GCRA 89-001

SUMMARY OF GAS-COOLED REACTOR PROGRAMS

GAS-COOLED REACTOR ASSOCIATES

JANUARY 1989

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L.D. MEARS
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January 26, 1989

TO: Distribution

Gentlemen:

Enclosed is a copy of the updated "Summary of Gas-Cooled Reactor Programs" document that GCRA has maintained over the years. This is the tenth issue of the document.

Our intent is to provide a concise overview, on approximately an annual basis, of the world-wide status of gas-cooled reactors. Any suggestions for further updates would be welcome.

Sincerely,

Dan

L. D. Mears
General Manager

LDM:lm

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Gas-Cooled Reactor Associates

January 1989

FOREWORD

This report has been compiled by Gas-Cooled Reactor Associates (GCRA) as a central source of summary-level information on the present status and future plans for High Temperature Gas-Cooled Reactor (HTGR) programs in countries who have had large and active programs in this technology for several years, i.e. United States, Federal Republic of Germany (FRG) and Japan. During this past year, the HTGR program in the Soviet Union (USSR) has gained considerable momentum with the announcement of plans for a cooperative USSR/FRG venture to build an HTGR plant in the Soviet Union.

Summary-level information is also provided for several other countries who are either showing an increasing interest in HTGR technology or are participating in development programs in support of another country's efforts. Similarly, summary-level information is provided on the gas-cooled reactor programs (MAGNOX and AGR) in the United Kingdom, since it is from this technology that the HTGR evolved and several basic design and developmental areas are of common interest.

Most of the new information for this issue was gathered from papers presented at the Tenth International Conference on the HTGR held in San Diego on September 19-20, 1988 and the subsequent International Atomic Energy Agency Technical Committee Meeting on Design Requirements, Operation and Maintenance of Gas-Cooled Reactors on September 21-23, 1988.

This is the tenth issue of this document, the first of which was issued in March 1979.

CONTENTS

LIST OF TABLES

SECTION 1

UNITED STATES (USA)

The USA gas cooled reactor program had its inception in 1957 when General Atomics, then the General Atomic Division of General Dynamics Corporation, evolved the first design concepts based on earlier work primarily in the United Kingdom on lower temperature, gas-cooled concepts. Driven by the incentive of higher efficiency electricity generation and supported by various utility organizations from the beginning, the program has been concentrated almost exclusively on the High Temperature Gas-Cooled Reactor (HTGR). The history of the USA program is marked by the following key events:

- Construction (1962-1967) of the 40 MW(e) Peach Bottom I developmental plant and its successful operation from 1967 to 1974.

- Construction (1968-1974) of the 330 MW(e) Fort St. Vrain demonstration plant and its troubled operation from 1974 to the present.

- The commercial entry into the USA market in 1971, the sale of ten commercial units (five twin plant contracts) ranging in size from 770 MW(e) to 1160 MW(e) in the period 1971-74, the cancellation of six of these units by utilities in 1974-75 due to the economic recession following the oil crisis in 1973, and the vendor termination of the remaining contracts and withdrawal from the market in 1975 due to loss of market.

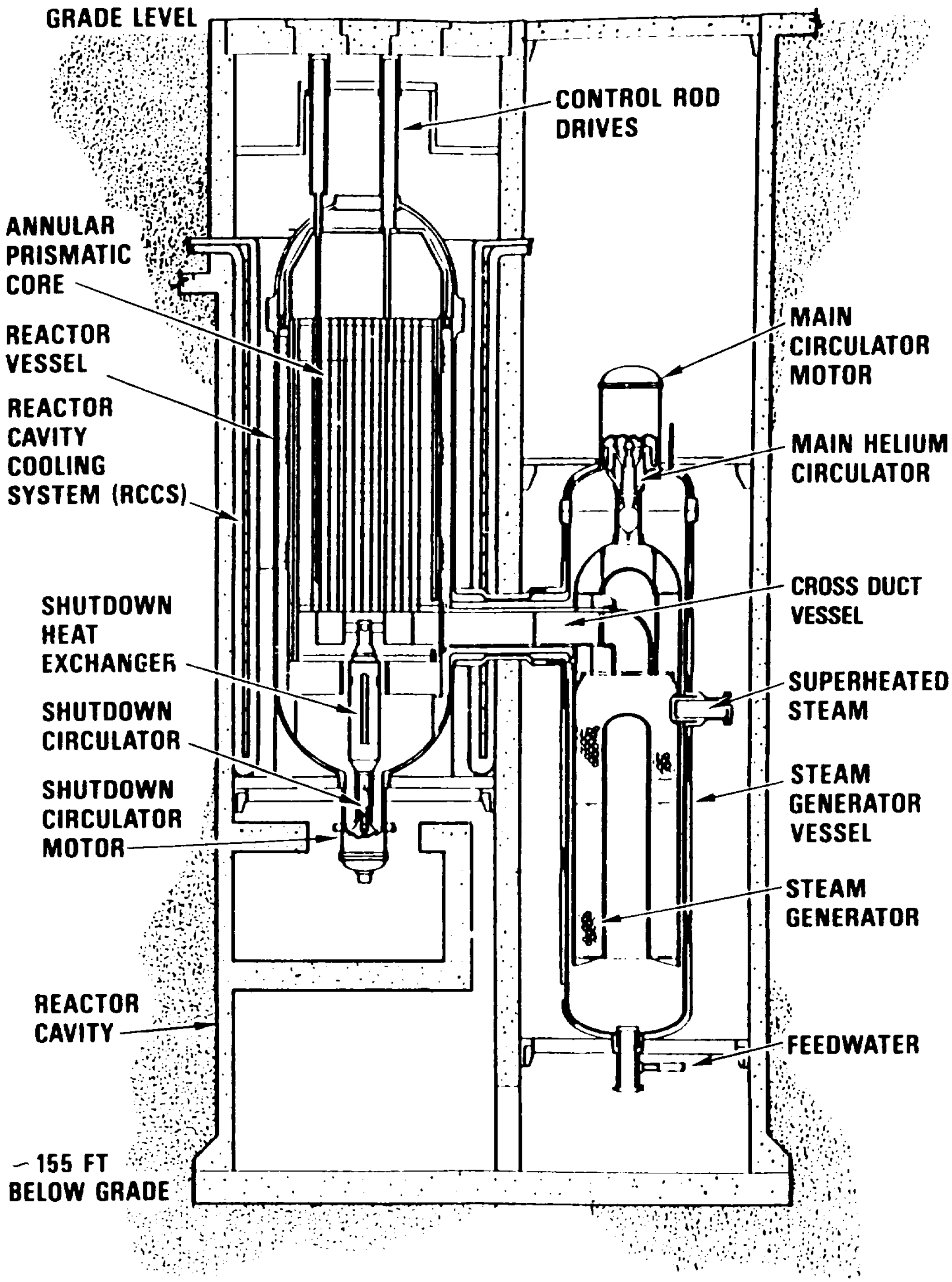
- The subsequent broadening of the DOE-sponsored HTGR program in 1977 concurrent with the formation of Gas-Cooled Reactor Associates to provide support and user direction to the HTGR Program. At that time, the effort was focused on the design and development of an 840 MW(e) HTGR which was based on evolving design improvements of the commercial plants and the once-through, low-enriched uranium/thorium fuel cycle.

