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SPECIAL APPLICATIONS OF GAS-COOLED REACTORS

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INTRODUCTION

Gas-Cooled Reactors (GCRs) can provide a unique source of energy and thus help reduce U.S. dependence on foreign sources of energy. The GCRs have been under development since the 1940s in Europe and since the 1950s in the U.S. The British led the development with the MAGNOX reactor, which was followed by the Advanced Gas Reactor (AGR). In the U.S. the High-Temperature Gas-Cooled Reactor (HTGR) was demonstrated by the Peach Bottom Nuclear Generating Station[1] and the Fort St. Vrain Nuclear Generating Station.[2] In Germany the HTGR has followed similar development with demonstration first by the AVR[3] and subsequently by the THTR, which is scheduled to operate in 1984. New applications as well as advanced concepts of the HTGR have been proposed and are in various stages of development under the sponsorship of the Department of Energy and guidance from the Gas Cooled Reactor Associates. The Gas-Cooled Fast Breeder Reactor (GCFR), which is derived from the HTGR and Liquid Metal Fast Breeder Reactor (LMFBR) technologies, is also a member of the GCR family. The application of the family of GCRs and their technology status are discussed in this paper.

HIGH-TEMPERATURE GAS-COOLED REACTOR

The HTGR is a high-efficiency, advanced converter with unique high-temperature capability. Unlike other nuclear systems, the HTGR can make a significant contribution to the displacement or increased production of fossil fuels in the non-electric areas of energy consumption, which represented almost 70% of the total U.S. energy in 1979.

The HTGR designs can be placed in two broad categories: (1) a nuclear heat source (NHS) operating at high temperature and (2) an NHS operating at very high temperature. The high-temperature NHS is similar to the design of the Fort St. Vrain reactor but incorporates a number of design improvements which are under development. This NHS can provide helium at approximately 700°C, which can be used to generate steam at 538°C, 17.2 MPa or which can be used to sensibly heat other heat transfer media (i.e., molten salt) for transmission and storage of energy. In the steam-producing mode, the HTGR can be coupled with a steam turbine generator to produce electricity, or the steam can be partially utilized for process uses and the balance for electric cogeneration. The process steam uses are numerous and varied; however, they can be broadly categorized as follows: chemical/petrochemical, primary metals, enhanced oil recovery, and synfuel processes. Table I gives the energy requirements and a comparison of the energy cost for these applications. As shown, the use of coal-supplied energy is 40% to 60% more expensive assuming utility financing conditions and including projections on the future cost of the resources. When the NHS is used in combination with molten salt transmission and storage, the application is referred to as the sensible energy transmission and storage (SETS) application. This system can be used to transmit energy economically over relatively long distances (up to 80 km).

The very-high-temperature NHS is an advancement of the design and makes use of materials capable of withstanding the higher operating temperatures. This NHS can provide helium at approximately 850° to 950°C, which can be used in various synfuel processes or thermochemical water splitting in lieu of fossil sources of energy. A number of synfuel processes have been identified which can be integrated with an HTGR. These processes fall into the following categories: coal gasification, coal liquefaction, oil shale retorting, and advanced processes such as thermochemical watersplitting and direct steam-carbon gasification. Table II summarizes these processes and typical energy requirements. The very-high-temperature NHS can also be coupled directly with a closed-cycle gas turbine to generate electricity.[4] This Brayton cycle leads to a high-efficiency electric producer capable of being sited in water-limited areas, since it can make economical use of dry cooling. In another application the high-temperature NHS is combined with a thermochemical heat pipe utilizing a reformer and a methanator to form a long distance heat transport system (greater than 80 km). In this system the reformer is located at the reactor site and produces hydrogen and carbon monoxide (endothermic reaction), which are transported by a pipeline to a remote methanator where the process is reversed (exothermic reaction).

STATUS OF HTGR TECHNOLOGY

The HTGR technology has been partially demonstrated with the operation of the Peach Bottom and Fort St. Vrain reactors and the German AVR reactor. These plants have confirmed major elements of the design: the fuel elements, prestressed concrete reactor vessel and its liner and thermal barrier systems, and major components such as the steam generator and helium circulator. Additional design improvements of the high-temperature NHS will require further design and design verification. This is estimated to cost about $300 to $350 million over approximately an 8-year period. A conceptual design of the NHS for a 2240-MW(t) core has been developed and is the basis for continuing design and application studies.[5] This design has been proposed for steam turbine electric and process steam cogeneration applications.

The very-high-temperature NHS requires additional development of approximately $150 to $200 million and an additional 2 to 4 years. New materials that are resistant to carburization in the high-temperature environment of the reactor will have to be developed. A design for this NHS has been proposed for steam-methane reforming.[6] Additional work is under way to integrate the HTGR and the potential process heat processes and to determine the economic and environmental incentives for these applications.

GAS-COOLED FAST-BREEDER REACTOR

Another member of the family of GCRs is the GCFR. The basic GCFR concept takes maximum advantage of the helium systems and component technology developed for the HTGR. The reactor core has been designed to be similar to that of the LMFBR so that the extensive development work on the fuel and physics of that concept could be utilized. This has led to a simpler system than the LMFBR with a significant decrease in capital cost. It also leads to a higher breeding ratio and ease of operability and maintainability.

The program, which continues to be international in nature, has progressed through significant developmental work which confirms the physics and heat transfer of the core. A design of a 350-MW(e) demonstration plant has also been prepared.

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TABLE I
HIGH-TEMPERATURE NUCLEUR HEAT SOURCE
SUMMARY OF ENERGY REQUIREMENTS AND COST COMPARISONS
FOR CANDIDATE PROCESSES

	Petrochemical	Primary Metals	Enhanced Oil Recovery	Coal Gasification
Energy requirements, MW(t)				
Process requirements				
Electric	111	240	1	147
Steam	1929	296	993	1005
Subtotal	2040	536	994	1152
Other electric uses	216	115	157	3
Losses				
Condenser	49	492	--	--
Other	35	27	19	15
Total	2340	1170	1170	1170
Energy cost, $\$/10^6$ Btu (~1995 dollars)				
HTGR	12.45	12.93	12.22	12.37
Coal	17.81	21.00	17.85	18.08
Coal/HTGR ratio	1.43	1.62	1.46	1.46

TABLE II
VERY-HIGH-TEMPERATURE NUCLEAR HEAT SOURCE
SUMMARY OF ENERGY REQUIREMENTS FOR CANDIDATE PROCESSES

Process	Process Thermal Efficiency (approx. %)	Process Energy Needs[a] [MW(t)]					
		High-Temperature Heat			Process Steam <540°C	Electrical[b]	Total
		800° to 900°C	700° to 800°C	500° to 700°C			
Oil shale retorting	70	185	580	55	25	300	1145
Coal liquefaction	65	290		300	535	15	1140
Coal gasification	65	50	70	30	1200	540	1890

(a) Based on plant capacity of 50,000 barrels per day oil equivalent.
(b) Assuming megawatts thermal is equivalent to three times megawatts electrical.