The security of energy supply in the 21st century

V4 collaboration in the field of nuclear reactor development

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Received: 25 November 2021; Accepted: 10 December 2021; Published online: 7 March 2022

Summary

The European goal to achieve climate neutrality by 2050 has serious implications for our energy system. All studied scenarios in the frame of this roadmap include a contribution of the nuclear energy in various ranges (up to 21%) depending on several hypotheses. In order to attract leading edge technology development into the Central European region and to share the common responsibility of EU member states in achieving sustainable energy production and contributing to the fight against climate change, the idea emerged that the Czech Republic, Hungary, Poland and Slovakia could host a major European nuclear facility as part of R&D efforts aiming at the development of the next generation of nuclear reactors. The paper introduces the ALLEGRO project and the international collaboration organized for developing the scientific and legal background for the licensing of a fourth generation nuclear reactor demonstrator.

Keywords: nuclear energy, generation IV, fuel cycle

Az energiaellátás biztonsága a 21. században

V4 együttműködés a nukleáris reaktor fejlesztése területén

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Összefoglaló

A 2050-re kitűzött klímacélok elérése érdekében az európai országok csökkenteni fogják a fosszilis tüzelőanyagok felhasználását, és a megújuló energiaforrások növekvő felhasználása mellett a nukleárisenergia-termelésre is támaszkodni fognak. A jövő nukleárisenergia-termelésének meg kell oldania hosszú távon a friss üzemanyag utánpótlását, és a kiégett üzemanyag elhelyezését, illetve újrafelhasználását. Az évszázad második felében várható azoknak a negyedik generációs gyorsreaktor típusoknak a megjelenése, amelyek képesek az üzemanyag takarékos felhasználását évszázadokig biztosítani. A visegrádi országok nukleáris kutatóintézetei között indult tudományos együttműködés a 2010-es években azt a célt tűzte ki, hogy egy negyedik generációs gázhűtésű gyorsreaktor demonstrátor berendezést (ALLEGRO) építsenek a régióban. A reaktor megvalósításához szükséges tevékenységek összehangolása érdekében 2013-ban megalapították a V4G4 Kiválósági Központot. Az ALLEGRO demonstrátor fejlesztése során megoldott technikai kérdéseken túl megoldandó kérdés maradt a megfelelő szervezeti struktúra kialakítása, amely kielégíti a jogi követelményeket, ugyanakkor biztosítja az európai nukleáris ipari vállalatok versenyképességét.

Kulcsszavak: nukleáris energia, IV. generáció, üzemanyagciklus

Introduction

The European goal to achieve climate neutrality by 2050 has serious implications for our energy system. The objectives are described in the "Energy Roadmap 2050", with ambitious targets regarding decarbonisation of the EU economy. All studied scenarios in the frame of this roadmap include a strong improvement of energy efficiency, an increase of renewable energy sources, a decrease of fossil fuels, and a contribution of the nuclear in various ranges (up to 21%) depending on several hypotheses.

To decrease this dependence on fossil fuels, several countries, among them the V4 countries, have decided to build their energy mix on nuclear and renewable, with a reduction of the use of fossil fuels as soon as possible.

The large majority of nuclear power plants operating today belong to the second generation, which was built in the sixties-seventies-eighties. These nuclear power plants operate safely and are usually built with such reserves that their further operation, the extension of the operating time by 10–30 years, does not cause technical problems even after the expiration of their planned operating time.

In recent decades, a number of types of nuclear power plants have been developed, which are collectively referred to as the third generation of nuclear power plants. These were created in an evolutionary way by the multidirectional development of the second generation. The installation of third generation nuclear power plants with better safety and economy parameters is hampered by the decades-long lack of orders for nuclear power plants and the technical possibility of extending the operating time of second generation nuclear power plants. The relative difficulties of the social acceptance of nuclear power plants and the high investment costs also apply to third-generation nuclear power plants.

