2021 International Nuclear Atlantic Conference – INAC 2021
Virtual meeting, Brazil, November 29 – December 2, 2021

ISBN: 978-65-594-1256-3

Overview and current perspectives for the use of the GFR reactor in research and electricity generation in Brazil.

F. Romano[1], P. Celestino[2], G. Barraviera[3], P. Silva[4]

[1]*fernando.romano@usp.br*
[2]*pedrocelestino@usp.br*
[3] *guibarraviera@usp.br*
[4]*paula.mendes1994@gmail.com*

1. Introduction

Nuclear reactor designs began their development in the 1940s and are categorized into generations. Up to the present day, only the Generation I, II and III reactors have come into full operation. However, the most widely used ones today are Generation II. In addition, Generation IV reactors are being developed (GU, 2018).

There are several characteristics that encouraged research to improve the nuclear reactor models, which we can mention: cost-effectiveness, safety, non-proliferation, adequacy of the network, marketing script and fuel cycle. With the incorporation of new technologies that improve the listed attributes, new generations are developed. Nuclear technology gradually becomes more attractive with each new generation implementation, favoring research for its improvement (PIORO; KIRILLOV, 2013).

In this way, a group of countries, including Canada, Russia, Japan and the USA, came together to develop a new nuclear reactor generation, Generation IV. The main project objective is to improve the reactor's thermal efficiency, which currently remains around 30-36% to a level close to 50% (GOLDBERG; ROSNER, 2011).

Given that most models are still in the improvement phase, it is expected that some Generation IV reactor models will already be commercially available from 2030 onwards. Thus, it is worth emphasizing the importance of monitoring the Generation IV reactors evolution, as well as studying which model is best suited for use in the Brazilian energy matrix.

In July 2001, Brazil became a framework member for international cooperation in research and development for the next generation of nuclear energy systems, known as the Generation IV International Forum (GIF). However, to this day, Brazil remains a non-active member, as it does not participate in any ongoing project to improve systems, nor has it even signed a memorandum of understanding to start its active participation (GIF, 2020).

In 2002, GIF selected the six most promising systems from nearly 100 concepts such as Generation IV systems. In this article, we will emphasize the Gas-Cooled Fast Reactor (GFR), in view of the characteristics that make it very attractive for a feasibility check for its implementation in Brazil. The fact of maximizing the fuel use, together with the possibility of using the thermal energy produced for other purposes, such as hydrogen cogeneration, make it particularly exciting. Thus, we can see the advantages that its incorporation could bring to the national scene, both in terms of energy production and in the waste reduction that can degrade the environment (GOLDBERG; ROSNER, 2011).

2. Methodology

Literature of the last 20 years (2001–2021, both included) dealing with the development of nuclear reactors generation IV was collected following GIF docs and guidelines. Different databases were checked including WNA, EPE and GIF resources, WOS and Scopus. Keywords included Gas-cooled Fast Reactor, GFR, Generation IV, GIF, Fast Neutron Reactor. Criteria for eligibility were: (i) detailed information about GIF, and specifically, from GFR type; (ii) abstract written or translated in English; and (iii) publication between 2001 and 2021, inclusive. Criteria for exclusion were: (i) studies focused on other type reactors not generation IV.

3. Results and Discussion

GFR technology will potentially minimize the production of long-lived radioactive waste, making possible the usage of fissile and fertile materials (including depleted uranium) about a hundred times more efficiently than thermal spectrum systems. Despite the great promise of GFRs, so far these systems have not been deployed and operated. Further investment in research and development would still be needed to advance GFR technology to the prototype level in order to demonstrate its performance characteristics and commercial viability.

One of the most perceived economic advantages means its promise to operate at high power densities. Helium-cooled GFRs have an advantage of using chemically inert single-phase gas to interact with neutrons, although they have high mobility, which is a technological challenge to be solved. The challenges of using helium are being addressed and resolved not only in GFR programs, but also in high temperature reactor (VHTR) programs. Specifically regarding the reactor core design, a ceramic fuel concept has been chosen. This fuel must have good thermal conductivity in order to obtain an average core exit temperature of 850 ◦C (for high energy conversion efficiency). In addition, the maximum fuel temperature should be around 1500 ◦C, as the (U, Pu)C fuel employs SiC coating and has a low pressure drop in the core (in order to facilitate the removal of heat from decomposition) (WEAVER, 2004).

