SUSTAINABLE NUCLEAR DEVELOPMENT IN ROMANIA

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Rezumat. *Lucrarea prezintă dezvoltarea sectorului energetic nuclear din perspectiva dezvoltării durabile. Este analizată situația, curentă precum şi dezvoltarea viitoare preconizată de strategiile şi viziunile existente. Este abordată implementarea demonstratorului LFR ALFRED în România (amplasament de referință: platforma nucleara Mioveni) din punct de vedere al stadiului curent al activităților de cercetare-dezvoltare-inovare cât şi al progresului proiectului, precum şi contribuția acestuia la dezvoltarea sustenabilă in Romania ş în Europa.*

Abstract. *The paper presents the development of the nuclear power sector in Romania from the perspective of sustainable development. The current state is analysed and the expected future development is investigated. The implementation of ALFRED LFR demonstrator in Romania (reference site: nuclear platform Mioveni) is approached from the point of view of the current stage of RDI and implementation and the contribution to sustainable development in Romania and Europe.*

Keywords: nuclear development, sustainability, fast reactors, lead technology.

1. Introduction

The development of any society is based on existing resources, defined needs, and appropriate ways for their implementation. Modern and complex technologies create social benefits and also some drawbacks.

Often the associated drawbacks and risks are not very well understand due to the level of the knowledge, level of awareness, and the level of the debate in society.

The concept of sustainable development is based on the requirements that the present generation development will offer sufficient chances for the development of the future generation.

This is strongly linked with the effect of exhausting the natural resources, affecting the environment, clime changes, knowledge capital transfer, jobs, cultural elements, etc.

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Modern technical design is not sufficient for a successful implementation of new modern technology. One of the most powerful criteria is the fulfilment of the sustainable development requirements. Nuclear power was gradually developed after the ‘60s and raised up to 13% of the total electricity of the world [1]. In Europe the sharing of nuclear in the total electricity is more important, around 26% [2].

The history of the nuclear development is based on a continuous progress of the nuclear technologies. Different commercial approaches have produced a variety of nuclear power plants (NPP) based on different concepts such as PWR, VVER, CANDU, BWR. Technological development introduced Generation I, II, and III of NPPs with systematic improvements in safety and security, economics, reduced environmental impact.

The current development is focused on Generation IV nuclear systems and Small Modular Reactors (SMRs).

Romania adopted CANDU technology based on the natural Uranium option due to the advantage of the using of national natural resources. The research, development and innovation (RDI) efforts are oriented to the development of Generation IV nuclear systems.

The present paper analyses the nuclear development in Romania from the perspective of sustainability requirements taking into consideration the current nuclear power and the RDI efforts dedicated to future developments.

2. The nuclear sector in Romania

Nuclear power is a stable component of the energy-mix in Romania on the basis of Cernavoda Nuclear Power Plant (NPP) with 2 units in operation (U1 from 1996, U2 from 2007, each unit of 705 MWe gross capacity). The current nuclear share in the total production of electricity is around 18%. Cernavoda NPP was designed for 5 units. The other three units planned for Cernavoda NPP (U3, U4 and U5) are under preservation, since 1992, each of them reaching different stages of the construction.

U5 was abandoned due to some discovered non-conformities appeared at civil engineering level. For U3 and U4 there is a political decision to continue the works and to increase the national capacity for nuclear electricity production. The economic crisis created financial difficulties and determined repeated delays of the project.

In 2013 the Environmental Impact Assessment (EIA) and the Strategic Environmental Assessment (SEA) were completed and the Environmental Agreement was released [3].

In 2014 a Partnership was signed between Romania and China aiming to supply the investment needs for U3&4 [4]. In accordance with the current vision, U3&4 should be commissioned around 2020 and the national installed nuclear capacity will be doubled to a total of 2820 MWe gross capacity.

All amount of nuclear fuel for the operation of Cernavoda is produced by the national industry based on national resources of Uranium. Romania has a complete cycle of fabrication of the nuclear fuel from the extraction of uranium ore to the final bundles to be used in the NPP.