A large-scale international project aimed at developing the 4th generation of nuclear power plants was launched in 2000 on the initiative of the United States *(GIF 2000)*. The aim of the developments is to create inherently safe reactors that go beyond the current types in terms of nuclear safety, economy, and non-military usability, as well as the specific amount of radioactive waste generated in them. For many types, high temperature process heat generation and hydrogen production are also targeted.

In parallel to the Generation-IV initiative, the International Atomic Energy Agency had also launched a dialogue, called INPRO *(INPRO 2000),* on the long-term planning for deploying sustainable nuclear energy.

The Generation-IV initiative had been focusing on the development of six nuclear reactor designs, all fulfilling the following requirements:

- a high level of security,
- reliability,
- economy,
- economical use of natural resources,
- minimizing the amount of radioactive waste generated during the energy production process,
- high level of proliferation resistance.

Closed fuel cycle as a key to sustainable nuclear energy production

In addition to the above, the basic goal of the Generation-IV initiative is to develop and commission reactor types that run on a *closed fuel cycle*. At present all nuclear reactors are utilized in an open fuel cycle, i.e. the fuel produced in fuel factories are burned in nuclear reactors and then the burned fuel is treated as a high level radioactive waste. The open fuel cycle on the one hand makes the public acceptance of applying nuclear energy difficult because of the produced high level radioactive waste, and, on the other hand, it is not economic as the burned fuel still contains a large amount of fissile materials which could be further burned after removing the fission products from the burned fuel. Moreover, if nuclear energy is used on the long run and on a large scale, the uranium resources of the world may be exhausted. The closed fuel cycle has two pre-requisites: nuclear reactors which produce enough fissile material during operation and reprocessing facilities which produce fissile materials from the burned fuel.

Only reactors with a fast neutron spectrum (fast reactors) can produce a sufficient amount of fissile materials. Almost all power reactors are operated with thermal neutron spectrum and they are unable to produce enough fissile materials, this is why the Generation-IV initiative (among others) aims at the development of fast reactors. As of today, all 4th generation reactor types are in the "pre-prototype" stage of development.

In the advanced fuel cycle the most important fissile material, the plutonium (together with uranium) is separated from the other radioactive isotopes in reprocessing plants and burned in fast reactors, thus closing the fuel cycle *(Gadó 2017)*. Reprocessing plants do exist but they represent a challenge from the point of non-proliferation as their product is the pure fissile material which can be used also for military purposes. Therefore, the Generation-IV initiative aims at the development of a proliferation resistant reprocessing technology and reprocessing of nuclear fuel could only take place in a limited number of countries with this new technology. The Generation-IV initiative involves the solution for long-term waste management. The reprocessing of spent fuel, the transmutation of fission products and actinides would generate less waste, so that spent fuel storage would become saturated over a longer period of time.

Adequate safety of nuclear power plants is already guaranteed by the 3rd generation units currently under construction, and the issue of safety (including the lessons learned from the Fukushima accident) is, of course, a priority for the 4th generation units as well.

The closed fuel cycle can ensure that nuclear energy contributes to the sustainable energy production on the long run. Solving the problems above seems to be sufficient to improve the acceptance of nuclear energy in the society.

Transition to 4th generation reactors in the Central European region

The first prototypes of the Generation-IV reactors can be deployed after 2040, and the transition to them in the Hungarian–Czech–Slovak–Polish region (hereinafter: the Region) will not be possible until the end of the century. Of course, this requires a large-scale political determination, an important part of which is the proper treatment of the proliferation issue. This decision may also be taken at European Union level, but given the current division in the Member States' relationship with nuclear energy it is more likely that regional decisions will be taken. In addition to this division, there is a trade-off between optimizing dimensions, i.e. minimizing the number of fuel reprocessing plants, and minimizing the fuel transport.

We analyzed how to manage the transition from thermal reactor to fast reactor power plants in the Region, where, by the middle of the century, 15-20 GW_e power will be provided by nuclear reactor units. They will start operating after 2030 and will be shut down at the end of the century or shortly thereafter. After that, either each pressurized water cooled reactor (thermal reactors) unit will be replaced by a fast reactor unit of the same capacity or a mixed fleet of pressurized water reactors and fast reactors units will exist.

