999: 144,657 tons
- 2000: 122,05 tons
- May 10, 2001: Total production of 1,000 tons of heavy water reached
During the period 1988-1989, the first two modules were put into operation.

"After 1988, the ROMAG staff defines its own development philosophy, gains a lot in the improvement of the operating staff, confirmed by reaching the capacity foreseen by the project, the production of high-quality heavy water and the maintenance of specific consumptions below the levels of international competition." (Glodeanu 2007)

After December 1989, operation of the modules was stopped. Through address no. 20111/1990, the Ministry of National Economy approved the suspension of works on the objective of the Drobeta-Turnu Severin Chemical Plant - Stage II "due to a lack of thermal and electrical energy at the national level", (Nică 2016) and by the Note dated 16.05.1990 ordered the final stop of the works related to modules 5-8 and their conservation. The plant was scheduled to be shut down for approximately three years, to upgrade technological equipment and environmental surveillance and protection systems. Because of this production shutdown, the heavy water required to start up Unit 1 at the Cernavoda NPP was borrowed from the Canadians, and significant corrosive effects occurred in the plant's facilities.

By GD 147/01.03,1991, the Romag Drobeta Autonomous Region was established. By Government Decision GD 195/April 23, 1992, the factory was transferred to RENEL.

On August 19, 1992, hydrogen sulfide recharging begins and the process of isotopic concentration was resumed. On October 7, 1992, heavy water is obtained again.

By Decision no. 365/1998, the Autonomous Directorate for Nuclear Activities (RAAN) is established by reorganizing the Autonomous Electricity Directorate Renel which, in Annex 2.3, includes the ROMAG-PROD Branch, the ROMAG-TERMO Branch, the Technological Engineering Branch for Nuclear Objectives (CITON Bucharest), and the Nuclear Research Branch Pitesti (ICN Pitesti). By Government Ordinance no. 126/2000 it was approved the continuation of the heavy water production activity by the ROMAG PROD Branch within the Autonomous Directorate for Nuclear Activities, and it was approved the export delivery, to Korea Hydro and Nuclear Power, of the quantities of heavy water produced in addition to the required requirements commissioning of Unit no. 2 – Cernavodă Nuclear Power Plant (16 tons of heavy water). According to the Activity Report of the Romanian Intelligence Service, the import of 335 tons was imposed in December 1994, although this would have been fully necessary only in July 1995, during this period, the Romag Plant producing heavy water which, by postponing the import, would have led to reduce the foreign exchange effort. (SRI 2001)

Decision no. 1259 of November 7, 2002 regarding the approval of the National Strategy for the development of the nuclear field in Romania and the Action Plan for the implementation of this strategy, in which it was stated that "Heavy water is produced at RAAN Romag Drobeta Turnu Severin, based on a process developed of Romanian science and technology, has a high quality, being, probably, the best performing among the existing large quantity offers in the world. The manufactured quantity allows covering the needs of the Cernavoda NPP units without delays." At point 4, it was decided to manufacture the heavy water necessary to ensure technological losses and to put Unit 2 into operation. (Guvernul 2002)

On April 12, 2003, 20 tons of heavy water were sold in China. (Nică 2016)

Through the Supporting Note - Emergency Ordinance for the amendment and completion of the Government's Emergency Ordinance no. 80/2006 regarding ensuring the production of heavy water in order to put into operation and complete the technological needs during the lifetime of units 3 and 4 at the Cernavodă nuclear-electric power plant, it is confirmed the idea that the Autonomous Directorate for Nuclear Activities (RAAN) has as its main object of activity the production of heavy water and technological engineering activities, the production of the amount of 1,100 tons of heavy water by RAAN is approved for the commissioning of units 3 and 4 at the Cernavoda Nuclear Power Plant, and after the production of this amount, the production continues of heavy water to complete the technological needs during exploitation.