The GFR system combines the advantages of fast spectrum systems for the long-term sustainability of uranium resources and minimization of waste, through multiple fuel reprocessing and actinide fission with those of high temperature systems (high thermal cycling efficiency and industrial use of generated heat). The GFR neutron spectrum is considered the most promising among fast spectrum systems for recycling all actinides including plutonium produced in LWRs and smaller actinides.

For maximizing the fuel usage in conjunction with the high thermal energy produced, it becomes quite interesting for hydrogen cogeneration, making it particularly exciting for deployment. The high coolant temperature, providing high thermal cycling efficiency enables the hydrogen production, also with other industrial sub products.

Key challenges for GFR's research and development efforts include the design of the reactor core, the helium turbine, the new fuel to be applied, the fuel cycles; of the materials used in its structures capable of operating at temperatures of 850 °C, and a full optimization especially in relation to the consequences of cooling with a high pressure gas with poor thermal characteristics, in addition to a lot of focus on system safety.

According to the Roadmap GIF (2014) the main challenges fall over the development of structural materials such as coating, reflector, guides and controls, among others, capable of withstanding neutron damage speeds associated with high operating temperature ranges. The main disadvantages or areas that still need a technological solution refer to a higher pumping power compared to liquid cooled reactors and the need to maintain the system pressure at high levels, with around 7 MPa for helium and 25 MPa for supercritical CO2.

The 2014 Technology Roadmap update confirmed the selection of those six fast reactor systems and reassessed their Technology Readiness Level (TRL) technology maturity levels. The GIF recognizes the benefits of fast neutron systems with a closed fuel cycle and, of the four fast spectrum systems, the SFR and LFR concepts are clearly the most advanced in development status (GIF, 2019b).

The GFR concept is currently in the project feasibility study phase and does not present strong practical results.

The experimental reactor (ALLEGRO) is in the advanced stage of development at final steps, and the licensing process has been started.
EPE's 2019 Ten-Year Energy Expansion Plan points out nuclear generation as a technically viable resource, which does not emit greenhouse gases (GHG) and which can play a strategic role for the country from the point of view of development technological and national sovereignty. Section 3.5 shows the conclusion of an extensive study carried out by Eletronuclear in cooperation with COPPE/UFRJ, which identified 40 large areas technically suitable for the installation of new nuclear power plants. Finally, some measures that should be taken to prepare the nuclear sector for the expansion of this option in the Brazilian Electric Sector were presented, among which it is worth mentioning (EPE, 2019):

- Further deepening of the criteria, targeting new potential areas for locating future nuclear power plants;
- Government's decision of which sites should be developed, seeking greater detail in the information;
- Survey of information, aiming at proving (or not) the location eventually selected;
- Start of environmental licensing, among others.

Concomitantly with the study of areas for the implementation of new nuclear power plants, there is fundamental importance that Brazil starts its active participation in the development of Generation IV nuclear reactors. For this, there are some strategies that can help, such as signing the GIF framework agreement, established in 2005. In this agreement, its parties formally undertake to participate in the development of one or more systems of the so-called fourth generation. Another way to participate more actively is by signing a "Memorandum of Understanding" (MOU), seeking partnerships for the development of technologies of greatest interest to Brazil.
Brazil recently converted the fuel from the IPEN/MB-01 reactor to plate-type fuel. In other words, Brazil has some experience in developing that type of fuel element, choosing plates instead of silicon carbide rods. However, there is still no background in the national fuel development (Pu, U)C with Si-C coating, which would be a great technological difficulty to obtain in a short or medium period of time.
The participation of fast neutron reactors (FNR) in the energy matrix is still small; however, the amount of this type of reactor in development is remarkable. There is still a big paradigm to be broken regarding the use of FNR reactors for the production of electricity. However, as new Generation IV reactor technologies consolidate as safer, more reliable, economically competitive reactors, promoting resistance to nuclear proliferation, and meeting the various sustainability criteria, they will undoubtedly have all the necessary elements to replace current thermal reactors in the generation of electricity worldwide.