A cardinal question is how to organize the transition to new fast-reactor power plants in terms of fuel supply. (Fueling the demonstration reactor is a separate and relatively easy question due to the small amount.)

Plutonium-containing fuel is necessary to operate the fast reactors. The secure use of plutonium in nuclear fuels is already demonstrated in several European countries where the so called MOX fuel is loaded in power reactors.

In the fast reactor power plants to be built, energy production may start (for about 6–8 years) using fuels from the reprocessing of spent fuel from pressurized water reactors. Spent fuel from fast reactors is then processed at a central reprocessing plant in the region. This plant would operate with a technology (currently under development) that separates plutonium and uranium from the high-level radioactive waste to be buried on the other. Minor actinides (Np, Am, Cm, Cf) present in the burned fuel will be also separated and burned in the fast reactors. Burning of minor actinides is a major step to reduce the long term radioactivity of the high-level radioactive waste,

The proliferation risk of the reprocessed mixture containing plutonium in our scenario is still acceptable (this is among the aims of the international developments). We note here that there is little or no need to use and enrich uranium while the minor actinides are burned continuously.

The scenario proposed above is one of the possible solutions. There are unresolved research and even political issues, but basically it enables the long-term, sustainable use of nuclear energy for the whole Region in a promising way. In order to materialize the scenario, a demonstration reactor must be built to prove the viability of the technology. This is the aim of the ALLEGRO project in the medium term together with the research on closing the fuel cycle.

ALLEGRO, the demonstrator of the Gas Fast Reactor

The attractive Gas-cooled Fast Reactor (GFR) concept aims to combine the benefits of fast spectrum and high temperature (up to 850°C), using helium as a coolant *(Poette et al. 2009; Stainsby et al. 2011)*. The high coolant temperature leads to target high energy conversion efficiency (43–48%) and opens the possibility for new applications of nuclear energy, by the direct utilization of the heat (metallurgy, hydrogen or synthetic hydrocarbon fuel production, etc.). The GFR concept aims to provide these new potentialities by affording a sustainable energy supply in the long term including minor actinides burning capabilities. In addition, the potential merits of the helium coolant regarding safety, in-service inspection, reparability, operability, and dismantling are acknowledged in spite of the long lead-time needed for the development of this new reactor type:

- no threshold effects due to phase changing,
- no chemical reaction,
- optical transparency,
- temperature measurement capabilities,
- inert and non-toxic,
- not activated.

Hopefully, these advantages will compensate for the safety problems caused by the lack of phase transition and for the technical problems caused by the leak of helium.

During the 1960s and through the 1980s, GFRs were being considered as an alternative to the mainstream, worldwide program development of the liquid-metal fast breeder reactor. These designs used technologies based on metal clad pins containing solid solution fuel; these were essentially sodium core designs that replaced the sodium coolant with helium, where the cladding was roughened (or finned) to enhance heat transfer during normal operation.

The GFR concept is clearly innovative, as no demonstrator has ever been built, and challenging because of the unusual thermal properties of the coolant. The key feasibility issue is to develop a fuel and clad technology able to withstand high temperature (in the range of 1000°C for the clad and 1300°C for the fuel on normal operation conditions). Innovative refractory materials are considered, leading to new phenomenology at very high temperature, regarding the core degradation (>2000°C).

For Gas Fast Reactor to become an industrial reality, a pre-requisite step is the designing and construction of a small, but real, nuclear reactor, named ALLEGRO. The role of ALLEGRO reactor is to demonstrate the GFR specific safety systems and to irradiate and qualify the innovative high-temperature fuel required for such reactors *(Zajac–Hatala–Darilek 2015)*.