"According to the technical specification of the SNN beneficiary, the "virgin" heavy water produced at RAAN- Romag Prod Branch in Drobeta Turnu Severin has superior quality parameters, this being also demonstrated by the results of the analyzes carried out on the occasion of exports from 2001 - 2004: CNE Wolsung - South Korea, CNE Qinshan - China and Nukem - Germany with CAMBRIDGE ISOTOPES LABORATORIES Inc. - USA, SPECTRA GASES Inc. - USA, ISOTEC Inc. - USA and CHEME UETICOKON. as end users" (Guvernul 2006)

Several specialized studies have shown that the use of heavy water of advanced concentration and purity in reactors leads to quantifiable positive effects, the most important of which are the increase in fuel combustion efficiency, thus achieving an economy of uranium and decreasing the corrosion rate.

Figure 4. Heavy Water Plant - Overview. Source: ROMAG website

The heavy water, super heavy water and super light water produced at the heavy water plant had the following official specifications:

Qualitative parameters	Value	U.M.
Isotopic concentration	min. 99.78	% wt. D_2O
Conductivity	max. 5	microS/cm
Turbidity	max. 1	NTU(ppmSiO_2)
Organics ($KMnO_4$ demand)	max. 10	mg/kg
Chloride	max. 0.5	ppm
Tritium	absent	microCi/Kg

Table 4. Heavy water technical specifications. Source: (ROMAG-Prod 2014)

The heavy water produced by ROMAG PROD complies with the requirements mentioned by AECL, Technical Specifications TS-XX-38000-001, approved by AECL on 01.02.1990.

Qualitative parameters	Value	U.M.
Isotopic concentration	min. 99.90*	% wt. D_2O
Conductivity	max. 5	microS/cm
Turbidity	max. 1	NTU (ppmSiO_2)
Organics ($KMnO_4$ demand)	max. 10	mg/kg

Chloride	max. 0.04	ppm
Tritium	absent	microCi/Kg

Table 5. Super heavy water technical specifications. Source: (ROMAG-Prod 2014)

* The minimum concentration of the product is specified with the following codes:

Code	Min % wt.D_2O
HG	**99.90**
VHG	**99.96**
EHG	**99.9996**

Table 6. Minimum concentration of super heavy water product. Source: (ROMAG-Prod 2014)

Qualitative parameters	Value	U.M.
Isotopic concentration	max. 80*	ppm D_2O
Conductivity	max. 5	microS/cm
Turbidity	max. 1	NTU (ppmSiO_2)
Organics ($KMnO_4$ demand)	max. 10	mg/kg
Chloride	max. 0.5	ppm
Biological purity	absent	No germs

Table 7. Technical specifications for superlight water. Source: (ROMAG-Prod 2014)

* The maximum concentration of the product is specified with the following codes:

Code	ppm D_2O
SU1	**0 - 20**
SU2	**21 - 40**
SU3	**41 - 60**
SU4	**61 - 80**

Table 8. Minimum concentration of the superlight water product. Source: (ROMAG-Prod 2014)

Romania thus became one of the major producers of heavy water. (Spinei 2020)

Shutting down

The specific social, economic and political problems that arose after the revolution of December 1989, but also the technological problems that arose in the operation of the heavy water plant, some of which were impossible to solve, determined the appearance of critical anomalies that led to a period of crisis in the evolution of the heavy water plant. This is how phase 3 appeared, predicted by Kuhn, in which the crisis can no longer be resolved in the existing paradigm and it is necessary to move towards a new paradigm.

The high quality of heavy water produced by ROMAG PROD was confirmed not only in the operation of the CANDU reactors at CNE Cernavodă, but also by AECL Canada which agreed to grant Romania a loan of 400 t of heavy water to put the first CANDU reactor into operation. The entire amount of borrowed heavy water was returned to AECL with high purity and high concentration. (Ioniţă 2018)

The heavy water was stored in 220-liter inert gas cushioned stainless steel vessels and 50 m^3 tanks, in secure storage.

During the period 1994 - 1998, an inventory of heavy water with the required quality parameters for Unit 1 from CNE Cernavodă (556 t) had already been carried out, and in the period 1999-2004 the necessary heavy water for the first loading for Unit 2 from CNE Cernavoda. Surplus heavy water was exported to countries such as Korea, China, Germany, USA. (Fako et al. 2019)

Emergency Ordinance no. 54 of May 29, 2013 regarding some measures for the reorganization by partial division of the Autonomous Directorate for Nuclear Activities Drobeta-Turnu Severin and the establishment of the Autonomous Directorate of Technologies for Nuclear Energy - RATEN decides to establish the autonomous authority of strategic interest, the Autonomous Directorate of Technologies for Nuclear Energy, hereinafter referred to RATEN, through the partial division of the Autonomous Directorate for Nuclear Activities Drobeta-Turnu Severin, hereinafter referred to as RAAN, without ceasing its existence, through the separation of research, development, technological engineering and technical support activities for nuclear energy and its moving to RATEN.

