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SUMMARY OF

FOREIGN HTGR PROGRAMS

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SUMMARY OF FOREIGN HTGR PROGRAMS

Gas-Cooled Reactor Associates

June 1980

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FOREWORD

This report has been compiled by Gas-Cooled Reactor Associates as a reference document for all U.S. Program Participants. It contains pertinent information on the status, objectives, budgets, major projects and facilities, as well as user, industrial and governmental organizations involved in major foreign gas-cooled thermal reactor programs.

This is the second issue of this document, the first was issued in March 1979. The format has been revised to consolidate material according to country. These sections are followed by the Foreign HTGR Program Index which serves as a quick reference to some of the many acronyms associated with the foreign HTGR programs.

I. FEDERAL REPUBLIC OF GERMANY

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A. Program Description and Status

The HTGR Program in the FRG is similar in many aspects to the U.S. program, both organizationally and technically. Organizationally, both programs have participation from utility/user groups, industry and the Government, both are substantially supported through government funding and the two programs have as their long-range goal the utilization of the HTGR for process heat and electricity production. Both programs share a broad base of common technology which provides incentives for cooperation and information exchanges between the technical areas. However, a principal technical difference lies in the reactor core design. The German design utilizes a Pebble Bed concept having spherical fuel elements which are continuously loaded and discharged through the core. The U.S. reference core design is based on a prismatic black fuel element design that employs a patch loading scheme in which only a portion of the core (nominally one-fourth) is reloaded on an annual basis. This difference in core design does, however, provide a backup design for each program, thus reducing the overall development risk for the HTGR.

As noted, the long-term goal stated for the German HTGR Development Program is the market introduction of the system for process heat and electricity production. The near-term goal is to demonstrate that HTGR technology is feasible for both applications and that it can be economically applied. The incentives for the FRG Program are derived from the general long-term energy supply strategy. It is expected that, as with the United States, coal will have to be a major contributor to the German energy supply in the foreseeable future. This is because considerable domestic resources exist in Germany in addition to the large world-wide deposits. It is the German position, however, that there are sufficient technical, economical and environmental aspects likely to have increasing importance in the future which necessitate the development of low pollution end-products by appropriate conversion technologies. Due to extensive experience and the advanced status of the conventional gasification technology of lignite and hard coal, the generation of synthetic natural gas (SNG) and industrial gas by the utilization of heat from HTGR's is the primary goal of the HTGR process heat program.

The potential of the HTGR for electricity production is also acknowledged as a National goal. The high coolant outlet temperature of the HTGR results in high efficiency and, therefore, a low waste heat discharge to the environment. Greater siting flexibility can be achieved in combination with dry cooling. There is a continuous trend, particularly from the FRG User's point of view, to have a diverse reactor system available competitive with LWR's in Germany and, furthermore, to maintain competition not only between reactor industries but also between reactor systems.

There is a need and strong justification within the German HTGR Program to develop a follow-on construction project to the THTR-300 plant which is expected to be completed in 1983/84. With the increasing demands on non-oil producing nations to find alternate energy sources, there is an added interest in the FRG in coal liquefaction and gasification. The obvious link between a high-temperature nuclear heat source with these processes has attracted the interest of the German Coal and Gas Boards, and the electric utilities, and these three groups have been contracted by the government to conduct a study to determine the feasibility of coupling an HTGR steam/electricity-producing plant with a coal gasification plant as a possible near-term project. Both the HHT and PNP Projects are currently viewed in the FRG as longer term projects requiring further technological development before a demonstration plant of either design can be built. This near-term project (which has yet to be named) is seen as a reasonable first-step toward the eventual goal of deploying the HTGR as a source of high-temperature process heat by linking the lower risk HTGR-SC with a coal gasification plant, and thereby concentrating efforts on solving institutional problems associated with coupling a nuclear energy source with a chemical process plant. This project also provides incentives to the German HTGR Utility Group, since it further advances the HTGR technology which, in their view, is a future source of safe and clean electric power.

Budget

From 1960 through 1979 the FRG has invested approximately 2.57 billion DM in HTGR development. The budget breakdown for the Program during 1979 is approximately as follows:

AVR Operation	10 M DM
THTR Construction	255 M DM
Advanced systems for electricity production; i.e. HHT	
Design work and R&D	75 M DM
Advanced systems for process heat applications; i.e. PNP	
Reactor design work and R&D	105 M DM
Coal gasification	40 M DM
Fuel recycle	15 M DM

Exclusive of the THTR, the budget is supported principally by the BMFT and the State Government of North Rhine - Westphalia (NRW), whose contribution accounts for approximately 90% of the program funding. Other participants contribute 10% towards the program funding. Work at the national laboratory, KFA, is supported at a level of about 100M DM/year, of which the BMFT contributes 90% and NRW contributes 10%.