4. Conclusions

Despite of Allegro project demonstrations generation IV reactors are mostly on a theoretical basis still inquiring heavy research investments for solving some structural project weaknesses. Nevertheless, the number of fourth generation reactors is still insignificant, compared to the total number of thermal reactors in operation, it has been remarkable that a large amount of research and development that has focused on fast neutron reactors, in recent years, had a deep employment to. Regarding the GFR, there is still pending research and development for a commercial reactor with this technology to start operation, although loosing and sharing other interests for generation 3.5.
Among the six technologies currently under development by GIF, four include the cogeneration of hydrogen, a topic of high relevance in Brazil. Large H2 production plants are under construction in the national territory and are, by their nature, abundant consumers of electricity.
During this work, the advantages that this technology will bring to the global energy matrix were presented. Before the GFR can be implemented in Brazil, it is important that projects, such as ALLEGRO, can have their theoretical proof demonstrated, and mainly, with respect to safety aspects, in addition to being, in addition to being economically competitive.

Brazilian research institutions in nuclear science have made considerable progress in different areas, such as the conversion of the reactor fuel IPEN/MB-01. Even so, the National Nuclear Safety Authority (ANSN), the new regulatory body for the Brazilian nuclear sector, would be responsible for licensing the GFR in Brazil and would certainly have numerous difficulties in licensing a completely new technology. However, benefits arising from partnerships with countries that are already commissioning ALLEGRO, and later, with the licensing of the first commercial power plants with Generation IV reactors, more specifically, of the GFR type, could bring the necessary knowledge to license this technology in Brazil.

Brazil has little, if any, experience in gas-cooled reactors. Therefore, the search for international institutions to improve the GFR is, without a doubt, a path that would significantly shorten its implementation schedule. Nevertheless, and perhaps being the most relevant decision in favor of the implementation of fast reactor technology in Brazil, its adherence to the GIF Framework Agreement is of paramount importance for the production of this technology in our society.

However, this race is about a great dispute for patents and for the domain of technology, aiming at the subsequent world trade. Therefore, no matter how much Brazil signs the GIF collaboration agreement, or any other agreement for the development of one of the fourth generation technologies, it is necessary to be aware of the financial risk that this would entail. Projects of this magnitude tend to dominate only a small portion of the total technology chain, which may restrict its viability. However, we know that investments of great magnitude are strategic decisions, which imply the planning of national development, often being decisions of a political nature, not necessarily in favor of science.

Acknowledgements

Here I express my thanks to PhD Luis A. A. Terremoto and PhD Guilherme Zahn, both from IPEN/CNEN, for their support in preparing the work on the topic and for suggestions received.

References

[1] GU, Z. History review of nuclear reactor safety. Annals of Nuclear Energy. vol. 120, pp. 682-690, 2018.

[2] PIORO, I.; KIRILLOV, P. Generation IV Nuclear Reactors as a Basis for Future Electricity Production in the World. Materials and processes for energy: communicating current research and technological developments. pp. 818-830, 2013.

[3] GOLDBERG, S. M.; ROSNER, R. Nuclear Reactors: Generation to Generation. Cambridge: American Academy of Arts & Sciences, 2011.

[4] GENERATION IV INTERNATIONAL FORUM (GIF). Parties to Gif Framework Agreement and System Arrangements. Gen IV International Forum, 2020. Available in: https://www.gen-4.org/gif/jcms/c_40369/framework-agreement.

[5] WEAVER, K. D.; STERBENTZ, J.; MEYER, M.; LOWDEN, R.; HOFFMAN, E.; WEI, T. Y. C.; Gas-Cooled Fast Reactor (GFR) Fuel and In-Core Fuel Management, 2004. International Joint Meeting Cancun 2004 LAS/ANS-SNM-SMSR.

[6] EMPRESA DE PESQUISA ENERGÉTICA (EPE). Plano Decenal de Expansão de Energia 2029. Brasília: Ministério de Minas e Energia, pp.382 (2019). Available in: <https://www.epe.gov.br/pt/publicacoes-dados-abertos/publicacoes/plano-decenal-de-expansao-de-energia-2029>. Accessed on: 22 abril 2021.