In 2013, based on Government Decision no. 85/2013, the heavy water plant goes into insolvency. In January 2014, the Judicial Administrator, S.C.P. Tudor and Associates developed the RAAN activity reorganization plan, the factory being completely shut down at the end of 2015.

GEO no. 20/2015 for establishing the maximum level of the heavy water product intended for units 1-4 at the Cernavodă Nuclear Power Plant for the entire period of their exploitation, as well as for the management of heavy water (Official Monitor no. 433 of 17.06.2015) considers that the further purchase of heavy water is no longer justified. The quantities of heavy water produced by the Autonomous Directorate for Nuclear Activities Drobeta-Turnu Severin until June 30, 2015 in order to reach the maximum levels provided for in art. 1 will be taken over to the state reserve by the National Administration of State Reserves and Special Issues.

In September 2015, the production of heavy water was stopped and the plant staff was laid off. By Sentence no. 10/28.01.2016 pronounced by the Mehedinti Court in file no. 9089/101/2013, it was ordered to start the bankruptcy procedure and to dissolve the debtor RAAN, sentence made final by Decision no. 563/14.06.2016 of the Craiova Court of Appeal. Eurolnsol SPRL was appointed judicial liquidator.

Since the heavy water management activity was left without funding sources, the heavy water management was ensured by RAAN, through the ROMAG - PROD Branch, with a number of approx. 96 employees, specialized staff, (Ministerul Energiei 2015) the National Heavy Water Management Center was established, an institution under the Ministry of Energy, with the following objectives established by OG 29/2017 and HG 914/28.12.2017: keeping the inventory of heavy water which is the object of the deposit and/or administration, the provision of technological and protective measures to maintain its integrity; taking over from RAAN the technical archive, including the classified documentation, regarding the installations, technological flows, technical prescriptions related to the production, storage and maintenance of the physico-chemical properties of heavy water; and obtaining and maintaining all the approvals and authorizations necessary for carrying out activities related to heavy water management, according to the legal provisions in force. (C.N.M.A.G. 2018)

Conclusions

According to an article from *Univers Ingineresc*, Marius Peculea claimed during a debate that

> "The PNN [National Nuclear Plan] can be likened to a pyramid whose base rests on uranium ore reserves, ... the ore is refined in Feldioara, it is then transformed into nuclear fuel in Pitesti, so that in parallel it can be produced heavy water at Drobeta Turnu Severin, ... supporting the operation of the Cernavoda nuclear power plant at the top of the pyramid. Outside the pyramid, for each individual floor, including its top, PNN was supported by the Romanian industry through the construction of equipment and apparatus, all at the level of nuclear quality, construction and assembly; in short - an important part of the national economy. Basically, the nuclear pyramid was organized as a unitary whole, with elements linked organically, functionally and economically." (Proca 2015)

> "The path of technological research to society is the story of the path of heavy water from the laboratory to its industrialization. ... the recommendations of Solon, the Greek who gave the laws of Athens, said that, 'when you want to analyze the life and activity of a man or some events, you must take into account two things: geography and history, the place where the events took place and in what time, under what historical conditions they took place'". (Peculea 2013)

Samuel Butler himself appreciates, in *Erewhon*, (Butler 1872) technology as a socio-cultural phenomenon.