- The redirection of the DOE program in 1984 to small modular designs and the selection in 1985 of the side-by-side, steel vessel configuration with an annular reactor core using prismatic fuel elements, the Modular High Temperature Gas-Cooled Reactor (MHTGR), as the reference concept.

- The completion of a Preliminary Safety Information Document (PSID) on the reference four-module MHTGR plant in 1986 and the submittal of this document to the Nuclear Regulatory Commission (NRC) for review.

FIGURE 1.1

USA MODULAR HTGR -- 350 MW(t)



Program, was the first HTGR power plant built in the USA. Construction on the plant was started in 1962 and was completed in 1967. Operation of Peach Bottom I during the seven-year period from 1967 to 1974 resulted in the generation of electricity for an equivalent of 1349 full power days with an overall average availability of 88% for the nuclear steam supply system exclusive of planned shutdowns for research and development programs.

The overall operation of Peach Bottom I was a significant accomplishment in terms of demonstrating the capability of equipment in a high temperature helium environment. The reactor did undergo one complete core refueling after the first 150 effective full days of operation as a result of fuel failure. The first core contained the earliest version of coated fuel, utilizing single pyrocarbon coatings to prevent hydrolysis of the carbide particles during fuel element fabrication, shipment and storage. During operation, cracking of the coatings resulted in fuel compact swelling and the subsequent cracking of some of the unique fuel element sleeves used in Peach Bottom I. The core was replaced with fuel elements containing the multiple-barrier type of coatings which were being developed for follow-on plants, such as Fort St. Vrain, and operated successfully for the remainder of the plant operation period.

Having completed its mission, the Peach Bottom I plant was shutdown in 1974 and has been partially decommissioned.

1.2.2 Fort St. Vrain

The 330 MW(e) Fort St. Vrain Nuclear Generating Station (FSV) constructed for and operated by Public Service Company of Colorado (PSC), is the only presently operating gas-cooled reactor in the USA. FSV contains many innovative features and first-of-a-kind components that, in part, have contributed to its poor performance. Most noteworthy in this regard are the steam turbine-driven helium circulators. To avoid the potential for oil ingress into the primary helium coolant system, the circulator design incorporates a water bearing/lubricating system and a labyrinth sealing system. The service system required to maintain proper operation under all reactor operating conditions was complex and the leakage of water from the bearing/seal system into the primary system has been almost a continuous problem and certainly the most significant unavailability factor for the plant. Considerable time and effort has been required to lower the moisture content to the required levels to permit power operation after each water ingress incident.

The succession of water ingress events led to the requirement to refurbish the control rod drives in 1984-85. Following the successful refurbishment, high power operation associated with the ongoing operating costs of FSV. Consideration is being given to the feasibility of converting FSV to a fossil-fueled plant.

Table 1.1 is a summary comparison of some of the key features of Peach Bottom I, FSV and the civilian MHTGR.

1.3 PROGRAM PARTICIPANTS

Key participants in the USA HTGR program include the following:

U.S. Department of Energy (DOE) -- Through the Division of HTGR's, which is part of the Advanced Reactors program area, the DOE provides the major budget resources for the ongoing design, licensing and technology development activities. The DOE HTGR budget for FY-88 was $23 million. For FY-89, a funding level of $20 million has been appropriated.

U.S. Nuclear Regulatory Commission (NRC) -- Through the Advanced Reactors and Generic Issues Branch, which is part of the Office of Nuclear Reactor Research, the NRC reviews safety and licensing documentation on the HTGR. During 1988, the NRC completed the draft Safety Evaluation Report and reviewed the issues and conclusions with the Advisory Committee on Reactor Safeguards.

Gas-Cooled Reactor Associates (GCRA) -- The utility/energy user organization that supports the development and commercialization of the HTGR. The GCRA organization provides utility/user requirements and priorities to guide the development of the MHTGR. Utility/energy user funding for the HTGR Program has been at a level of approximately $2 million for the past several years.

General Atomics (GA) -- The industrial pioneer of the HTGR concept in the USA and the prime nuclear systems and fuel design contractor. Designer of the Peach Bottom I nuclear systems and designer/constructor for the Fort St. Vrain Nuclear Station.

Combustion Engineering, Inc. (CE) -- Current LWR vendor with vendor/supplier interest in HTGR. Performs work on steam generators, other heat exchangers and steel vessels development and design. Also supports Stone and Webster Engineering Corporation for plant control development.

Bechtel National Inc. (BNI) -- An architect engineering/ construction firm that is a division of Bechtel Corporation. Performs engineering and design work on buildings, structures and related systems on the Nuclear Island.

Stone and Webster Engineering Corp. (SWEC) -- An architect engineering/construction firm. Performs engineering and design work for the Balance of Plant.

Oak Ridge National Laboratory (ORNL) -- One of the DOE's national laboratories; has broadest experience base in performing base technology work in several HTGR related areas. MHTGR Lead Lab with responsibility for the base technology program.

SECTION 2

FEDERAL REPUBLIC OF GERMANY (FRG)

The gas-cooled reactor program in the FRG has followed an evolutionary path similar in many aspects to the USA program. Initial work was carried out in 1956 on advanced gas-cooled concepts utilizing spherical graphite fuel elements and helium coolant to achieve the higher temperatures required for efficient electricity generation. The spherical fuel element core, or pebble bed, has been retained as a basic feature of all gas-cooled reactors in the FRG. Driven as much, if not more, by the potential applications to process heat and specifically to coal gasification processes, the High Temperature Reactor (HTR) Program in the FRG has been highlighted by several key events:

- Design and construction (1959-1967) of the 15 MW(e) AVR experimental reactor and its excellent operation over a 21 year period as a test bed for several advancements in high temperature reactor technology.

