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Application of nuclear energy for environmentally friendly hydrogen generation

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Abstract

It is universally admitted that hydrogen is one of the best energy media and its demand will increase greatly in the near future. However, little hydrogen exists naturally, so that how to generate hydrogen without bringing forth much CO_2 will be very important research subject. Hydrogen generation from water using nuclear energy is one of the solutions for this problem. Especially, the high temperature gas cooled reactor (HTGR) has a possibility to generate hydrogen economically compared with other types of nuclear reactors. As for long-lived radioactive waste to be generated by nuclear reactors, it is expected to significantly reduce its burden to the human environment by applying transmutation technologies. This report describes the feature of the hydrogen generation with HTGR and the development of the accelerator-driven subcritical system to reduce radioactive waste ongoing at JAEA.

Keywords: Hydrogen generation; Nuclear energy; High temperature gas cooled reactor; IS process; Radioactive waste; Accelerator-driven subcritical system

1. Introduction

It is universally admitted that hydrogen is one of the best energy media and its demand will increase greatly in the near future, because it can be used as clean fuel in a variety of energy end-use sectors including the conversion to electricity without CO_2 emission, and also can be stored and transported over long distance with lower loss compared to electricity. If hydrogen is produced with nuclear energy, it could much contribute to the solution of the global warming issue.

A high temperature gas-cooled reactor (HTGR), which provides high-temperature heat at above 900 °C, can generate hydrogen economically without CO_2 emission. In particular, the high temperature engineering test reactor (HTTR), the first HTGR in Japan, was constructed at Oarai Research and Development Center of Japan Atomic Energy Agency (JAEA), with the reactor outlet temperature of 950 °C being achieved in April, 2004. Since hydrogen generation from water is considered as an ideal method for hydrogen generation using the HTGR due to no CO_2 emission is expected from the system, JAEA has been conducting R&D on the thermochemical Iodine–Sulfur (IS) process for hydrogen generation process by water splitting. IS process utilizes plural chemical reactions and works like a chemical engine to generate hydrogen by absorbing high-temperature heat from HTGR. Continuous hydrogen generation by IS process was successfully achieved for the first time in the world, using a bench-scaled apparatus in August, 2003. The R&D program on hydrogen production with HTGR has been carried out at JAEA from January in 1997 as a study consigned by Ministry of Education, Culture, Sports, Science and Technology (MEXT) of Japan.

As for long-lived radioactive waste generated by nuclear reactors, it has been proposed and eagerly studied to transmute minor actinides (MA) and long-lived fission products (LLFP) into stable or short-lived nuclides by means of accelerator-driven systems (ADS). By applying new technologies, it is expected to significantly reduce the load to the human environment caused by long-lived radioactive nuclear waste.

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2. Activities on hydrogen generation in Japan

The current society depends on the fossil energy, and it causes the issues on global warming, acid rain etc. To mitigate the issues, the Japanese government has been conducting R&D on hydrogen energy. For example, the WE-NET (World Energy NETwork) project was carried out to develop technologies on hydrogen generation, hydrogen use such as a fuel cell and a hydrogen combustion turbine, transportation and storage, a hydrogen station, etc. Now, the JHFC (Japan Hydrogen & Fuel Cell Demonstration) project is underway. The project consists of the fuel cell demonstration program, included in the support project for "empirical and other research on solid high-polymer fuel cell systems" under the auspices of the Ministry of Economy, Trade and Industry, and the demonstration study of hydrogen fueling facilities for fuel cell vehicles.

Fig. 1 shows the prediction of hydrogen demand for fuel cells in Japan. The target of introduction of fuel cell vehicles is 50 thousand by 2010, 5 million by 2020 and 15 million by 2030. The target of stationary fuel cells for residence use is 2.1 GW by 2010, 10 GW by 2020 and 12.5 GW by 2030. Each hydrogen demand is predicted to be 6 billion Nm^3 in 2010, 28.3 billion Nm^3 in 2020 and 46 billion Nm^3 in 2030, respectively. Hydrogen is generally generated from carbonized hydrogen and oxidized hydrogen, namely fossil fuel and water because little hydrogen exists naturally. Accordingly hydrogen is decomposed from fossil fuel or water by providing much energy such as heat and electricity. Then, how we can generate a large amount of hydrogen economically and reduce CO_2 emission simultaneously? Hydrogen generation with nuclear energy is one of the solutions for this question. In Japan, the Basic Plan for Energy Supply and Demand based on the Basic Law on Energy Policy Making was decided by the Cabinet on October 6, 2003. The plan prescribes that commercialization of hydrogen generation system using nuclear, solar and biomass, not fossil fuels, is desired.