CANDU nuclear fuel fabrication started in 1980, through the commissioning of a CANDU type Fuel Pilot Plant operating as a department of INR (Institute for Nuclear Research) Pitesti. In 1994, AECL and Zircatec Precision Industries Inc. Canada qualified the Nuclear Fuel Plant (FCN) Pitesti as a CANDU 6 fuel manufacturer. The plant has a current production of 210 tons of UO2 per year, respectively about 46 bundles per day. In the last year due to the increasing of the costs of the exploitation of national uranium reserves an orientation to the import of uranium powder was produced.

The national industry produced also the heavy water needed as coolant and moderator at Cernavoda NPP operation. A heavy water factory is in operation (from 1987) in Drobeta Turnu Severin. The activity of the factory was reduced over the last decade due to the delay of Cernavoda U3&4 project. The current planning is to close the factory in 2016.

The nuclear sector benefits from the existing RDI infrastructure. The most important is included in the nuclear platform Pitesti (two research reactors, post-irradiation laboratory, nuclear material laboratory, radioactive waste management unit, out-of-pile testing laboratories, etc.). The old VVR-S research reactor (IFIN-HH Magurele) is currently in decommissioning process.

The spent nuclear fuel from Cernavoda NPP is stored in the Interim Dry Storage Facility located on the NPP site, with the planned operational period of 50 years. The radioactive waste originated from operation of NPP is stored into a concrete storage facility also located on Cernavoda NPP site. A near surface repository for LILW (Low and Intermediate Low Waste) is planned to be built in the next years and the siting process in Saligny area is in progress. According to the current national strategy for energy sector (HG 1069/2007) a geological repository is expected to be commissioned around 2055 in order to accommodate spent fuel generated by the NPP operation.

The following aspects are considered in the national energy strategy in relation to the nuclear power in Romania:

- The nuclear option is a key issue to ensure the security of supply (one of the main function of the State),
- Nuclear is a strategic component contributing to the independency on the import of resources (oil & gas affected by political instabilities, variation of prices),
- Nuclear is a green energy and an easy way to reduce CO2 emissions (Kyoto Protocol),
- CANDU technology and the development of the national nuclear industry (nuclear fuel and heavy water) is a more appropriate solution than the dependence on import of fuel and technology,
- The good operational experience at Cernavoda U1 and U2 is a basis for the success of the future U3 and U4.

3. The development of GenIV, ALFRED demonstrator in Romania

The Strategic Research and Innovation Agenda (SRIA) of the Sustainable Nuclear Energy Technology Platform (SNETP) [5] include the development of fast reactors with closed fuel cycle.

Lead Fast Reactor (LFR) has been identified as a technology with a great potential to meet the goals of increased safety, improved economics for electricity production, reduced nuclear wastes for disposal (both as total amount and as radio-toxicity), and increased proliferation resistance.

The LFR is based on a closed fuel cycle for efficient conversion of fertile uranium and management of actinides (enhanced sustainability), the inert nature of the coolant provides important design simplification (improved economics) and allows for designing decay heat removal systems based on well-known light water technology and passive features (increased safety).

Moreover, the reference LFR fuel (MOX) constitutes a very unattractive route for diversion or theft of weapons-usable materials and provides increased physical protection against acts of terrorism (Non-proliferation and Physical Protection).

The LFR Roadmap is targeting 2050 for the starting of the commercial deployment and 2030 as the operation of the demonstrator of the technology (ALFRED - Advanced Lead Fast Reactor European Demonstrator).

In 2011, the Romanian Government approved the Memorandum 2025/2011, "Romanian option to host ALFRED demonstrator", initiated by the Ministry of Economy, Trade and Business Environment.

The document declares the availability of Romania to host ALFRED demonstrator and nominates the Institute for Nuclear Research (INR) to initiate the preparatory actions at international level for ALFRED consortium construction.