The thermal power of the ALLEGRO reactor will not exceed 75 MWth. Though this relatively low power makes licensing somewhat easier, the demonstration of the GFR technology assumes that the basic features of an originally planned 2400 MWth or a Small Modular Reactor (SMR) of 100-200 MWth GFR reactor can be tested at ALLEGRO. Therefore, most of the main parameters of ALLEGRO, the GFR2400 and the SMR-GFR reactor must be similar.

The foundation of V4G4 Centre of Excellence

Central European members of the European Union, the Czech Republic, Hungary and Slovakia are traditionally prominent users of nuclear energy. They intend to use nuclear energy on the long run and besides the lifetime extension of their nuclear units, each country decided to build new units in the coming years. Poland, another country of this Region, recently decided to include nuclear energy in its energy mix, and therefore launched a nuclear program with the perspective of building four Nuclear Power Plants by 2030.

The nuclear research institutes of the Visegrád-4 (V4) region (ÚJV Řež a.s., Husinec, Czech Republic, EK-CER, Budapest, Hungary, NCBJ, Świerk, Poland and VUJE, a.s., Trnava, Slovakia) agreed to establish the V4G4 Centre of Excellence for performing joint research, development and innovation in the field of Generation-4 (G4) nuclear reactors. The new Association "V4G4 Centre of Excellence" was introduced to the public at the Hungarian Academy of Sciences on July 18, 2013.

The V4G4 could rely on the scientific support from the French CEA, which has the largest experience in fast reactors throughout the world and has developed, first, the concept of Gas Fast Reactor.

The aim of the V4 partners has been from the very beginning to host the construction and operation of the ALLEGRO gas-cooled fast reactor demonstrator in one of the V4 countries. The work has been supported by the Euratom several times within the 7th Framework and in the Horizon2020 Programs.

The preparatory work, called ALLIANCE Project, was launched in 2012 for three years *(ALLIANCE 2012)*. The project aimed at elaborating the preliminary safety report of the ALLEGRO design, also providing an overview on the governance and financial aspects.

One of the most important results of the ALLIANCE Project was the change of the design of the ALLEGRO reactor. The safety analysis within the project was complemented by the results of the European stress tests following the Fukushima events. The safety margin of the fuel cladding material chosen for the early design was rather low and could not provide the necessary protection against a Fukushima type accident. Therefore, a new strategy for developing the ALLEGRO was then prepared and accepted by the partners in 2015. In the new design the further reduction of the thermal power and the use of uranium-oxide instead of MOX are foreseen. The main blower inertia is increased *(Mayer 2020)*.

The new design parameters have been tested under the Euratom VINCO Project between 2015 and 2018 *(VINCO 2015)*. VINCO Project aimed at building capacities and financing specific R&D activities among the partners. Benchmarking exercises carried out allowed for the unification of simulation procedures in participant laboratories. Research procedures on nuclear technologies in V4 countries have been compared leading to better understanding, more precise definition of specializations and efficient structure of current and future research activities. Principles of cooperation and rules of access to existing and planned infrastructure have been developed.

The R&D activities related to the safety of ALLEGRO are also supported by the Euratom in the recently launched SafeG project (2020–2024). The project aimed at improving the safety of the ALLEGRO, review critically the Gas Fast Reactor reference options in materials and technologies and improve the collaboration with the relevant research teams in the EU and worldwide *(SAFEG 2020)*.

Concept of a governance and legal framework for Generation-IV reactors

In order to increase the competitiveness of industry branches relying on energy, the European nuclear industry should be able to produce fully operational Generation-IV nuclear power plants by the end of the 21st century. However, to achieve this goal, the legal and financial bases should be brought together with the scientific and industrial bases already at the beginning of the century.

At the moment the Generation-IV technologies are still in a pre-mature stage and it would be difficult to select with a good certainty the technology which will be found to be viable and industrially realizable from the point of view of safety, economics and public acceptance in the coming decades. The most important aim from the viewpoint of R&D&I is that by the years 2040–2060 a successful prototype should be created and its adaption for commercial purposes should be started.