B. Reactor Demonstration Project

THTR-300

After the first successful and encouraging experience with the small 15 MWe research reactor (AVR), the construction of the 300 MWe demonstration plant (THTR) was started in 1972. The completion of this power plant has been given first priority in the German HTGR Program. This means that the main industrial and engineering capacities are working for the THTR-300 project while a lesser, although substantial, effort is currently being directed toward the more advanced future projects. Both the successful start of operation and operating experience of the THTR-300 are considered as indispensable prerequisites for commitment to a subsequent plant.

For the THTR-300, a construction time of 61 months was expected in 1972--the presently expected figure is 130 months. Approximately 80% of the total construction is now completed and the majority of the partial construction permits has been granted. Following a commissioning phase of approximately one year, hand-over of the plant to the utility is now scheduled for 1984. The main construction delays have arisen due to the development process of the licensing procedures and criteria which changed significantly from the position in 1972, when the basic design was completed and licensed.

C. Advanced Design Projects

The German HTGR Program strategy is now governed by the questions of the timing for a construction project after completion of the THTR and the type of plant considered as feasible.

There is general agreement between all the German parties involved (Users, reactor industry and government) that a successful industrial development and an economic application of the technology in the electricity and particularly in the heat market, can only be achieved on the basis of further construction and operation experience and not with long-term research and development programs. As mentioned above, it is the German government's position that this requires a near-term decision for a subsequent construction project most consistent with development maturity and feasibility. It is stated that this rationale requires the start of construction of the next HTGR plant approximately one to two years after full power operation of the THTR.

The emphasis of the FRG advanced HTGR design work until recently has been on two Projects and these are described briefly below:

a) HHT Project which aims at the combination of the HTGR with a direct cycle helium-gas turbine. This system has been investigated since 1972 in a joint German/Swiss Program. The motivation of this advanced HTGR application was derived from the expectations concerning high plant efficiency, utilization of dry cooling towers and district heating without reduction of efficiency. In the last two years, detailed design and optimization studies concentrated on open problem areas of this concept. Several technical design details have been identified which require additional design and research and development work; some of it not foreseen. Although some problem areas with respect to the pebble bed core have been identified, the design has been determined to be fundamentally feasible.

One of the major findings of recent FRG studies was that the necessary HHT Project development tasks such as materials testing, gas turbine demonstration, component development and testing, graphite qualification, design optimization and licensability require a longer development time than originally projected and, therefore, will not allow a decision for construction before the late 1980's. As a result, the German government has concluded that the HHT Project, in its present design, is not sufficiently mature to be a near-term successor to the THTR Project.

b) PNP Project is the design study for the application of the HTGR for process heat generation as a first step aimed at the gasification of lignite and hard coal to produce substitute natural gas. In 1977 a program was launched to introduce the technology on the basis of a 500 MWt prototype plant (PNP) with two gasification loops: one for the hydrogasification of lignite including a branch for the chemical heat pipe system, and the other for combined steam/hydrogasification of hard coal. A preliminary project time schedule envisaged start of construction in 1985. The main technically innovative features of this system are the increase of the maximum reactor gas temperature to 950°C, the combination of a reactor with a large chemical plant, and the gasification processes.

In the last two years a preliminary reference design of the prototype plant has been developed by the FRG. From this design work it was possible to identify the open problem areas and main development tasks, to define the boundary conditions and requirements for the component and materials development, and to define safety-relevant questions on the basis of a preliminary plant concept. It is the opinion of the BMFT that the material qualification, development and testing of the heat-exchanging components, elimination of tritium in the final product, licensability of the combined nuclear-chemical plant, and successful demonstration of the feasibility of the steam gasification on a pilot plant scale are the most important and time-consuming development tasks. Based upon these preliminary design efforts, the BMFT has concluded that a decision for a construction start could not be made before the end of the 1980's. Therefore the PNP Project, in its present design, is not currently viewed as an appropriate near-term THTR successor.