In December 2013 an international consortium for co-operation on the development of the Lead-Cooled Fast Reactor Demonstrator, named FALCON was signed by RATEN ICN, Ansaldo Nucleare, and ENEA. In 2015 CV Rez (Czech Republic) joined the consortium. Some other organizations are expected to enter the FALCON consortium in the next period. More than 10 other RDI organizations from the EU signed agreements on different research topics in order to contribute to the development of ALFRED and LFR technology. In January 2014 the Romanian Government approved another Memorandum re-affirming the availability for hosting ALFRED and introducing some actions for the implementation, the most important being the creation of Inter-Ministry Working Group in charge for the solution for funding. In June 2015 the FALCON consortium finalized the Action Plan and in September the document was discussed in Brussels with representatives of DG-RTD, DG-Energy, DG-Regio and JRC.

ALFRED is a 300 MWth scaled demonstrator of the LFR technology. It was designed, at the conceptual level, in the frame of FP7-LEADER project [6] involving 17 partners from industry, research organizations and universities during 2010-2013. The main parameters of ALFRED are presented in Table 1.

Table 1. ALFRED – Main parameters

Items	***ALFRED Options***
Thermal Power (MWth)	300
Electrical Power (MW_e)	125
Primary Coolant	Pure Lead
Primary System	Pool type, Compact
Primary Coolant Circulation: Normal operation Emergency conditions	 Forced Natural
Allowed maximum Lead velocity (m/s)	2
Core Inlet Temperature (°C)	400
Steam Generator Inlet Temperature (°C)	480
Secondary Coolant Cycle	Water-Superheated Steam
Feed-water Temperature (°C)	335
Steam Pressure (MPa)	18
Secondary system efficiency (%)	40
Maximum Structural material neutron Damage (dpa)	2

Fuel type	MOX (max Pu enr. 30%)
Maximum discharged burn-up (MWd/kg-HM)	90÷100
Maximum Clad Neutron Damage (dpa)	100
Maximum Clad Temperature in Normal Operation (°C)	550

The configuration of the ALFRED primary system is pool-type [7]. It eliminates all problems related to out-of vessel circulation of the primary coolant.

A simple flow path of the primary coolant with a Riser, Pump, Steam Generator, and a Downcomer is present allowing also an efficient natural circulation of the coolant.

The Reactor Vessel is cylindrical with a toro-spherical bottom head. It is anchored to the reactor cavity from the top, by means of a vessel support (Figure 1).

The core design has been driven by the implementation of the so called "walk away" and "adiabatic" [8] reactor concepts. The adopted core configuration of ALFRED [7] is constituted by wrapped Hexagonal Fuel Assemblies. The fuel is MOX type with hollow pellets and a low active height in order to improve the natural circulation. The core (Fig. 2) consists of 171 Fuel Assemblies (FAs), 12 CR (Control Rods) and 4 SR (Safety Rods), surrounded by 108 Dummy Elements (ZrO_2-Y_2O_3) shielding the Inner Vessel.