- Construction of the THTR 300 MW(e) plant and it's successful commissioning in 1987.

- The construction and operation of several large test facilities specifically designed to enhance coal gasification technology and test specific components needed in the transfer of nuclear heat to the gasification processes.

- The design evolution of the 550 MW(e) HTR-500 concept from the essential bases established by the THTR.

- The design evolution of two small modular concepts, the 100 MW(e) HTR-100 in-line concept by HRB and the side-by-side 80 MW(e) HTR-Module by Interatom for potential application to utilities and/or industrial users.

- The signing of an agreement in 1988 between the State Committee for the Utilization of Nuclear Energy of the USSR and the FRG HTR industry to jointly develop and build an experimental modular HTR. A government-to-government agreement between the FRG and the USSR to cooperate in research and development for the process heat application of the HTR was also signed in 1988.

- The signing of an agreement in late 1988 between industries and research centers in the FRG and in the Peoples' Republic of China (PRC) for cooperation aimed at

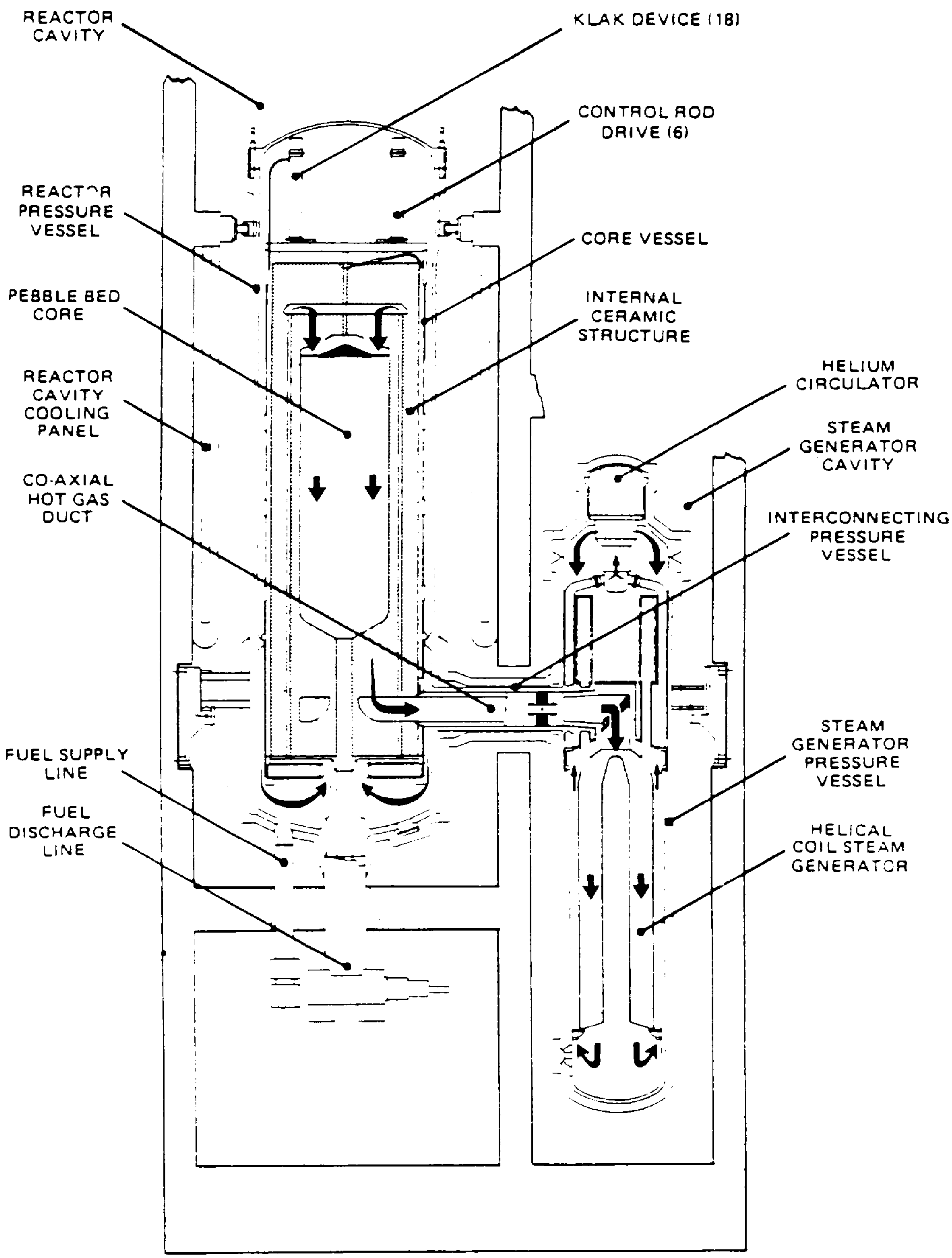
The 80MWe HTR-Module concept, developed by Siemens/ Interatom and shown in Figure 2.2, was the first small, modular-type reactor concept to be proposed worldwide. Although initially developed in the early 1980's for industrial process heat applications, the passive safety features of the side-by-side concept coupled with the other attractive characteristics, now widely recognized, of the modular concept soon led to the proposed electricity generation application. During 1988, work continued on the generic, site independent, safety assessment initiated with the filing, in May 1987, of a safety analysis report in the State of Lower Saxony. Several meetings were held and supplementary reports were submitted, culminating in the submittal of a revised safety analysis report in August 1988. The issuance of a concept license, completing this phase of the work is expected in during 1989.

The other modular concept, the HTR-100 (100MWe), shown in Figure 2.3, is referred to as in-line concept due to the arrangement of the steam generators above the core, similar to the AVR experimental reactor. Following the initial conceptual design by ABB/HRB in 1983-84, a development consortium of five industrial companies plus a central coordination company was formed early in 1985 to further the development of the concept. Early in 1988, work was initiated on a site-independent safety analysis report for the concept to serve as the basis for a safety assessment by the licensing authorities.

