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Strategy of VHTR Realization

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1. Introduction

High temperature gas cooled reactor has been developed since 1956.[1] Fundamental idea of a gas cooled reactor is to achieve high temperature which is suitable for high efficiency application such as electricity generation. The core is composed of ceramics, graphite blocks which are mechanical stable up to very high temperature. Fuel is ceramics, TRISO (tri-isotropic coated micro particle) whose dense coating layers work as small radioactivity containment. Coolant is inert gas, helium, which is stable chemically, neutronically, and thermal hydraulically. Several test reactors such as DRE, PB-1, FSV, AVR, THTR, HTTR, HTR-10 were built and demonstrated their safety.[2] Large GA-HTR, RSA-PBMR projects are canceled and US-NGNP project is idling. Only Chinese HTR-PM demonstrator is under construction.

2. Characteristics of VHTR

2.1. Strong points

VHTR(and HTGR) has very low radioactivity leakage to coolant and environment mainly due to robust TRISO fuel particles. TRISO is a micro particle coated in three tight layers of inner pyrolytic carbon, silicon carbide, and outer pyrolytic carbon. Those layers protect fission product release well up to 1800^{o}C. Part of released radioactivity is trapped in graphite block. Helium gas does not attach other molecules or particulate, such behavior is different from water. Radioactivity leakage to coolant and reactor building is very small, which is strong point for maintenance.

Large heat capacity of solid moderator results slow thermal transient of reactor core. High thermal conductivity of graphite and thermally connected core mitigate local effect, such as local power peaking due to rod ejection. Moderate heat transfer to coolant means less impact from coolant disturbance, such as loss of coolant accident.

High temperature achieved by combination of helium coolant, ceramics fuel and core means the high cycle efficiency for electric power generation, and wide application area such as high temperature steam production and efficient hydrogen production.

Low neutron capture of graphite moderator and helium coolant means higher neutron utilization of fuel. It means higher uranium resource utilization and thermal thorium breeding.

Long term environmental stability of ceramics even at spent fuel phase helps simpler backend. Spent fuel generated less decay heat per produced power. Once-through cycle is preferable in HTGR though recycling of the used fuel is not impossible. Spent fuel can be easily disposed to final repository.

2.2. Weak points

Modern VHTR has limited the core capacity not to exceed 600 MW thermal with a stainless steel pressure vessel. The power capacity limit was introduced to guarantee the inherent passive decay heat removal after shutdown which is a key feature for the ultimate safety. This capacity limitation blocks possibility of achieving economics of scale.

There are only 7 reactors ever built and about 80 reactor-years of operating experience. FSV and THTR are regarded as a commercial failure due to low availability caused by frequent shutdown, although those were not significant radiological incidents. Such failures are partially come from premature commercialization driven by industries without enough operation experience at the time of the design and construction

HTGR requires special components such as nuclear graphite, high temperature seals, pump, and others. However, since there was no significant construction since 1970's, component supply chains are destroyed nowadays. It will demands large investment to reconstruct the essential component supply chains.

Another problem arises from low power density characteristics which is good for safety, albeit. Larger construction cost per kW is expected due to small power capacity per module comparing with large LWRs. Volume of waste such as graphite and fuel must be larger due to low power density and solid form of graphite blocks. Waste graphite is also problematic by activation of graphite impurities (N-15, Cl-36) and trapping of metallic fission products.

3. Strategy for realization

General strategies are promoting benefit of the strong points, improving weak points, finding potential market, and preparing for real work.

3.1. Potential market

There exist well developed industries, under big competition, already for most applications. So it is required to find a niche market which is relatively easy to penetrate. Example of VHTR application market are as follows.

Carbon free energy source for industry complex - Stable supply of electric power and steam from low carbon emission is selling point for energy demanding industry. Safety and radioactivity contamination is the first consideration at hazardous industry complex such as refineries, chemical plants, and steel mills. HTGR at underground silo is well protected from external explosion and fires. Slow thermal transient characteristics provide enough time for operator action during accident recovery. Even without any prompt action, HTGR will safely shutdown by thermal feedback.

Electric power for small grid - Small power of HTGR is suitable for grid where infrastructure is usually poor. Slow thermal transient characteristic is helpful to avoid human error caused by not well trained operators. Assistant from remote urban technical center can be usable thanks to slow transient. Small grid is usually accompanying poor cooling resource. High temperature of HTGR is useful to generate electric power without much sacrifice in the cycle efficiency. Even at frequently freezing area, HTGR can be designed to work since the primary coolant is not freezing.

Carbon free hydrogen production – Water splitting process using VHTR heat does not produce carbon. Steam methane reforming by VHTR heat will significantly reduce carbon emission. High temperature of VHTR is suitable for efficient hydrogen production. However, the lifetime of the components at high temperature, corrosive environment is short, that could hamper economics of the system. Hydrogen economy that demands large hydrogen supply is slowly coming.

Power source for space colony – VHTR is ideal for outer space where no cooling water exists and energy density of fuel is of critical importance. VHTR can emit waste heat by radiator without significant loss of efficiency. It does not freeze in space where shadow side is extremely cold. However, extraterrestrial colony is just dream yet.

3.2. Technology Readiness Level

High level of TRL[3] is necessary to get large funding from investors including government. Especially, climbing TRL ladder above level 3 requires a lot of funding to build scaled experimental facilities, man powers, methodology validations, and supporting databases. It is a kind of chicken-egg problem to climb up the TRL ladder. But once it hatches, it can lay more eggs at the end.

Cooperation between the interested parties is essential to reduce the investment risks. Under GIF, this kind of cooperation scheme was established. However, it was experienced that the most participants are only exchanging published results and trying to hide key know-how.

3.3. Role of Participants

For realization of VHTR, a clearly divided role of participants in the universities, the national institutes, and the industries are essential. Universities will supply man-powers who have knowledge of HTGR systems, and develop basic ideas and principles. National institute will prove the ideas, study the concept, and develop, verify and validate the design tools. Finally, industry will design, construct, and operate. They shall fetch and establish the supply chains required for the construction and design.

3. Summary

HTGR has long history of development. HTGR has significant strong points in safety and high efficiency. However, it still failed in commercialization. It is needed to emphasize the strong points and improve the weak points. For realization and market penetration, VHTR community should look at niche market such as carbon free energy supply to industry complex, electric power for small grid, carbon free hydrogen production, power source for space colony. Technology Readiness Level should be advanced to get proper investment from industry. For this, cooperation between international R&D institutions is required. Clearly divided role between universities, research institutions, and industries will reduce complication and shorten VHTR realization day.

REFERENCES

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