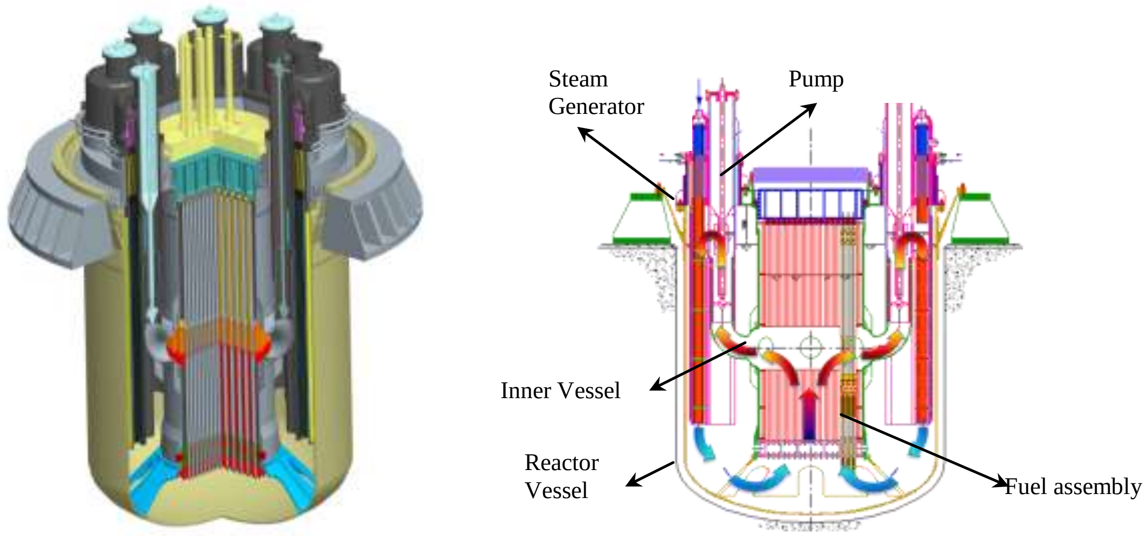

Fig. 1. ALFRED 3-D Sketch and Reactor Block Vertical Sections.

ALFRED is equipped with two diverse, redundant and separate shutdown systems: (1) Control Rod (CR) system, used for both normal control of the reactor (start-up, reactivity control during the fuel cycle and shutdown) and for SCRAM in case of emergency; (2) Safety Rod (SR) system, is the redundant and diversified complement to the control rods for SCRAM only. For both systems the materials considered are B4C enriched in 10B at 90% as absorber, T91 for the guide tube, 15-15 Ti for the clad and ZrO2 (95%) - Y2O3 (5%) for the insulator and reflector.

The CRs are extracted downward and rise up by buoyancy in case of SCRAM. The structure of CR consists of a 19 pins absorber bundle, cooled by the primary coolant flow. These pins are fitted with a gas plenum collecting the Helium and Tritium, produced by nuclear reaction of B10.

The absorber bundle for SR stays in the primary coolant. The rod is extracted upward and inserted downward against the buoyancy force. The absorber gets inserted by the actuation of a pneumatic system. In case of loss of this system, a tungsten ballast will force the absorber down by gravity in a slow insertion.

The steam generator (SG) and primary pump (PP) are integrated into a single vertical unit. Each SG consists of a bundle of 542 bayonet tubes immersed in the lead vessel pool for six meters of their length. Eight SG/PP units are located in the annular space between the cylindrical inner vessel and the reactor vessel wall. The primary pump is placed in the hot side of the steam generator, having its mechanical suction in the hot pool inside the inner vessel. The primary coolant moves upward through the pump impeller to the vertical shaft, then enters the SG through the lead inlet holes, flows downwards on the shell and exits the steam generator. The pump motor is located above the reactor roof.

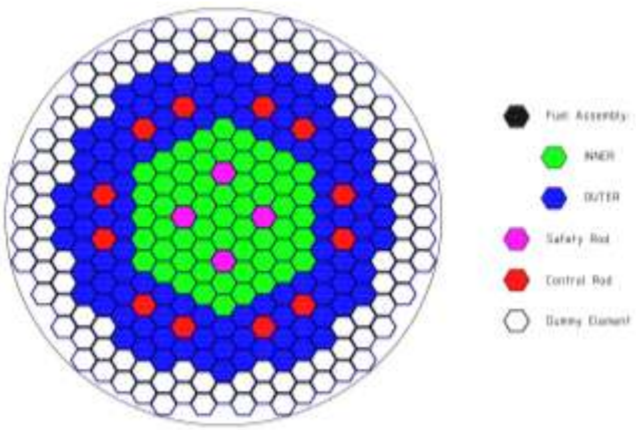

Fig. 2. ALFRED core configuration.