Design and licensing work on all HTR concepts in the FRG is funded by private industry; research and development support within industry and at the KFA national laboratory is funded by both the national and state governments. Both reactor suppliers have been very active in marketing their HTR concepts worldwide, particularly in the People's Republic of China (PRC) and the Soviet Union (USSR). Future plans regarding small modular concepts and also the HTR-500 would appear to be strongly affected by the recent cooperation agreements between the USSR and the FRG and between the PRC and the FRG. In late 1988, as a result of high level decisions to expedite project development, several agreements were reached regarding the prototype plants to be built in the USSR. In particular, agreement appears to have been reached on the basic nuclear steam supply configuration for the first project. As described in Section 5 of this report, the configuration chosen is the side-by-side arrangement, similar to the Siemens/Interatom HTR-Module and the USA MHTGR. Furthermore, in late 1988, industries and research centers in the FRG and the PRC signed an agreement for cooperation aimed at the design and construction of a side-by-side pebble bed reactor in Beijing. As a result of these agreements, design work on the HTR-100 concept was reduced and was essentially

FIGURE 2.2

HTR-MODULE



terminated by the end of 1988. Moreover, in order to combine their capabilities and to avoid competition, both German reactor suppliers, ABB/HRB and Siemens/Interatom have announced their intention to form an HTR joint venture that will consolidate the FRG HTR vendor/supplier interests for HTR projects.

2.2 OPERATING REACTOR EXPERIENCE

2.2.1 AVR

The 15 MW(e) AVR developmental plant built by Brown-Boveri-Krupp, the predecessor of HRB, is one of the two HTR plants in the FRG. Operated by the utility group, Arbeitsgemeinschaft Versuchsreaktor GmbH, the AVR has been in operation since 1967 at the KFA National Laboratory in Juelich in the State of North Rhine Westfalia. Most noteworthy in its operation has been the sustained operation with core outlet temperatures as high as 950°C.

In completing 21 years of operating in December 1988, the plant had accumulated greater than 122,000 hours of operation with a 66.4% overall average availability and had generated 1.67 billion KW hours of electricity. AVR was shutdown on December 31, 1988 and will be subsequently decommissioned. Decommissioning will include a safe enclosure with partial dismantling of components and performance of a post-irradiation examination program.

During the past few years, the operating mode of AVR had been increasingly oriented to performing test programs related to HTR performance and safety and the basic testing of pebble fuel elements of various types. During 1988, operations were centered almost exclusively on tests related to the safety of HTR's and in particular to the performance of simulated loss-of-cooling accidents and the planning for a controlled partial depressurization event to measure the release of fission products and activation products deposited on dust in the loop.

The simulated loss-of-cooling accidents were an extension of previous experiments performed in 1975 to demonstrate the response of the reactor to loss-of-forced cooling conditions. The present series simulated the more severe depressurization with loss-of-forced cooling accident. The first set of tests was run in May 1988 and temperature measurements were taken at several locations during the course of the event. The second series was run in October 1988 and temperatures internal to the core were measured by having pebble elements containing an assortment of metals and alloys with different melting points located throughout the core. The temperature vs. time measurements from the May series confirmed the expected slow

In fall 1988, during a planned shutdown for scheduled maintenance and in-service inspection, several bolt heads holding down the cover plates on the insulation in the hot ducts were detected in the six hot gas ducts which take hot helium from below the core to the steam generators. A few graphite dowels used to align the graphite blocks near the hot gas duct entrances were also found. The impact of these findings on the restart schedule is being determined and the shutdown period has been extended to February, 1989 to permit continued investigations.

The THTR is operated under a risk-sharing contract between the Federal Government, the State Government of NRW and HKG. The contract stipulates that, during the demonstration phase which terminates in 1991 according to the contract, the operating losses and the final decommissioning costs of the plant are to be shared on the basis of 60% by the Federal Government, 30% by the State Government and 10% by HKG. A funding limit of DM-450 million had been established to cover these costs. In late 1988, HKG submitted a request for the early decommissioning of the THTR on the basis that the present funding limit was insufficient to cover the recently estimated increase in decommissioning costs, the additional losses due to increased licensing requirements and potential downtime losses due to the possible interruption of the fuel supply for the plant. The request was submitted as a precautionary measure and was required by the contract when HKG foresaw the possible early attainment of the limit due to the cost increases and not on the basis of any dissatisfaction with the operation to date of the THTR. Increasing the funding limit and extending the demonstration phase are being considered by the government bodies with resolution expected in early 1989.

Table 2.1 is a summary comparison of some of the key features of the HTR plants in the FRG.

2.3 PROGRAM PARTICIPANTS

Key participants in the FRG-HTR program include the following:

Bundesministerium fuer Forschung and Technologie (BMFT) - The Federal Ministry for Research and Technology who provide funds for the HTR program which are also handled through the Project Office located at KFA Juelich. The Project Office is responsible for coordinating and monitoring both the Federal and State funded programs and for international cooperation.

North Rhine Westfalia (NRW) - The State in the FRG with, in the past, a strong engagement in the development of the

HTR. Provided funds for the HTR primarily for researchand development work related to coal processing using nuclear heat.

Hochtemperatur-Reaktorgesellschaft (HRG) - A group of utility companies incorporated in 1981 as a basic support group for future HTR projects. Current emphasis is on the HTR 500 design and licensing development.

ASEA-Brown Boveri Group (ABB) - A European manufacturer of power generation equipment formed by the merger, in January 1988, of ASEA and Brown Boveri. Hochtemperatur Reaktorbau GmbH (HRB) - is a member of the ASEA-Brown Boveri Group, serving as their HTR vendor. HRB is owned 55% by ASEA-Brown Boveri and 45% by General Atomics.

Siemens AG - A European manufacturer of power generation equipment and reactor vendor. Interatom (IA) - is a subsidiary of Siemens with responsibilities for advanced technologies including the HTR, and liquid metal reactors.

Hochtemperaturreaktor-Brennelement GmbH (HOBEG) - The subsidiary of NUKEM, the FRG nuclear fuel supply company, formed in 1972 with responsibility for manufacturing the fuel for the AVR and THTR and process development work on HTR fuels.

Kernforschunganlage Juelich GmbH (KFA) - The national laboratory in the FRG that is the center of HTR research and development and the site of the 15 MW(e) AVR plant. KFA is located near Juelich in the State of North Rhine Westfalia (NRW) and receives funding from the BMFT and NRW.