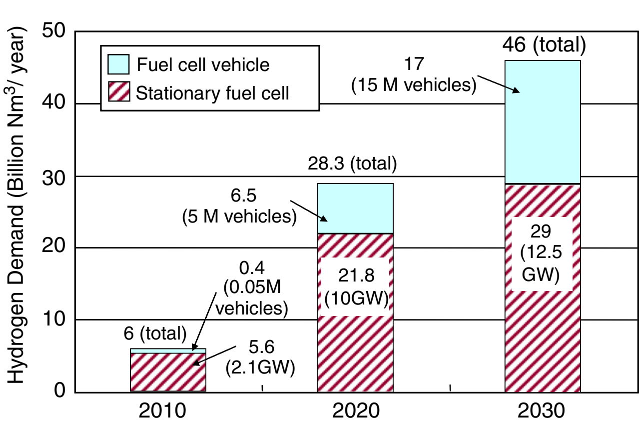

Fig. 1. Hydrogen demand for fuel cells in Japan.

3. Feature of hydrogen generation with HTGR

3.1. HTGR

The light water-cooled reactor (LWR), which is popular as nuclear power reactors in the world, uses water as coolant and metal as in-core materials. The outlet temperature of the coolant is approximately 300 °C, and the nuclear heat application is limited to electricity generation. On the other hand, HTGR can generate high-temperature heat above 900 °C using graphite as in-core materials and helium gas as coolant. The high-temperature heat can be used for hydrogen generation as well as electricity generation as shown in Fig. 2.

Furthermore, HTGR has excellent inherent safety. The fuel particle coated with graphite and silicon carbide has high thermal integrity and high FPs retention capability, and the core made of graphite has no possibility of meltdown. Chemical reaction between the coolant and core components does not occur in high-temperature environment because helium gas is inert. Therefore, it can be said that there is no severe accident causing large scale fuel failure or core meltdown.

Fig. 3 shows the cutaway view of the HTTR reactor. The HTTR, the first HTGR in Japan, can supply a high-temperature heat of 950 °C at the reactor outlet with the thermal power of 30 MW, using helium gas as coolant and graphite as materials of core and reactor internals such as fuel elements, replaceable and permanent reflector blocks and core support structures [1]. The reactor consists of a reactor pressure vessel, fuel elements, replaceable and permanent reflector blocks, core support structures, control rods, etc. Thirty columns of fuel elements and seven columns of control rod guide blocks form the reactor core called fuel region, which is surrounded by replaceable reflector blocks and large-scale permanent reflector blocks. The fuel element of the HTTR is a so-called pin-in-block type. The reactivity of the HTTR is controlled with 16 pairs of control rods in the fuel and replaceable reflector regions of the core.

3.2. Hydrogen generation

Nearly 90% of hydrogen generated in the world today is that produced with a steam reforming process industrialized mainly

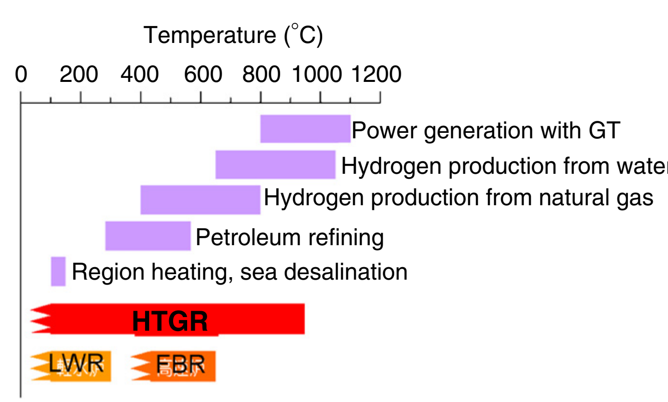

Fig. 2. Temperature regions on heat application.