D. Major Facilities

1. AVR

The AVR is a 15 MWe HTGR steam cycle demonstration plant in Germany. It was built by Brown-Boveri-Krupp Reaktobau GmbH and has been operating since 1967. Its purpose is to demonstrate the feasibility of an HTGR with spherical fuel elements and high operating temperatures. The operating utility group is Arbeitsgemeinschaft Versuchsreaktor (AVR) mbH. The following is a summary of operating experience on the AVR:

a) Average availability over ten years of 78% with its annual availability in 1976 reaching 92%.

b) In 1974, core outlet temperature was raised from 850°C to 950°C.

c) Over 1.5 million spherical fuel element movements have been made with several different types of fuel. The oldest have reached burn-up values of 180,000 MWD/t heavy metal.

d) Loss-of-coolant flow tests have been performed which include failure to insert control rods. The reactor shut itself down and remained subcritical for 24 hours.

e) A steam-generator leak occurred in May 1978 which dumped 24 tons of water into the PCRV while the plant was shut down. After the remaining water is removed, it is planned to dry the system using evacuation. The plant has been repaired and is now in the final check-out phase prior to returning to normal operation.

2. EVO (Oberhausen)

Background

The Oberhausen helium turbine plant was put into operation in 1975 and was designed for both the commercial production of electric power and heat for district heating. The overall system was designed for nuclear service, particularly the shaft seals and helium cleaning systems. The unit is operating, however, with a coke oven gas-fired heater rated at 160 MWt. The electric power rating is 50 MWe, the district heating output is 53 MW, and the waste heat is 57 MW which leads to an overall efficiency of 64%.

Operating Experience

To date, 10,000 hours of operating time have been achieved. At higher speeds, vibration in the rotor shaft has developed. It has been determined that the vibration is caused by gap excitation at the blade tips and in the labyrinth seal because of the long and narrow high pressure shaft. The vibration has limited the plant operation to 70% of design.

The rotor is currently being replaced with a new design. When the rework is complete, test programs will be conducted on:

a) Causes of rotor vibration.

b) Mechanical vibrations and sonic fields in hot gas ducts.

c) Insulation materials performance.

d) Dynamic behavior of turbine auxiliary systems.

3. HHV (Helium Circuit Test Facility)

Background

The HHV facility was designed as an integral part of the HHT Program. It was designed so that test results could be extrapolated for use by the HHT Project. The system was designed to give helium mass flows of about 200 kg/sec, at temperatures of approximately 850°C and a pressure of at least 50 bar. The order for the plant was placed by KFA to BBC Mannheim in 1972 and construction was completed near the end of 1976. The commissioning phase for this facility began in early 1977.

Operating Experience

During the start-up period, several interruptions occurred caused by oil leakage. Due to improper handling of the oil cooling system of the turbine bearings, an oil ingress of more than 1000 l into the circuit led to contamination of the total system including insulation and valves. The system required extensive clean-up after this spill, and in the subsequent check-out testing some helium gas leakages at connections and flanges were detected, which were probably due to the oil effects on the gaskets. Weld sealing of the flanges was therefore necessary and this task was accomplished in late-1979. Subsequent trial runs during early 1980 have given indications of helium and oil leaks within the system which will require further corrective action before the HHV facility can be commissioned.

E. User/Industrial Participants

1. Users

a. Utilities

The utilities listed herein will be members of the proposed HTGR Utility Users Group. There are private and municipal utilities in the project group, and are organized as shown in Figure 1. They are listed below:

Preussiche Elektrizitats AG (PREAG)

PREAG is the second largest utility in FRG. It is privately-owned and located in Hannover. It has assumed the lead in organizing the HHT Utility Group. Its operating manager is H. Suchanek who is in charge of the operations of all generating stations. He has been the leader of the utilities for the German HHT Program and has assumed the leadership role in forming the Utility Group.

Rheinish-Westfalisches Elekltrizitatswerk AG (RWE)

Headquartered in Essen, RWE is Germany's largest utility with approximately 50% of FRG's installed capacity. By the fact of its size, RWE has a major voice in the Utility Group.

Nordwestdeutsche Kraftwerke AG (NWK)

A privately owned utility headquartered in Hamburg. It is the lead operating utility for the HHV Project.