SECTION 3

JAPAN

Since more than 60% of Japan's primary energy supply comes from imported oil, reducing this dependence by using nuclear and coal continues to be a high priority in Japan. Japan already has a well established LWR industry to provide electricity and the long range strategy for electricity production emphasizes Fast Breeder Reactors and Advanced LWRs. A single, small (160 MWe) gas-cooled Magnox plant, Tokai 1, was built in the 1960's as a demonstration plant and continues to operate.

In recognizing that process industries in Japan required large quantities of high temperature heat (35% of total energy consumed is used to provide heat between 300°C and 900°C) and that future needs for coal gasification and thermochemical water splitting would require process heat at temperatures of 900°C or greater, Japan foresaw the Very High Temperature Gas-Cooled Reactor (VHTR) to supply industrial process heat as the most promising application of the HTGR technology. The VHTR was characterized as capable of producing outlet gas temperatures of up to 1000°C.

As a result, the Japan Atomic Energy Research Institute (JAERI) initiated research and development work on the VHTR in 1969. The following events have highlighted the HTGR program in Japan:

- Completion and successful operation of the main loop (1982) and two test sections (1983 and 1986) of the Helium Engineering Demonstration Loop (HENDEL) facility.

- Successful operation of the Semi-Homogeneous Critical Experiment Facility (SHE) to measure basic physics parameters and its reconstruction, completed in 1985, as the Very High Temperature Reactor Critical Assembly (VHTRC) to measure parameters as a function of temperature.

- Successful operation of the Orai Gas Loop-1 (OGL-1) since 1976 in the Japan Materials Testing Reactor (JMTR) as a test loop for the irradiation of HTGR-type fuel and fuel configurations.

- The investment in the HTGR program in Japan through FY-1988 totals about $465 million and the planned budget for FY-1989 is Y4862 million (about $39 million at 125 yen/dollar).

phase was initiated in Spring 1988 and is expected to result in clarifying Japanese criteria and requirements and in the selection of suitable concepts for Japan. Broader concerns being raised by the Japanese people on the safety of nuclear power have given additional impetus to these Study Group efforts.

3.2 PROGRAM PARTICIPANTS

Science and Technology Agency (STA) - The agency of the Japanese government providing funding for work at JAERI and through JAERI to industrial program participants.

Japan Atomic Energy Research Institute (JAERI) - The national nuclear research center responsible for performing and coordinating the government-sponsored efforts on the HTGR. JAERI subcontracts work to several industrial organizations who also conduct their own HTGR research and development programs. These industrial organizations include:

- Fuji Electric Company Ltd. - Work includes methods development and materials studies on the effects of the environment on high temperature metals and creep of tube metals at high temperature. Together with KHI, responsible for core design.

- Hitachi and Babcock Hitachi, Ltd. (BHK) - Perform general research and development activities. Would be responsible for the design of the pressure vessel and the metallic part of the reactor internals.

- Ishikawajima-Harima Heavy Industries, Ltd. (IHI) - Perform research and development work in the following areas: (1) hydrogen permeation testing; (2) improvement of heat transfer in heat exchangers; (3) testing of characteristics of high-temperature thermal-insulating materials; (4) development of emergency shut-off and bypass valves; (5) development of helium circulators, and (6) experimental study on helical coil heat exchangers.

- Kawasaki Heavy Industries, Ltd. (KHI) - Has been conducting studies in various fields of the HTGR such as: bellows, ceramic-coated thermal insulation materials, adhesion properties, and high-temperature metals, including welding techniques. Also, using their own test loop facilities, KHI is developing valves and heat exchangers. Together with Fuji, responsible for core design.

- Mitsubishi Heavy Industries, Ltd. (MHI) - Constructed its own helium loop test facility to perform materials tests and other high-temperature tests. MHI has had a major role in overall system design and international heat exchanger design since 1985.

- Nuclear Fuel Industries, Ltd. (NFI) - Performs research and development activities on fuel.

- Toshiba, Ltd. - Performs general research and development activities for reactor control and instrumentation in support of the JAERI Program.

- Toyo Tanso Co. - Develops graphite for use in HTGRs.

Japan Association for Nuclear Process heat (JANP) - A consortium of eight major Japanese industrial firms interested in applying nuclear heat to industrial processes. The companies are Mitsui and Co., Ltd.; Toshiba Corporation; Ishikawajima-Harima Heavy Industries Co., Ltd.; Toyo Engineering Corporation; Fuji Electric Co., Ltd.; Kawasaki Heavy Industries, Ltd.; Hitachi, Ltd.; and BHK. They perform VHTR application and process design studies for JAERI. In addition, they are encouraging studies of the use of the HTGR for both high temperature process steam and process heat for industry and for electric power production.

Research Association on HTGR Plant - A vendor study group interested in the potential of the HTGR for electricity production in Japan. Participants include Professor Shigehiro An, Emeritus Professor of the University of Tokyo as Chairman and Professor Yoichi Takahashi of the University of Tokyo and representatives from IHI, KHI, Toshiba, Hitachi, Fuji Electric, MHI, Japan Atomic Power Company and Kansai Electric Power Company.

SECTION 4

SOVIET UNION (USSR)

The USSR has had an ongoing HTGR research and development program for many years. Most of the work is performed at the Kurchatov Institute in Moscow. A number of experimental facilities are in operation including an irradiation loop for spherical fuel elements, two critical facilities and facilities to investigate pebble bed core characteristics, graphite friction and wear, and helium coolant technology at temperatures up to 1000°C.

Prior to the Chernobyl accident, technical papers by USSR delegates at various conferences indicated that two reactor designs using pebble bed cores were being investigated. One was the 50 MW(e) VGR-50 which would be used for the dual purpose of power and gamma irradiation. The other was the VG-400, shown in Figure 4.1, a dual purpose pebble bed HTGR producing both process heat for ammonia production and steam for electricity. The plant would have a thermal rating of 1000 MW(t), four primary loops, and a helium inlet temperature of 950°C into the intermediate heat exchangers.