The Decay Heat Removal system (DHR) consists of two passive, redundant and independent systems, DHR1 and DHR 2, both composed of four Isolation

Condenser systems (ICs) connected to four Steam Generators (SGs) secondary side (i.e. one IC for each SG).

The Secondary system proposed for ALFRED is based on a dual turbine configuration with three extractions in the HP turbine and three more in the LP turbine, with an axial outlet.

An auxiliary lead heating system is added. This system would work when the power cycle is not in operation, in order to ensure the minimum temperature of the lead by transmitting heat from the secondary system if it is needed. A sketch of the current ALFRED layout with forced draft cooling towers is shown in Fig. 3.

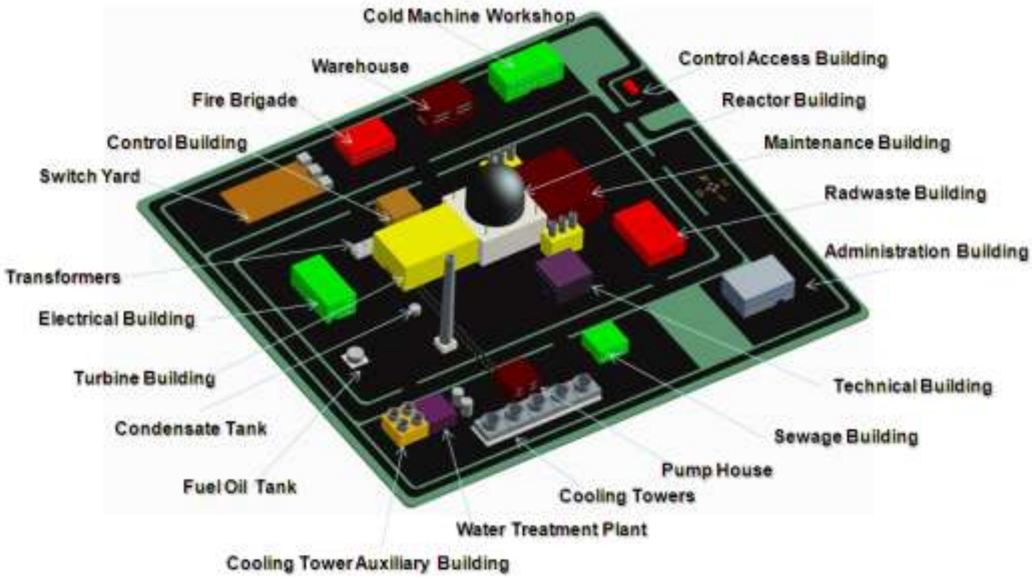

Fig. 3. Alfred General Layout.

According to the FALCON consortium the reference site for ALFRED demonstrator is the nuclear platform Mioveni based on the advantages of existing infrastructure support, proximity of specialists and favourable opinion public.

4. Nuclear and sustainable development

According to the most agreed definition (Brutland commission) the sustainable development is the kind of development that meets the needs of the present without compromising the ability of future generations to meet their own needs. It is based on three main pillars: (1) Economic Growth; (2) Environmental Protection; (3) Social Equality.

In the frame of sustainability concept the following elements in relation with the nuclear power are considered:

- High complexity of technology (deep and complex knowledge),
- High efficiency of the energy production (comparison with the quantities of equivalent coal, gases, biomass, etc.),
- Environment and the climate changes (CO2 free for nuclear technologies),
- Very promising development (Generation IV perspective).

On the other hand the acceptability of any modern technology is a matter of the democratic debate. Participation of the public and other stakeholders in the decision making process is more and more present in the attention of the policy-makers with the aim to share the responsibilities and to smooth the way to the implementation.

In the post-Fukushima context some concerns of the public raised and have produced emotional decisions. On the other hand, in Europe, there is enough potential for researching and enhancing governance in order to fill the gaps and reduce the weaknesses in the governance field related to nuclear energy. There is room for more comprehensive approaches and strategies.