In general, the very large demand for capital, the long recovery of expenditures and the difficulties of financing are peculiar to the nuclear industry. In its present state, the European nuclear industry has difficulties even in completing its current developments. According to our studies, it has a significant drawback compared to those countries of nuclear capabilities (e.g. South-Korea, Russia, China), where the domestic nuclear industry is fully or partly state owned. These countries are subsidizing the nuclear R&D activities, the utilization of developments and innovations of the industry in practice and even the commercial activities. Supporting the nuclear industry is a declared part of these countries' competitiveness strategy. On the market of nuclear power plants, in the last decade, these countries achieved leading positions, while the European competitors are at best in a stagnating position. Movements on the market of nuclear power stations render it probable that a vast number of newcomer countries are starting the utilization of nuclear energy, and that many countries with an existing nuclear program will continue or even widen their nuclear program.

Nuclear energy presently provides 30% of Europe's electricity. Nevertheless, some European countries possessing nuclear power plants intend to phase out nuclear energy or reduce the number of NPPs. This will further worsen the competitiveness of the European nuclear industry; losing the European markets may be the most painful effect for the leading European nuclear energy enterprises. At the same time the 2015 Energy Union Package stated that the EU should ensure that it maintains technological leadership in the nuclear domain. This is currently an impossible objective unless much more is done to advance key technologies within a European context.

The way-out from this controversial situation can be assumed only via harmonized R&D&I activities, common sales policy and unified behavior outside of the EU.

Evidently, the present structure, regulatory system, subsidy policy of the EU does not make possible the direct realization of the above vision. However, a new system of conditions can be elaborated by 2030, which could ensure the coupling of the European nuclear industry and the related R&D activities to achieve an enforced nuclear industry which is competitive at the world market. The re-generation and even the survival of the competitive European nuclear industry can be imagined only by joining of forces and common action of EU member countries. The Generation-IV developments may provide a good basis to create a new European competitiveness policy which is based on a transparent, controllable and fair model of regulation not causing disadvantages for any participant on the market. These conditions must entirely be fulfilled for the aim that each member country and industrial participant should contribute with satisfaction to call a new model into being. The new model to support competitiveness – above a certain limit of value – may be of use also for other branches of industry. The introduction of the new model supported with new subsidizing, competitiveness, taxation and public procurement rules seems to be the only way to achieve a situation where the new Generation-IV reactors appearing on the market can boldly be labelled: „DEVELOPED AND MADE IN EUROPE".

The existing legal and structural framework has to be made use of as much as possible for the practical realization of this concept. It is not necessary to invent a totally new logic as quite well-functioning models exist for other branches of industry. It is suggested to elaborate the new governance system and legal framework utilizing the experiences of the systems already existing and being in use:

- Joint Undertaking
- European Research Infrastructure Consortium
- Public and Private Partnership (PPP)
- Intergovernmental Agreements
- European Grouping for Territorial Cooperation (EGTC)
- European Economic Interest Grouping

The Double-pool system

The governance system and the legal framework outlined below are aiming at increasing the competitiveness of Europe. We endeavored to present the bases of such a framework which can be suitable to coordinate developments of exceptionally high value. The goal was to build up a model, through which the R&D domain could transparently be connected with the industrial area. The subsidies should be accessible for both spheres, and the nuclear industry enterprises in the member countries could take part in the creation of a pan-European product under equal conditions.

To accomplish the above aims it would be expedient to create a double system; on one branch of it the R&D participants would take place as an alliance, while the other leg of the project could be an industrial consortium. The two units should be concentrated in a common European enterprise which would finally manufacture and commercialize the product. This system can be conceived making use of the ideas developed for the ALLEGRO Project (related to the second, realization phase of the ALLEGRO Project after 2025).

The R&D pool

In the first pool research institutions carrying out R&D activities should belong. This formation should be a legal entity as it is the association V4G4 Centre of Excellence in the case of the ALLEGRO project. As it was discussed earlier, the association was founded to carry out the Preparatory Phase. It will dispose of the know-how of the experimental Generation-IV reactor to be built. In the new system, this pool would give the scientific basis for licensing and constructing the ALLEGRO reactor.