4.1 PRESENT PROGRAM DESCRIPTION AND PLANS

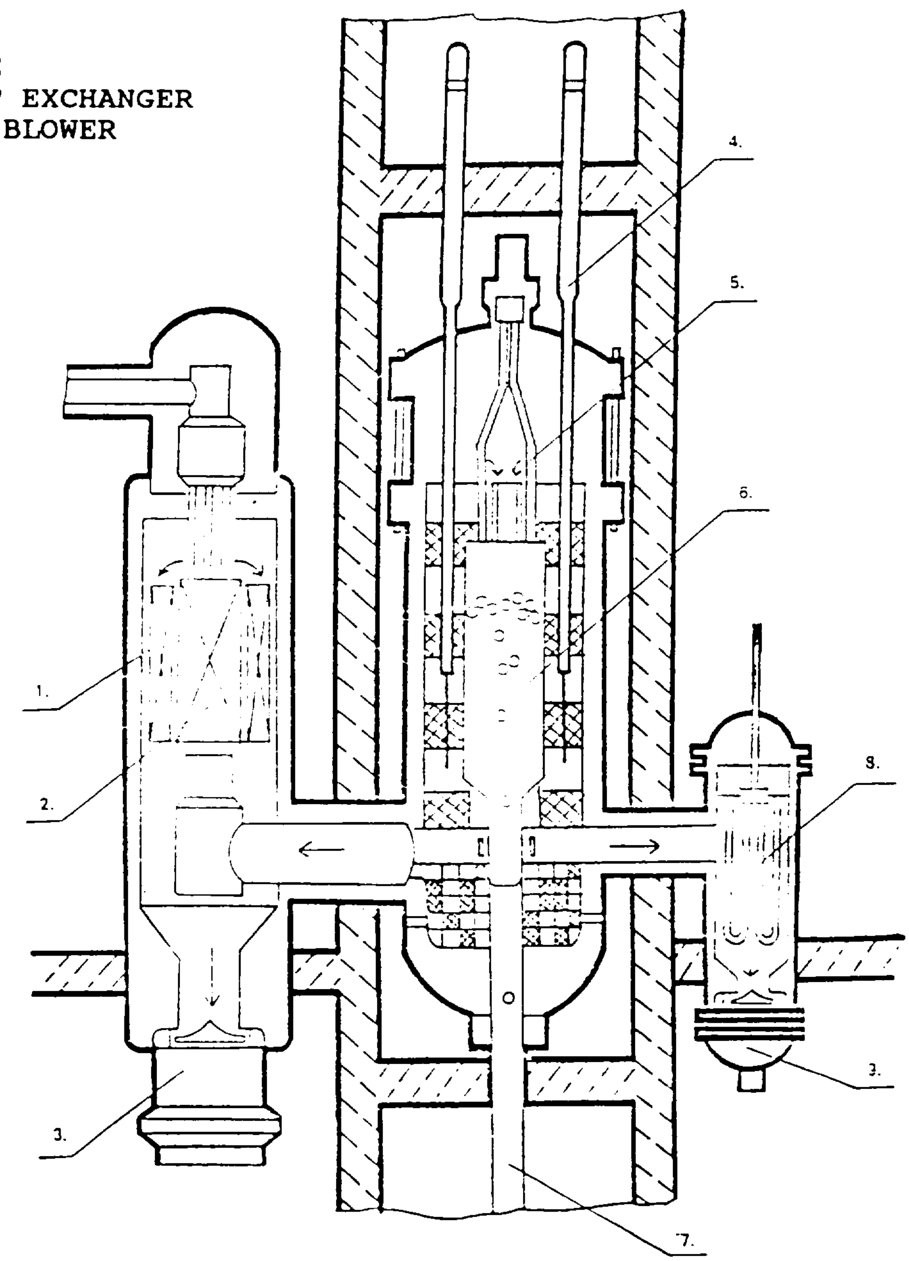
An interest in smaller, more inherently safe reactors became apparent after the Chernobyl incident. A closer working relationship developed between the FRG and the USSR and, in 1988, agreements were signed between the State Committee of the USSR for the Utilization of Nuclear Energy and the German HTR industry, ABB/HRB and Siemens/Interatom. Under the agreements, the USSR intends to build an experimental modular HTR plant with the support of the German industry. The details of the working arrangements are under discussion and formal contracts are still to be negotiated.

The conceptual design of the modular plant (VTR-M) that has evolved to date is very similar to the Siemens/Interatom side-by-side HTR-Module and is shown in Figure 4.2. Notable differences include the use of two auxiliary loops for decay heat removal and the incorporation of both an intermediate heat exchanger (for process heat experiments) and a steam generator in the main heat transport system. The stated intent is to operate initially with an outlet temperature of 750°C by mixing an adjustable core bypass helium flow with the higher temperature core outlet helium flow and generate steam only. Later, the mixed outlet temperature would be adjusted to 950°C, by changing the core bypass to zero flow, to generate both high temperature helium for process heat use in the intermediate heat exchanger followed by steam generation.

FIGURE 4.2

USSR VTR-M REACTOR

1. STEAM GENERATOR
2. HEAT EXCHANGER
3. MAIN GAS BLOWER
4. CONTROL ROD
5. LOADING TUBE
6. REACTOR CORE
7. DISCHARGE TUBE
8. AUXILIARY HEAT EXCHANGER
9. AUXILIARY GAS BLOWER



SECTION 5

OTHER COUNTRIES

5.1 UNITED KINGDOM

The United Kingdom (UK) has considerable experience with gas-cooled reactors. It has twenty-six Magnox reactors and fourteen Advanced Gas-Cooled Reactors (AGR's) in operation. The last four AGR's (Heysham II and Torness) entered service in 1988, essentially completing the present gas-cooled reactor construction program in the UK.

The British were early pioneers in the field of gas-cooled reactors and made significant contributions to HTGR development, especially in the areas of fuel, core and heat transfer technology. The 20 MW(t) Dragon reactor, which was sponsored by the Organization for Economic Cooperation and Development (OECD), Euratom and the UKAEA, was one of the principal HTGR test facilities until its decommissioning during the mid-1970s. The British HTGR Program was discontinued at that time because of a decision by the U.K. Department of Energy to concentrate on the development of the Steam Generating Heavy Water Reactor concept which, however, was abandoned a few years later. The AGR became the mainstay of the British nuclear reactor program in the 1970's but continuing controversy over the economics of the AGR system led to an extensive evaluation of the pressurized water reactor (PWR) and the decision to turn to the PWR for their next program. A summary of all of the Magnox and AGR plants in the world is given in Table 5.1.

