Progress in Nuclear Energy 85 (2015) 156–163

Contents lists available at ScienceDirect

Progress in Nuclear Energy

journal homepage: www.elsevier.com/locate/pnucene

The design and utilization of a high-temperature helium loop and other facilities for the study of advanced gas-cooled reactors in the Czech Republic

Jan Berka [a, b, *], Tomáš Hlinčík [b], Ivan Víden [b], Tomáš Hudský [b], Jan Vít [a]

[a] Research Centre Rez, Hlavní 130, 25068 Řež, Czech Republic
[b] Department of Gas, Coke and Air Protection, University of Chemistry and Technology Prague, Technická 5, 16628 Prague 6, Czech Republic

A R T I C L E I N F O

Article history:
Received 12 March 2015
Received in revised form
28 May 2015
Accepted 1 June 2015
Available online xxx

Keywords:
Helium experimental loop
High temperature reactor
Gas fast reactor
High temperature materials

A B S T R A C T

This paper focuses on the research infrastructure of advanced gas cooled reactors in the Czech Republic, particularly on the high-temperature helium loop HTHL, which is a unique facility of its kind. HTHL is intended mainly for testing structural materials. It also can be used to research technologies relating to helium coolant. The maximum temperature and pressure that can be used within the specimen testing space are 900 °C and 7 MPa, respectively, and the maximum gas flow rate in the main loop is 38 kg/hr. Originally, the equipment was envisaged as a device for corrosion tests of materials in the reactor LVR-15 but, according to current plans, a different equipment will be built for this purpose within the frame of the SUSEN project. At the same time, an additional helium loop (S-Allegro) will be built to test selected components of advanced gas-cooled reactors.

1. Introduction

Advanced nuclear reactors of the so-called Generation IV reactors should be more efficient in transforming heat energy to electricity; they should better utilize nuclear fuel, produce less radioactive waste and maintain a high degree of safety. Some types should allow the direct utilization of process heat (for example in the production of hydrogen). For these reasons, different kinds of coolants than those used in today's most common reactors are needed for Generation IV reactors. At the same time, an increase in the working temperature of the coolant is under consideration (A technology roadmap, 2002).

Most of the Generation IV reactors are conceived as reactors that use fast neutrons to sustain the fission chain reaction. These so-called fast reactors allow for the production of fissile material (e.g. from the spent fuel from conventional nuclear reactors). Generation IV reactors are not yet in operation and their commercial application is expected no sooner than 2030. Currently, these systems are the subject of research and development at the international level (Locatelli et al., 2013).

The worldwide representation of individual nuclear reactors is shown in Fig. 1. The most frequent type is a light water pressurized water reactor (PWR) (PRIS database, 2013).

According to the database IAEA – PRIS (PRIS database, 2013) there are a total of 15 gas-cooled reactors (GCR) in operation in the year 2013. These are AGRs (Advanced Gas Reactors) cooled by carbon dioxide and moderated by graphite. These reactors are located in the UK. Besides the reactors cooled by carbon dioxide, countries such as Germany and USA have worked on a design of high-temperature reactors cooled by helium (so called High Temperature Reactor – HTR or High Temperature Gas Reactor – HTGR). Research reactors of this type and demonstration power plants were built in these countries. High temperatures of coolant characterize these reactors. In demonstration power plants the coolant maximum temperature is 775 °C; in research reactors the coolant temperature may reach up to 950 °C (Wright et al., 2012; Shimizu et al., 2014). The HTR demonstration power plants are no longer in operation and only two research reactors are operated in the world, one in China and one in Japan. Construction of a demonstration HTR power plant was started in 2013 in China. It is the so-called HTR-PM High Temperature Reactor Pebble Bed Module with an electrical output of 200 MW. HTR and VHTR reactors are characterized by a high degree of passive safety especially by their low heat load on the reactor core. The risk of reactor core melting is said to be avoided even when the coolant leaks (Zhang et al., 2009).

* Corresponding author. Research Centre Rez, Hlavní 130, 25068 Řež, Czech Republic
E-mail addresses: jan.berka@vscht.cz, jan.berka@cvrez.cz (J. Berka).

http://dx.doi.org/10.1016/j.pnucene.2015.06.003
0149-1970/

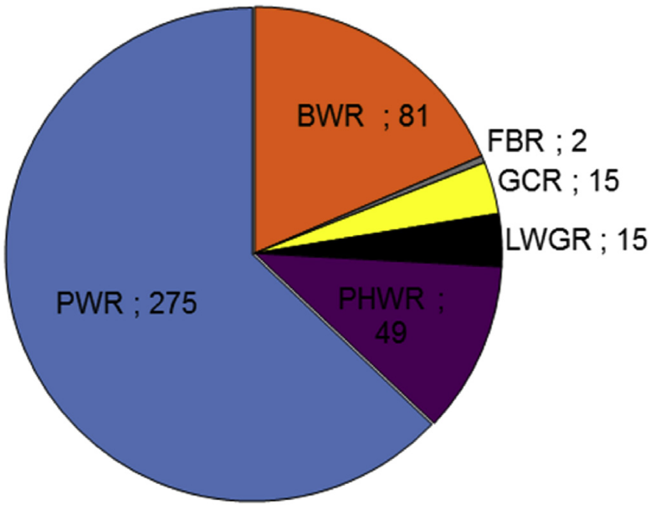

Fig. 1. Representation of individual types of nuclear reactors. Description: PWR – light water pressurized water reactor; BWR – light water boiling water reactor; FBR – fast breeder reactor; GCR – gas-cooled reactor; LWGR – light water graphite reactor; PHWR –pressurized heavy water reactor (PRIS database, 2013).