This first pool has to establish a mutually fruitful connection with a fuel factory which is able to supply fuel of the ALLEGRO reactor.

The cornerstone of realizing the ALLEGRO project is the financing. Detailed elaboration of the financing scheme of the project will be one of the determining tasks of the preparatory phase.

The investment can be covered from three different sources, as foreseen in the structure below:

- Contribution of the V4 and other interested member countries: prospectively they will have to provide a half of the sum, according to the following proportions: from the 50% (e.g. in the case of 4 countries) the host country of the demonstration reactor would cover 20%, the others 10% each of the total sum.
- Contribution of nuclear industry: as the final goal of the project is the demonstration and ultimately the commercial utilization of the technology, the significant contribution of the nuclear industry (e.g. 25%) is a pre-requisite in proving the potential in commercializing the product.
- Contribution of the European Union: though at present there are no means for the involvement of the European Union in the investment after 2030, and even the potentially available funding cannot be estimated, it is expected that somehow the EU will be able to be directly involved in the funding.

Key issues of financing the project are:

- the EU funds available for the V4 member states should be allowed to be used for financing the construction of the demonstration reactor,
- the financing by the nuclear industry should be legally possible.

Therefore, it is very important that the EU could prolong the supporting schemes (Structural Funds) available for the period of constructing the ALLEGRO reactor. The V4G4 Centre of Excellence should identify further financial sources. It is suggested to analyze the following frameworks as potential sources of financing the realization phase of the ALLEGRO project:

- EURATOM loans
- Horizon 2020-like programs
- EER/NER300
- EU Cohesion Policy
- European Investment Bank
- Joint Undertaking

The governance system of this pool may coincide with the model used for the Preparatory Phase of the ALLEGRO project. The members of the project could take part in managing the European Joint Enterprise through the Steering Committee of the V4G4 Centre of Excellence association to be established and owned by the two pools.

The legal framework established in the ALLEGRO project may serve as a legal framework of the first pool.

The industrial pool

The interested companies of the nuclear industry would belong to the second pool. Development of a Generation-IV nuclear reactor is inconceivable without the extensive participation of the nuclear industry. However, it should be admitted that today no single company would alone be able to finance the design and construction of a Generation-IV reactor. Therefore, in order to enhance the competitiveness of the European nuclear industry, it would be expedient to establish a common pool with the support of the EU and its member states, making use of investments by industrial participants, which with united forces could hold its ground on the industrial side and realise the Generation-IV reactor conceptually designed by the first pool.

It should be made possible for each, preferably state-owned (or partly/indirectly state-owned) enterprise registered in any of the member states, to take part in the second pool. Ownership of the state provides a warranty that the know-how created by the first pool should remain in the property of member states. The involvement of the states provides significant control possibilities for the EU. The EU can strictly supervise this legal entity in respect of both the competition law and also the subventions from the states.

In the case of the ALLEGRO project the European participants of the nuclear industry may be members of the second pool. In the realization phase of the ALLEGRO project these industrial participants could share among each other the design and manufacturing of large components. Today it is hard to conceive that the competitors would join their forces to build an experimental reactor. The idea could be still digestible taking into consideration the successful development of a pan-European reactor type would almost guarantee significant jobs with the new Generation-IV NPPs to be ordered both in Europe and at the world market.

This concept obviously contradicts the present regulations in respect of state subsidies. However, it seems to be an attractive goal to establish those forms of supports and subventions which allow the member states to initiate highlighted projects based on subsidies allocated dedicatedly to the relevant companies. If projects which are aiming at realizing the jointly determined goals of the EU, with big capital demand, long developing time but promising big profits could be supported both by the EU and also directly by the member states, then the European nuclear industry and the EU itself as an economic entity will join the group of economically successful industries and countries. The governance system of the second pool should be settled by the members.