Some of the oldest Magnox reactors, the first generation of gas cooled reactors, have been in operation for more than 25 years. Those reactors are fueled with natural uranium metal, clad with magnox (a magnesium-aluminium alloy), and use CO_2 as the coolant. The early Magnox plants had steel pressure vessels while the later, higher output versions at Oldbury and Wylfa use prestressed concrete reactor vessels. In the United Kingdom, the higher power output versions had to be de-rated by approximately 20% following discovery of a steel oxidation problem in 1969 and except for the twin Hunterston A station, these reactors continue to be operated in this manner. Other temporary operating restrictions on the Magnox plants have gradually been relieved through refurbishment of equipment and in general the Magnox reactors have shown a steady improvement over the years in capacity factor. Reviews were initiated in the early 1980's to investigate the potential of extending the operation of the older Magnox plants beyond the original design life. In April 1988, as a result of their review, the Central Electricity Generating Board (CEGB) decided to shutdown the Berkeley station. One of the reactors was shutdown in late 1988; the second reactor is scheduled for shutdown in early 1989. The CEGB is continuing to assess and modify the Bradwell station to meet the requirements for continued operation. The South of Scotland Electricity Board (SSEB) long term safety review of Hunterston A was delivered to the Nuclear Installation Inspectorate in 1988. Initial indications are that continued operation of Hunterston A to at least 1994 (30 years) will be recommended.

The AGR plants have also had problems with oxidation and have experienced other problems which precluded on-line refueling in the early years of operation. Development work has resulted in the ability to progressively raise the outputs to more than 97% of the original designed gross electric output and thermal ratings greater than 100% of design. On-line refueling was able to commence in 1982 but with the power outputs temporarily reduced to 30-40%. It is expected that incorporation of new fuel elements will permit refueling at power levels up to at least 70%.

The operation of the last set of AGRs (Heysham II and Torness) has been very satisfactory to date. Heysham 2 has had an availability factor well above the target level since commissioning in mid-1988. The CEGB anticipate that the output of the reactors will be able to be progressively raised to about 700 MWe each (about 40 MWe above design rating) with minor modifications. The first reactor at Torness has been running at a high load factor with a gross output as high as 682 MWe.

Despite the problems, the overall experience gained in the United Kingdom gas-cooled reactor program is of great value to the development of the HTGR. Much of the experience in designing, building and operating their gas-cooled reactors comprises an excellent support base. An agreement to implement a formal cooperation between the United Kingdom and the United States was signed in 1988. It is expected that this agreement will enable an effective sharing of information.

Also in 1988, the U.K. Government announced that legislation to privatize the electricity supply industry would be proposed. The framework would separate generation from distribution and split up the present monopolies held by the CEGB in England and Wales and by the SSEB and the North of Scotland Hydro-Electric Board (NSHEB) in Scotland. When implemented, the changes in structure might present an opportunity for other nuclear systems in addition to the large PWR's. In particular, repowering of some of the early reactor sites could provide an opportunity for the MHTGR.

industry to maintain their knowledge of HTR technology and to be able to participate in future projects. The IGNT request to the Swiss Ministry of Energy for funding for research and development support work for this reactor power plant has been approved by the government with the proviso that industry share the cost on a 50/50 basis.

The members of the IGNT include:

- Swiss Federal Institute for Reactor Research (EIR)
- Bonnard and Gardel Consulting Engineers, Ltd. (PCRVs)
- Brown, Boveri & Cie AG of Baden (BBC-CH) - now a member of the ASEA Brown Boveri Group (Turbomachinery)
- Electrowatt (Consulting Engineers)
- Gebruder Sulzer (Sulzer Brothers of Winterthur) (Heat Exchangers)
- Motor Columbus (Architect-Engineers)

5.4 PEOPLE'S REPUBLIC OF CHINA (PRC)

The People's Republic of China (PRC) is indicating an increasing interest in the HTGR, particularly in the smaller modular versions being developed in the FRG and in the USA. These modular HTGRs would satisfy the country's need for smaller electricity generating units for isolated areas not presently covered by the existing grid system and as cogenerating units for both densely and sparsely populated regions. The possible use of the HTGR in heavy oil recovery has also been a motivating factor.

Although interest began in the early 1970's and research work, primarily in coated fuel particles, was started at the Institute of Nuclear Energy Technology (INET) at Tsinghua University in Beijing and at other energy research institutes under the Ministry of Nuclear Industry, interactions with organizations outside of the PRC did not begin until the early 1980's. Since that time, attendance at various conferences, visits by experts and the assignment of technical people to work in the FRG have led to a greater insight into the PRC program. The main interaction has been with the FRG program but an increasing interest has also been developing in the USA MHTGR Program.

The major problem in the PRC regarding a greater participation in HTGR activities is the lack of hard currency to support large scale foreign interactions. It is evident that the PRC would like to build a modular HTGR if favorable terms could be reached.

SECTION 6

INTERNATIONAL AGREEMENTS

International Agreements to exchange information in HTGR technology play an important role in furthering the development efforts, in eliminating unnecessary overlap in some technology areas, and in some cases, implementing cooperative programs towards a common goal. The following summary of International Agreements may not include all such agreements.

6.1 UNITED STATES AND FEDERAL REPUBLIC OF GERMANY

- Under an overall government-to-government "Umbrella Agreement" signed in 1977, an avenue for cooperation in government sponsored work between the USA and the FRG (the agreement was also signed by Switzerland and France) was established. In 1979, the final wording for the Implementing Agreement for the Umbrella Agreement was negotiated and initialed by representatives of the USA and the FRG. Subsequent agreement with the text was obtained from Switzerland. The Implementing Agreement has never been formally signed. However, it was agreed in 1980 by the USA, FRG and Swiss representatives that further cooperation was in the mutual interest of the parties and that the ongoing cooperation would be conducted in a manner consistent with the terms of the agreement.

  Whereas work under the Umbrella Agreement had previously been carried out through Project Work Statements (PWSs) of which some 100 separate cooperative tasks had been identified in eleven different technical areas, the Implementing Agreement permitted the consolidation of several small tasks into better defined cooperative programs. This was achieved for the ongoing work in the subprogram areas of:

  - Fuel, Graphite and Fission Products
  - Spent Fuel Treatment Development
  - Metallic Materials

  Technical personnel in these subprogram areas have been exchanged between the USA and the FRG since 1980 with such assignments lasting up to a year or more. Regular meetings on the subprograms are also held.

Energy Authority (UKAEA)/Central Electricity Generating Board (CEGB) and the United States Department of Energy (USDOE). Implementation would involve the CEGB in the UK, GCRA in the USA, as well as national and industrial laboratories on both sides. The exchange of information will initially concentrate on graphite technology, particularly related to specifying failure criteria.