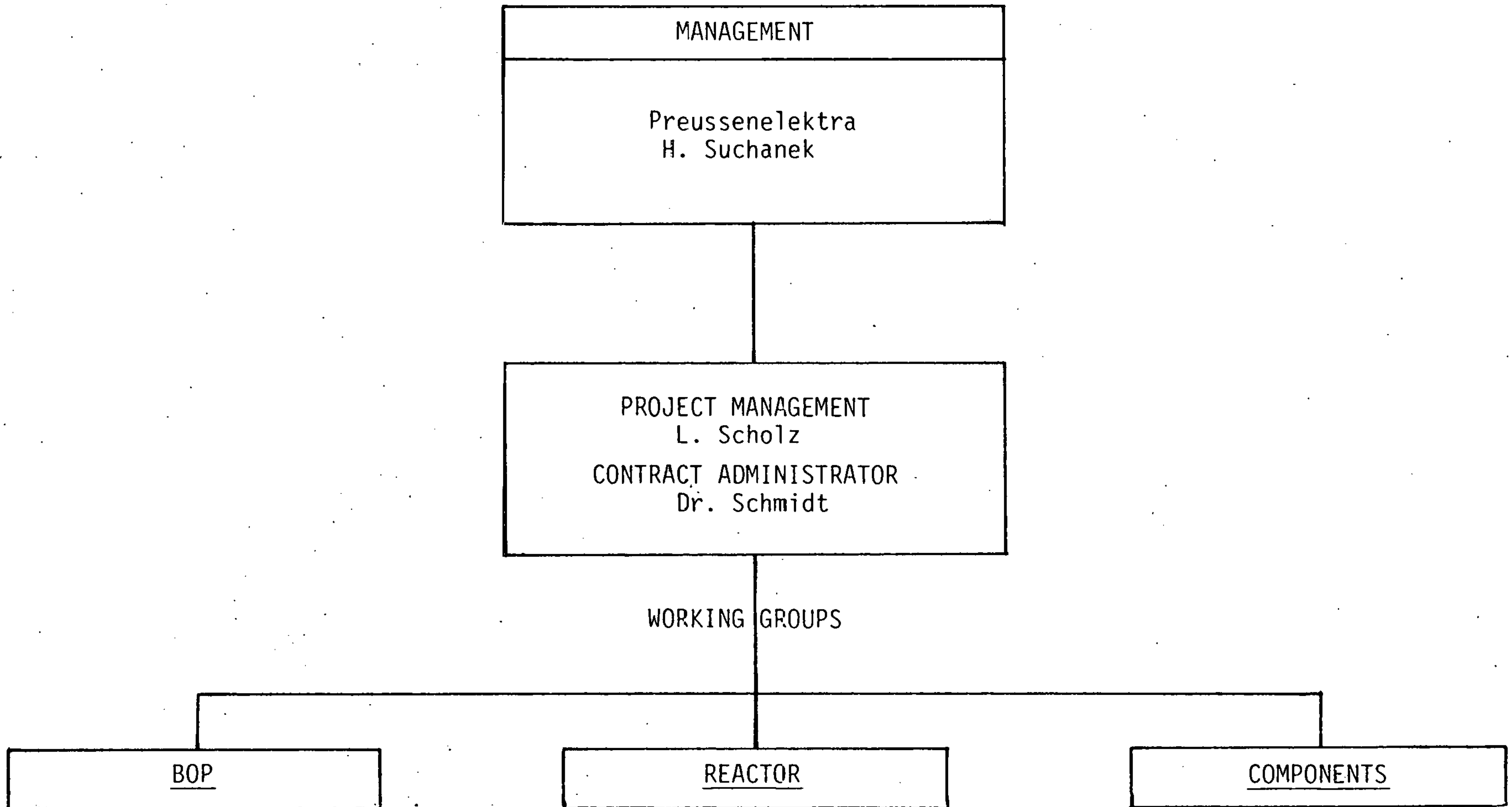
STEAG Aktiengesellschaft (STEAG)

Private electricity generating company located in Essen and a subsidiary of Ruhrkohle.

Hamburgishe Elektrizitatswerke AG (HEW)

Municipal utility of Hamburg.

EXPECTED ORGANIZATION CHART OF FRG UTILITY USERS GROUP



Neckarwerke Electrizitatsversorgungs AG (NW)

Municipal utility of Esslingen.

Stadwerke Dusseldorf AG (SWD)

Municipal utility of Dusseldorf, lead utility of a consortium of small municipal utilities holding approximately one-quarter of the shares of the utility group.

b) Process Heat Users

Ruhrkohle

German coal company that is a member of the PNP Users Group (PPNP).