The Joint European Enterprise

The two pools cannot work separately because the aim is to couple the R&D and the industrial players. A supporting scheme that would subsidize both pools with the same technique is unimaginable. Therefore, it seems to be advisable to create a legal system which would permit the use and commercialization of research and industrial results achieved by the two pools by one legal entity. In the case of a nuclear project this enterprise could fulfil the position of the Licensee of the experimental nuclear installation needed as a technology demonstrator or a prototype before the product reaches final maturity.

Technically, the joining of the two pools could be carried out in a new form of enterprise (incorporated company). Taking the ALLEGRO project as an example, the R&D pool could acquire property in the company by bringing into the business the relevant know-how, while the basic capital would be provided by the industrial pool.

Conclusion

The support of the current fleet and more particularly the extension of their life operation with the highest level of safety remains the first priority for nuclear research organizations like the four founding members of the V4G4 Center of Excellence. To prepare the future, their main objective is the development of the 4th generation of nuclear reactors based on fast neutrons. This new generation of nuclear reactors will meet the objective of a sustainable nuclear energy, based on the highest safety standards.

An experimental reactor is an essential step to establish confidence in the innovative GFR technology. The proposed experimental reactor ALLEGRO would be the first ever gas cooled fast reactor to be constructed. The objectives of ALLEGRO are to demonstrate the viability and to qualify specific Gas Fast Reactor technologies such as fuel, the fuel elements, helium-related technologies and specific safety systems.

The successful realization of such an innovative technology requires the involvement of the nuclear industrial partners. The efforts made in R&D&I will only be of any use if the European industry can utilize them. Consequently, the general legal framework has to be basically renewed along this or similar ideas since competitiveness of EU certainly remains a target issue.

References

ALLIANCE (2012) Preparation of ALLEGRO – Implementing Advanced Nuclear Fuel Cycle in Central Europe. ALLIANCE Project. https://cordis.europa.eu/project/id/323295

Gadó, J. Bělovský, L. Hatala, B. Vasile, A. Wrochna, G. (2017) The ALLEGRO experimental gas cooled fast reactor project. The International conference on fast reactors and related fuel cycles: next generation nuclear systems for sustainable development, Book of abstracts, International Atomic Energy Agency (IAEA), p. 448.

GIF (2000) Generation IV International Forum. https://www.gen-4.org/gif/jcms/c_59461/generation-iv-systems

INPRO (2000) International Project on Innovative Nuclear Reactors and Fuel Cycles (INPRO). https://nucleus-new.iaea.org/sites/inpro/Pages/home.aspx

Mayer, G. (2020) Hot duct break transient with two- and three-loop ALLEGRO models. Nuclear Engineering and Design, Vol. 370. 110911. DOI: https://doi.org/10.1016/j.nucengdes.2020.110911

Poette, Ch., Brun-Magaud, V., Morin, F., Pignatel, J.-F., Stainsby, R., & Mikityuk, K. (2009) Allegro: The European Gas Fast Reactor Demonstrator Project. International Conference on Nuclear Engineering, Proceedings, ICONE. 2. DOI: https://doi.org/10.1115/ICONE17-75326

SAFEG (2020) Safety of GFR through innovative materials, technologies and processes. SafeG Project. https://cordis.europa.eu/project/id/945041

Stainsby, R., Peers, K., Mitchell, C., Poette, Ch., Mikityuk, K. & Somers, J. (2011) Gas cooled fast reactor research in Europe. Nuclear Engineering and Design, 241. 3481–3489. https://doi.org/10.1016/j.nucengdes.2011.08.005

VINCO (2015) Visegrad Initiative for Nuclear Innovation. VINCO Project. https://cordis.europa.eu/project/id/662136

Zajac, R., Hatala, B., & Darilek, P. (2015) Overview of ALLEGRO project. In: Vajda, J. & Jamnicky, I. (eds.) Proceedings 21 International Conference on Applied Physics of Condensed Matter and of the Scientific Conference Advanced Fast Reactors (p. 400). Slovakia: Slovak University of Technology