In terms of sustainable development a set of indicators is defined in order to judge if an energy alternative really meets the sustainability requirements:

(I_1) Availability and distribution of the involved resources,

(I_2) The intensity of the energy use and the fluxes of raw materials,

(I_3) The impact on the health,

(I_4) Critical limits for environmental loads,

(I_5) The use of the lend and the impact on the habitats,

(I_6) The potential risk for major and irreversible events.

Taking into consideration the economic, social and environmental dimensions of the sustainable development the following quantitative parameters are defined for energy alternatives:

(1) Economic indicators: capital ($/kWe), marginal cost ($/kWh),

(2) Social indicators: public dose (Sv/KWh), number of employees (pers./kWh), education (number of university courses),

(3) Environmental indicators: volume of the solid wastes (m^3/kWh), activity of solid wastes (Bq/KWh), fuel use (tU/kWh), activity of the gaseous and liquid effluents (Bq/kWh).

For CANDU technology the total cost is estimated at .5 to 4.0 cents/KWh. These values include the security and decommissioning costs. In Table 2 the capital and construction duration for nuclear, coal and gas are compared.

Table 2. Comparison of the capital cost and duration of the construction

Plant	*Capital per* KWe [USD]	*Estimated Duration for construction* [years]
Nuclear	2000 ÷ 2500	5 ÷ 7
Coal	1500 ÷ 2000	5
Gas	500 ÷ 900	2 ÷ 3

One of the major advantages of nuclear is the stability of the production cost due to the low share of the uranium cost in the total cost of the electricity.

From the point of view of the environment a 1GWe nuclear plant eliminates the emissions of 1.75 mil.t. CO_2 if the energy should be produced by coal (or 1.2 mil ton for oil land 0.7 mil ton for gas). The energy produced per mass unit in nuclear plant is 10000 times greater than the energy produced in the case of fossil fuels.

From the point of view of the existing resources the actual reserves of uranium at world level can easily cover the energy for the future 70 years. This period can be extended to 250 years if the estimations for new reserves will be considered. As we mentioned in the previous section the Generation IV fast reactors and implicitly ALFRED LFR will extend the period of reserves with at least 1000 years due to the high efficiency in the use of uranium.

On the other hand the amount of generated radioactive wastes and their radio-toxicity will be reduced at least with a factor of 10 in comparison with the actual nuclear systems.

From the point of view of social dimension the nuclear power represent a high intensity and complex knowledge capital. The nuclear energy is the main discovery in the humankind history since the discovering of the fire. An important number of high specialization jobs are offered by the nuclear power units and the supporting RDI.

Conclusions

(1) Nuclear power is an important option of the energy mic for Europe and for Romania taking into consideration the present pressures of the emissions, needs for security of supply, need for the diversification, stability in production, and affordability of price for the economy and individuals.

(2) The nuclear can ensure the reduction of CO2 based on the replacement of old fossil based power units. The nuclear will offer a great stability of the national

power network in the condition of the increasing of the sharing of the renewable.

(3) Generation IV nuclear systems offer promising alternatives of energy systems. LFR technology is based on a closed fuel cycle with an efficient conversion of fertile uranium, management of actinides (enhanced sustainability). The inert nature of the coolant provides important design simplification (improved economics) and allows a high performance design of the decay heat removal systems based on well-known light water technology and passive features (increased safety).

(4) Romania had started important efforts in the development of LFR technology. The ALFRED demonstrator is intended to be constructed on nuclear platform Mioveni based on the existing advantages of an existing nuclear site.

(5) ALFRED is an important opportunity for local, regional, and national development (economy, R&D sector, E&T, stimulate SMEs development) and will contribute to a sustainable development of the nuclear sector in Romania and in Europe.

(6) The development of ALFRED is coordinated by an international consortium. The funding scheme is based on multisource option with a dominant component of the structural funds. The demonstrator will involve national implementation efforts, RDI European support, nuclear industry involvement, a large debate involving all the stakeholders.

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