The heavy water factory was recognized as the only heavy water producer in Europe and the largest in the world. Its development (research, design, execution, putting it into operation) and operation was an exclusively Romanian achievement, and this unit was a unique state-of-the-art technological facility of the Romanian industry. (Fako et al. 2019)

Unfortunately for the Romanian economy, the history of the heavy water factory was a unique and unrepeatable experience. No other heavy water plant or other industrial complexes of such a size will be built in Romania, at least not in the foreseeable future. But the experiences gained by the research, design, manufacturing, construction and assembly communities have been of unparalleled value. According to Mircea Turtureanu, "The heavy water factory from Turnu

Severin was born in a not very lucky sign. But I think he had a lot of guardian angels." (Turtureanu 2016)

The research on the production of heavy water, started at the Institute of Atomic Physics in Cluj in 1958, later included dozens of research and design institutes from all fields. The fact that all machines and equipment had to be of exclusively Romanian production created many difficulties, but at the same time it was a chance for researchers and designers to develop innovative solutions, which materialized in hundreds of invention patents. The most important roles in the development of this community at the national level, in the sense of Kuhn's paradigm, were played by the Institute of Atomic Physics from Cluj in scientific research, Uzina G from Râmnicu Vâlcea in technological research (with a special mention for Marius Peculea), and the IITPIC Bucharest design institute in the design of the heavy water plant and the improvements made to it during operation. But we must not forget the research and design institutes that were called upon for various studies, all the research and design departments of the machinery and equipment factories and construction-assembly enterprises, and even the specialists of the heavy water plant who collaborated closely with all these research and design units noticing various problems that arose during the construction and then the operation of the factory, and proposing practical solutions, some of which were taken over and developed by the designers.

The quality assurance system implemented since the design phase, and maintained throughout the construction and operation of the factory equally by the designers, the factories that provided the materials, machinery and equipment, the construction-assembly companies and the beneficiary, ensured a very strict technological discipline. This way of working was later applied in the construction and operation of the reactors at Cernavodă, but also in other industrial fields, making Romanian institutes and enterprises competitive at the international level.

Drobeta Turnu Severin heavy water plant has shown, all these years, that the Romanian school of scientific and technological research and design can be as competitive as any other such institutes worldwide. Through the achievements in all phases and the large number of entities involved at the national level, the heavy water plant can be considered the greatest success of Romania's chemical industry. (Turtureanu 2016) Marius Peculea states that the development of the heavy water plant in Romania

> "it was a moment of courage that demonstrated the effectiveness of the collaboration between technological research, higher technical education, design and specialized industry, all marking the superior level of technical culture in Romania... Romania can become a country that builds its own industry and education of all degrees and to ensure specialized staff." (Peculea 2019)

"The history of heavy water in Romania is, perhaps, the most beautiful epic in the history of Romanian technology in which the ‘idea’ generated an explosion in the training of people in school, or as it is said today in the world, where something is achieved ‘learning by doing’ , in which people, by their own conception, were able to create technologies, equipment of great complexity and originality." (Proca 2015)

Marius Peculea stated that all the participants in the realization of the ambitious project "believed, fought and succeeded, supporting each other to overcome failures, finding the way to solve them through the free circulation of information, where criticism was a sincere form of collaboration". (Peculea 2020)

According to the former general director of IITPIC Bucharest, Mircea Turtureanu,

"Today, Romania no longer has engineers with such rich experience who could design a new heavy water factory. All the know-how was lost in time, as were the specialists in the field. The Turnu Severin plant provided all the heavy water required for the four nuclear reactors at Cernavodă, and Romania is thinking of changing its supply chain and building reactors with enriched uranium and light water. The heavy water plant at Turnu Severin, after it has fulfilled its purpose... will remain a memory in pictures, as will the pilot installation at Uzina G." (Turtureanu 2016)

The fourth phase of Kuhn's structure of scientific (and technological!) revolutions states that the emergence of critical anomalies, which can no longer be resolved, requires a shift in paradigm, in which basic principles are re-examined and a new paradigm is established. Unfortunately, this phase of the scientific (and technological!) revolution has expanded a lot in Romania. Now, more than ten years later, we are at the same stage. But the last phase is beginning to be foreshadowed, the one in which the new paradigm takes shape. One possibility is that of Small Modular Reactors (SMR), (nuclear fission reactors smaller than conventional nuclear reactors, with an electrical output of up to 300 MWe or a thermal output of less than 1000 MWth. They are designed to be prefabricated and transported to where they are to be installed (OECD-NEA 2016) A new chance for the Romanian nuclear industry.

Will we be able to enter the new paradigm soon?

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