The Generation IV nuclear reactors also include a group of six new types of gas-cooled reactors. These facilities are not yet operational. Research and development on them is done mostly at the international level. Two basic types of gas-cooled reactors are being investigated: Very High Temperature Reactors (VHTR) and Gas Cooled Fast Reactors (GFR). The VHTR uses helium as a coolant and is moderated by graphite with thermal neutron spectrum (see Fig. 2).

The coolant temperature at the exit from the reactor core should reach up to 1000 °C. At these high temperatures the coolant can be used not only to produce electrical energy, but also directly in technological processes – so-called cogeneration or tri-generation. The coupling of cogeneration with gas-cooled reactors is being considered for advanced methods of hydrogen production using thermochemical cycles (e.g. iodine–sulfur cycle) or high temperature electrolysis. Another possibility is the direct use of heat generated by the nuclear reaction in a high temperature reactor for coal gasification. The efficiency of these processes is directly proportional to the temperature. It is therefore desirable to work at a high coolant temperature. Some VHTR designs place the turbine into the primary cycle to maximize the efficiency of the electrical energy production (this solution has not yet been tried for gas-cooled reactors). The VHTR project builds on the above-described high-temperature reactors HTR (Kelly, 2014).

Research and development related to VHTR focuses on several areas. The most important areas include the research of structural materials and their long-term resistance at the extreme conditions of the coolant, development of fuel and fuel cycle, design of certain components (e.g. intermediate heat exchanger), development of gas turbines, issues of reactor safety, and direct utilization of process heat in technological processes (Garcia et al., 2014).

The Gas-Cooled Fast Reactor (GFR), see Fig. 3, differs from the VHTR mainly by the spectrum of neutrons used to fission reaction in the fuel and by the unit heat load on the reactor core. Contrary to VHTR, the reactor core of GFR does not contain graphite, which can influence the content of minority chemicals (impurities) in the coolant. It is desirable that the coolant temperature in GFR reaches values high enough to utilize heat directly in technological processes.

The fast spectrum of neutrons should enable the production of new fissile material, for example from spent nuclear fuel or from depleted uranium.

As of yet, no country has been able to build an operational Gas-Cooled Fast Reactor. A number of technical problems concerning structural materials, the physics of the reactor, safety, etc. hinder the GFR development (Stainsby et al., 2011). Melted metals are used to cool all fast reactors developed so far.

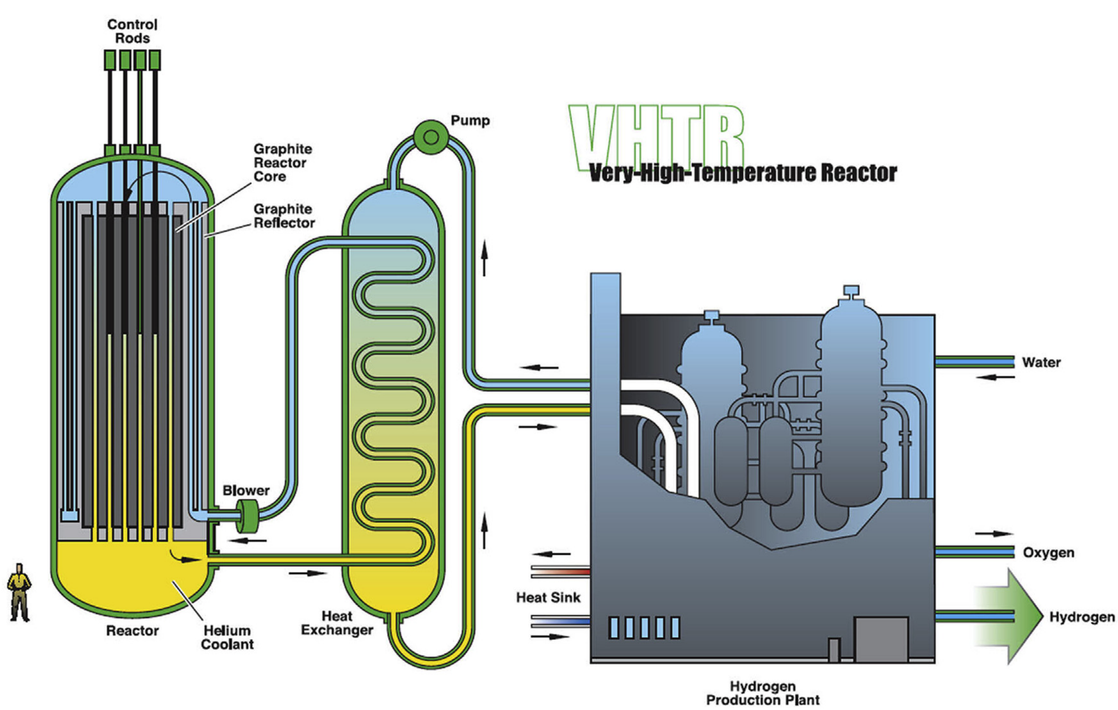

Fig. 2. Diagram of the very high temperature reactor (VHTR) (A technology roadmap, 2002).