Chapter 7

SUMMARY AND CONCLUSIONS

The primary focus of this CRP was to perform detailed investigation of the high temperature industrial processes that are attainable through incorporation of an HTGR, and for their possible demonstration in the HTTR. The HTGR has the capability to achieve a core outlet temperature approaching 1,000° C in a safe and effective manner. These attributes, coupled with the offer by JAERI to utilize the HTTR, resulted in the initiation of this CRP by the IAEA.

7.1 HIGH TEMPERATURE ENGINEERING TEST REACTOR

The HTTR utilizes a 30 MWt HTGR comprised of 30 fuel columns of hexagonal pin-in-pin graphite block type fuel elements. The fuel consists of UO_2 TRISO coated particles with an enrichment of ~ 6%wt. Relative to the demonstration of high temperature heat applications, the HTTR will be capable of producing 10 MWt of heat at 950°C. However, the thermal power for these applications has the potential to be increased up to 30 MWt in the future, which may be required for demonstration of gas turbine system components. The HTTR reached initial criticality in November, 1998. Initial operational plans includes a series of rise to power tests followed by tests to demonstrate the safety and operational characteristics of the HTTR.

In addition to completion of the HTTR demonstration tests, it was recommended that the R&D given in Appendix "A" be performed within the HTTR project. JAERI is encouraged to publicize the results of the HTTR tests and "lessons learned" from their experiences including potential capabilities of the HTGR for heat applications. This could be in the form of JAERI/HTTR personnel arranging for international technical seminars, conferences and publications to industries, utilities and financing organizations.

7.2 PRIORITIZATION OF HEAT UTILIZATION SYSTEMS

Paramount among the recommendations of the Chief Scientific Investigators (CSIs) was the prioritization of individual heat utilization systems for demonstration using the HTTR. This prioritization was influenced by the significance of the application, the current state of technology development for each application, and the capability to couple it to the HTTR.

It was determined that the major focus should be on high temperature applications of nuclear power which would result in the production of hydrogen. The need to depart from the burning of fossil fuels was considered to be a priority worldwide requirement.

Production of hydrogen as an energy carrier for the future through the reforming of methane was selected as the highest priority heat utilization application. Reforming of methane with steam and carbon dioxide were investigated and, although the primary goal was the production of hydrogen, both processes have the proven ability to result in the final production of methanol (or syngas) through subsequent synthesis. This chemical conversion of natural gas with the HTGR offers the added benefits of a substantial decrease in CO_2 emissions and an increase in calorific value of the products with a corresponding greater fuel versatility.

The next priority application was determined to be the generation of electricity through the use of the gas turbine. Application of the Brayton Cycle utilizing high temperature helium from a modular HTGR was chosen for development because of its projected benefits as an economic and efficient means for the production of electricity.

Evaluation of the remaining high temperature heat utilization applications chosen for investigation by the CSIs resulted in the prioritized selection of hydrogen production through thermochemical water splitting, followed by the conversion of coal into higher quality fuels. These processes are to be demonstrated by out-of-pile tests prior to coupling to the HTTR.

The main findings and conclusions for each of the systems evaluated within this CRP are as follows:

- Reforming of Methane for Hydrogen Production and Synthesis

  Steam reforming of methane for the production of hydrogen is planned to be the initial heat utilization process demonstrated with the HTTR. This reforming process for hydrogen production is well known industrially and is technologically mature. The hydrogen production performance with a heat utilization ratio (i.e. ratio of the product energy to total input energy) of up to 78% in the reforming system is expected to be demonstrated with the HTTR at a thermal power level of 10 MW. The integrated control system of the HTTR with the steam reforming system is determined to be technically feasible and will also be demonstrated in the HTTR.

  Significant experience in out-of-pile tests and design studies associated with steam reforming of methane exist in Germany, China and Russia. The R&D activities to be conducted prior to demonstration of this process in the HTTR include out-of-pile testing and additional studies associated with design and safety such as the establishment of safety standards associated with the explosion of feed and product gases and determination of the tritium permeation rate.

- CO_2 Reforming of Methane for Hydrogen

  Large resources consisting of a mixture of CO_2 and natural gas exist worldwide which have the capability to be converted into usable synthesis gas. Also, bio-resources (CO_2/CH_4) can be used for conversion into synthesis gas with no net generation of CO_2. Although not as highly developed as the steam reforming process, CO_2 reforming of methane has been proven experimentally.