6.4 FEDERAL REPUBLIC OF GERMANY AND JAPAN

- An agreement between KFA and JAERI to cooperate in selected R&D areas on the VHTR was signed in 1979.

- An agreement for information exchange on the KVK facility at Interatom and HENDEL facility at JAERI was signed by Interatom and JAERI in January 1984.

6.5 FEDERAL REPUBLIC OF GERMANY AND THE SOVIET UNION

- An agreement to jointly develop and build an experimental modular HTGR plant was signed in 1988 between the State Committee of the USSR for the Utilization of Nuclear Energy and the German HTR industry, ABB/HRB and Siemens/ Interatom. Further implementing agreements are under discussion.

- A government-to-government agreement to cooperate on research and development for process heat applications was also signed in 1988.

6.6 FEDERAL REPUBLIC OF GERMANY AND THE PEOPLE'S REPUBLIC OF CHINA

- A nuclear cooperation agreement between Interatom and KFA in the FRG and the Institute for Nuclear Technology of the Tsinghua University in the PRC was signed in late 1988. The construction of a 10 MWt HTR test reactor is contemplated under the agreement.

6.7 INTERNATIONAL ATOMIC ENERGY AGENCY (IAEA)

- The IAEA sponsors an International Working Group on Gas-Cooled Reactors (IWGGCR) which holds working group meetings, technical specialists meetings and provides information exchange on HTGRs. Current member countries are Austria, Belgium, France, FRG, Japan, Netherlands, Poland, Switzerland, UK, USA and USSR. The IWGGCR holds meetings to review progress and facilitate technical exchange in HTGR programs among the member nations and specialists and technical committee meetings covering various technical subjects.

SECTION 7

GAS-COOLED REACTOR PROGRAMS ACRONYM INDEX

ABB	ASEA Brown Boveri Group - the large power equipment design and manufacturing company formed by the amalgamation of ASEA of Sweden and the Brown Boveri Company of Switzerland.
AGR	Advanced Gas-Cooled Reactor - United Kingdom's advanced design gas reactor.
AVR GmbH	Arbeitsgemeinschaft Versuchsreaktor GmbH - The utility group which operates the AVR nuclear power station.
BBC-CH	Brown, Boveri & Cie AG of Baden (now part of ABB) - A major Swiss company which manufactures turbomachinery.
BBC-D	Brown, Boveri & Cie AG of Mannheim - (now part of ABB) A large German power equipment manufacturer. BBC-D built AVR together with Krupp, under joint company BBK (Brown Boveri Krupp). Responsible for construction, BOP engineering and certain nuclear component manufacture for THTR-300.
BBW	Bundesamt für Bildung und Wissenschaft - Swiss office of Science and Research. Equivalent to U.S. DOE insofar as energy research and development is concerned.
BMFT	Bundesministerium für Forschung und Technologie - Federal Ministry for Research and Technology in the FRG. Equivalent to U.S. DOE insofar as energy research and development is concerned.
BMU	Bundesministerium für Umwelt, Naturschutz und Reaktorsicherheit - Federal Ministry of Environment, Protection of Nature and Reactor Safety in the FRG.
BNI	Bechtel National Inc. - A large architect engineering/construction firm and a participant in the USA MHTGR program.
CEA	Commissariat a L'Energie Atomique - The French Atomic Energy Commission.
CE	Combustion Engineering Inc. - One of the light water reactor (PWR) vendors in the United States and a participant in the USA MHTGR program.

IA	Interatom GmbH - The subsidiary of Siemens AG located in Bensberg. Responsible for work on advanced reactor concepts and developer of the 80 MW(e) HTR-Module concept.
IAEA	International Atomic Energy Agency with headquarters in Vienna, Austria.
IGNT	Schweizerische Interessengemeinschaft zur Wahrnehmung Gemeinsamer Interessen an der Entwicklung Nuklearer Technologien - Swiss industry and national nuclear reactor research laboratory group interested in participating in the HTR with Germany.
IHI	Ishikawajima-Harima Heavy Industries, Ltd. - Industrial participant in Japanese HTGR program.
INET	Institute of Nuclear Energy Technology at Tsinghua University in Beijing, People's Republic of China (PRC) - major center for HTGR technology in the PRC.
IWGGCR	International Working Group on Gas-Cooled Reactors is an information exchange group under IAEA auspices.
JAEC	Atomic Energy Commission of Japan.
JAERI	Japan Atomic Energy Research Institute - The Japanese national laboratory (counterpart of KFA and ORNL).
JANP	Japan Association for Nuclear Process Heat - A consortium of seven industrial companies in Japan headed by Mitsui Co. - Promoting Japanese VHTR process heat applications.
JAPC	Japan Atomic Power Company - Company set up by Japanese utilities to construct and operate first-of-a-kind nuclear power plants in Japan.
JMTR	Japan Materials Testing Reactor.
KFA	Kernforschungsanlage Jülich - One of the two national laboratories for nuclear-related research in Germany. A significant fraction of its activities are devoted to HTR R&D.
KHI	Kawasaki Heavy Industries, Ltd. - Industrial participant in Japanese VHTR program.
KVGH	Company formed to sell licenses for technology developed under the German HTR Program (40% HRB, 30% IA, 30% KFA).

PNDC Power Reactor and Nuclear Fuel Development Corporation - Japanese company which does research and development, design and construction of nuclear power plants.

PNP Prototypanlage Nukleare Prozesswaerme - Prototype Nuclear Process Heat System program supported by BMFT and the State of Northrhine Westphalia (NRW) for nuclear-heated coal gasification.

PSC Public Service Company of Colorado - A United States utility headquartered in Denver, Colorado - owns and operates The Fort St. Vrain Nuclear Generating Station.

PTH Projekttrager HTR - The Project Office of BMFT located at KFA responsible for coordinating and monitoring the BMFT funding, the project progress and international cooperation.

RSK Reaktorsicherheitskommission - Reactor Safety Commission in the FRG.

SHE Semi-Homogeneous Critical Experiment Facility - Used for HTGR physics tests in Japan.

STA Science and Technology Agency Japanese government agency which is funding the HTGR Program.

SWD Stadtwerke Duesseldorf AG - Municipal utility of Düsseldorf - The lead utility in AVR and HTP.

TUEV German Federal licensing agency.