



# Very High Temperature Reactor (VHTR) – A proposal to Generation IV Reactors

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## 1. Introduction

The aim of this article is the assessment of the Very High Temperature Reactor (VHTR), one of the Generation IV reactors that have listed possible technological routes for a future of nuclear energy generation based on fissile material, including safety requirements, nuclear energy efficiency and less waste generation. The VHTR concept is presented through the exploration of its technology, possibilities, obstacles, as well as the challenges to overcome, for a promising viable source of thermonuclear generation. Currently, reactors in operation all over the world are considered second or third generation systems; first generation systems have been discontinued some decades ago and are no longer used.

Hydrogen production is also a standard quest in VHTR research, as this is a disruptive new energy source [2].

## 2. Methodology

Since the creation of the Generation IV International Forum (GIF), in 2000, many different studies of these reactors have been published [1][3]. This paper comprises a wide literature research not only of the VHTR concept and Generation IV reactors, but also the technology and physics of a nuclear reactor operation to describe the VHTR reactor, in terms of historical context, proof of concept, advantages, disadvantages and its implementation effort.

A bibliographic search was carried out in this study, providing a range of sources dealing with the subject as a whole. Authors around the world were read, stating a comprehensive compendium of historical and forward-looking information about possibilities and challenges.

## 3. Results and Discussion

The VHTR set consists of a reactor, an external intermediate heat exchanger, a refrigerant gas circulation system with an external heat exchanger, operating as a source of heat for the hydrogen production plant and a gas turbine, for electricity generation [5]. The reactor has graphite as a moderator and uses helium gas as a refrigerant. The outlet temperature provides its application in secondary industrial processes, such as the

production of hydrogen, desalination of sea water or producing heating for the population.

The technology designed for the VHTR concept uses processes without the emission of greenhouse gases and with production of carbon-free hydrogen [7][8][9], leading to the possibility of obtaining this important source. The production of nuclear hydrogen is achieved, then, as a valuable technology for complementing renewable energies.

The VHTR, as a thermal reactor, has the ability to apply heat in industry processes, used as a thermal source in processes for refineries, petrochemicals and metallurgy, replacing fossil fuel applications [7][10].

The graphite used as a moderator in the VHTR reactor, in addition to having great thermal inertia, absorbs additional heat, even in the hottest fuel element. It also offers the advantage that it can be recycled [10][11][13]. The reactor has the potential for inherent safety, high thermal efficiency, low operating/maintenance costs and modular construction.

The VHTR has a negative temperature reactivity coefficient too, which serves to suppress fission power in the event of accidents. There is flexibility in fuel usage [9][12]; the VHTR can support alternative fuel cycles, such as U-Pu, Pu, MOX U-Th. The VHTR has versatility not only in the use of fuel, but also in the energy conversion unit.

In addition to the challenges inherent in the processes involving 4th generation nuclear reactors, safety control issues arise when associated with thermal behavior. In this regard, two points must be considered: (1) maintaining the pressure limit of the reactor core; (2) preventing explosions and contamination [14]. The temperature above 1000 °C at the gas outlet, by itself, poses a great technological and safety challenge [4][15].

Reactors that work with the concept of High Temperature - HT, in general, must follow the safety protocols, using low power of the core, so the heat is passively released to the environment, without harming the fuel or even radioactive material during accidents. The reactor size and core configuration are designed to ensure that the core has a relatively small diameter, to assist in the shortest path from within to the vessel [16]. Engineering challenges lie here.

Metal components exposed to core conditions may be susceptible to failure. Valves, rods, tubes and connectors would be the most vulnerable, which can cause core depressurization, which does not represent great damage in relation to the fuel; however, it can provide the circulation of fission products.

The metal alloys used in the construction of high temperature reactor plants, currently available, determine the maximum temperature limit of the VHTR (700-950 °C), which implies a demand for research and superalloy projects, which are more resistant and less subject to failures [17].

The project also requires other materials that operate at higher temperatures and neutron fluxes than experiments in previous nuclear processes. The high temperatures and neutron fluxes of a VHTR represent a complex interaction between radioactive damage, diffusion phenomenon and direct chemical reactions. The development of structural components and refrigeration systems are essential for the operation of a VHTR [14].

Considering the long-term implementation, some challenges and R&D keys for an operational VHTR system, in the next 10-15 years, are here mentioned [18].

- Completion of the fuel test and qualification capacity (including manufacturing, irradiation, safety test and PIE (Post-Irradiation Examination)).
- Qualification of graphite; hardening of graphite against air and water ingress; also waste management of this material.
- Coupling technology and related components.
- Establishment of design codes and standards for new materials and components.
- Advanced manufacturing methods (cross cutting challenge).
- Cost reduction.
- Licensing and location.
- Integration of the system with other energy carriers in hybrid systems.
- Exchange with several startups, private investors and new programs.
- Safety demonstration tests and coupling to the hydrogen production plant.

#### 4. Conclusions

The study sought to map the perspectives of nucleoelectric generation in terms of a new paradigm of its production; obtaining a new disruptive technological concept. Generation IV became known as a scientific forum, which seeks advancement in terms of economically viable technologies to scale production [6]. In this context, routes have been studied, in order to establish, in years to come, which ones will be more promising.

Generation IV reactors are a set of theoretical nuclear reactor projects, which are still being researched; most of the projects will be made available for commercial use, initially, with construction scheduled for the 2030s. In relation to the nuclear energy currently used, the benefits of 4th generation reactors will be: sustainability; increased security; better use of nuclear fuel; high efficiency; greater savings; minimal waste in production; ability to consume existing nuclear waste in the production of electricity [4].

During the beginning of generation IV work, many reactors were speculated; however, the list was shortened; therefore, there is a focus on most promising technologies and those that had the potential to meet the forum initiative's objectives. Certainly, VHTR is a promising one; in terms of new researches; considering disruptive and feasible technologies. Ones that can even bring spinoffs to the industry as a whole.

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