As with steam reforming of methane, the R&D needs, design, safety assessment requirements such as the tritium permeation rate and explosion of feed and product gasses and goals of the carbon dioxide reforming process have many common similarities and the same facility can be used for the demonstration of both reforming systems. In this regard, the initial design work has been completed by JAERI for the HTTR heat application systems of steam and CO_2 reforming of methane and out-of-pile demonstrations of both processes will be performed prior to coupling to the HTTR.

- Gas-Turbine for Electricity Production

The generation of electricity through the use of the gas turbine was determined to be a priority application (of similar status as steam reforming of methane) for demonstration with the HTTR. The CSIs determined that investigating the coupling of the HTGR with a gas turbine energy conversion system is an important milestone in the development of advanced nuclear power. This system eliminates the constraints imposed by the use of steam via the Rankine Cycle, which is predominant in the current generation of nuclear power plants.

Significant interest exists worldwide in this concept and several plant designs are currently in progress. Both the direct and indirect cycle systems are determined to be technically feasible. Out-of-pile testing experience exists in Germany on the helium gas turbine [1], and the potential exists for demonstration of associated power conversion system components with the HTTR.

Based on the understanding that further evaluation and consideration is necessary by JAERI prior to proceeding with the gas turbine system, the CSIs proposed connection of both the direct and indirect cycle systems to the HTTR. Besides the integrated HTTR demonstration test, this could include evaluation of component performance and material testing within the HTTR Project.

- Thermochemical water splitting for hydrogen production, Iodine-Sulfur (IS) Process

Of the many chemical reactions that have been evaluated utilizing the HTGR as the heat source, the IS process is considered one of the most attractive for thermochemical water splitting to achieve hydrogen. This process provides several significant features, including the capability to produce hydrogen from naturally abundant water, freedom from carbon emission thereby helping prevent environmental issues such as global warming, direct conversion of nuclear heat into chemical energy and the ability to provide a relatively (>40% has been evaluated) high thermal efficiency.

The basic concept of this process was developed by GA and demonstrated at JAERI in the course of this CRP on laboratory-scale experiments attaining continuous and "closed-cycle" hydrogen production. Because of this achievement, a larger scale test was initiated in 1999 to develop closed-cycle operation techniques with modified Bunsen reaction conditions.

In addition to this test, studies are underway on the membrane technologies for establishing efficient processing of hydrogen-iodide and on the materials of construction for a bench-scale plant.

It was concluded by the CSIs that this thermochemical process is worth continuing as a future candidate for potential demonstration in the HTTR following bench- and pilot-scale experiments.

- Coal Conversion

The world reserves of high and low grade coal greatly exceed the known resources of oil and natural gas. Significant investigation has been undertaken by Member States into the processes for conversion of coal into higher quality, more convenient to use, fuels. Conversion of these reserves provides the benefits of easier fuel product transportation and improved environmental conditions, compared to the direct burning of coal.

Gasification of coal using external heat from the HTGR can have a 150 to 180% yield compared to conventional conversion processes. Research carried out within the scope of this CRP by Germany, Russia, China and the USA has demonstrated that coal reforming via HTGR produced thermal power can be technically feasible and is expected to be economically competitive. This nuclear heat process offers advantages over conventional gasification processes in terms of more efficient and environmentally friendly utilization of available primary resources. Use of the HTGR allows a nearly 40% reduction in coal consumption compared to existing methods for the same output in syntheses gas. Converted coal can be used as a fuel in conventional fossil plants, and hydrogen produced by an HTGR can be utilized for hydrogasification of coal and subsequent conversion into hydrocarbons.

The conventional technology of coal gasification is mature. Although the use of high helium temperature as achieved in the HTGR has been demonstrated for this process in out-of-pile tests, evaluation to determine the most advantageous process to be utilized (steam gasification, hydrogen addition, etc.), including further investigation into the associated safety and economic issues, and component/material development is required prior to coupling to a nuclear heat source.

- Heavy Oil Recovery

Investigation within the scope of this CRP into the feasibility of using the HTGR in the recovery of heavy oil concluded that HTGRs are capable of producing the high temperature and high pressure steam necessary for this process and could be used as the need arises with current technology. Also, through the ADAM/EVA tests, Germany has investigated and demonstrated the capability for chemical energy transport over long distances in oil fields. However, it was determined by the CSIs that research and development specific for oil recovery was not a feasible application for demonstration with the HTTR and this heat utilization application was deleted from the CRP.

7.3 REFERENCES TO CHAPTER 7

[1] WEISBRODT, I.A., "Summary Report on Technical Experiences from High Temperature Helium Machinery Testing in Germany", IAEA-TECDOC-899, Vienna, (August 1996).