Ruhrgas

German gas company that is a member of the PNP Users Group (PPNP).

Rheinishe Braunkohlenwerke AG (RBW)

This German coal company participated as a member of the PNP Users Group to provide technical input into the coal gasification portion of the PNP technology.

2. Industry

Brown-Boveri & Cie AG (BBC-D)

Brown-Boveri of Mannheim is a large European manufacturer of power generation equipment such as turbine generators, transformers and circuit breakers. It joined with General Atomic Company (GAC) to form HRB in which it holds 55% equity interest.

Hochtemperatur Reaktorbau GmbH (HRB)

HRB is owned by BBC-D (55%) and GAC (45%). It was formed to design and offer HTGR's in Germany. HRB is currently developing and designing the nuclear heat source for the HHT Project. Besides being the leading industrial partner in the HHT Program, it also is the NSS supplier for the THTR-300 Project.

Kraftwerkunion (KWU)

KWU is the leading European LWR supplier, and is owned by Siemans, which is one of the world's leading manufacturers of heavy machinery and consumer appliances. KWU, through its Erlangen offices, has recently become more directly involved in the HTR Program as a principal participant in the on-going near-term project study.

Gesellschaft fur Hochtemperaturreaktortechnik (GHT)

GHT is a subsidiary of INTERATOM which is a wholly-owned subsidiary of Kraftwerk Union (KWU). GHT was formed specifically to market and produce the nuclear heat source for the PNP Project. It is now a member of the Konsortium HTR and the Development Partnership HTR (EG) and will produce reactor internals for the HHT.

Konsortium HTR

This consortium was formed by the combination of HRB and GHT from the HHT and PNP Projects. It was to provide the engineering and design base for the nuclear heat supplies for both German HTR Programs.

Nuclear-Chemie und Metallurgie GmbH (NUKEM)

NUKEM is a leading German nuclear fuel company and is a participant of the HTGR Program. It owns 100% of HOBEG and is in turn owned by Degussa (45%), Reinish-Westfalisches (RWE) (25%), Rio Tinto Zinc (18%), and Metallgesellchaft (12%).

Hochtemperaturreaktor-Brennelement GmbH (HOBEG)

HOBEG is a subsidiary of NUKEM (see above). It was formed by NUKEM in 1972 and holds GAC's license for German HTGR fuel technology. At present, it is manufacturing fuel for both the AVR and THTR reactors, as well as doing research work for new fuels production processes. HOBEG is 100%-owned by NUKEM, but GAC has an option to buy 49% equity.

Bergbau Forschung GmbH (BF)

BF participated as one of the partners in the PNP industrial consortium. BF has been working on the design and research for the coal gasification portion of the PNP plant, and also operates a pilot hydrogasification plant (WKV-I) in Essen, Germany.

F. Umbrella/Implementing Agreements

Background

Although limited cooperation has been under way in the field of the Gas-Cooled Reactors since 1977, efforts have been proceeding to develop the next level of Implementing Agreements and to provide proper management and the legal basis for further cooperation. In November of 1979 the final wording for the HTR Implementing Agreement was negotiated and initialled by representatives of the BMFT and DOE. Subsequent agreement with the text was obtained from the Swiss BBW.

Status

At the present time (July 1980) the status of the Implementing Agreement is as follows:

The U.S., FRG and Swiss met to review the national Gas-Cooled Reactor programs in February 1980. It was agreed at that time that cooperative activities could not be planned beyond the U.S. FY 1980 because of uncertainties in the U.S. programs' funding, but that provisions should be made for further cooperation beyond FY 1980, since such cooperation was in the mutual interest of the parties. The following recommendations were developed for the HTR Implementing Agreement:

a) Formal signature should be deferred until the U.S. Program is better defined.

b) On-going cooperation will be conducted in a manner consistent with the terms of the Agreement.

c) Final signatures will not require further reconsideration of the Agreement.

Work under the Umbrella Agreement had been carried out through Project Work Statements (PWS's) of which some 100 separate cooperative tasks had been identified in eleven different technical areas. An objective of the Implementing Agreement is to consolidate these small tasks into better defined sub-programs, and a recommendation resulting from the February meeting was to condense the work which is scheduled to continue into two sub-programs: (a) Fuel, Graphite, and Fission Products, and (b) Spent Fuel Treatment. Planning in the sub-program areas of Materials, Process Heat Design and Reactor Analysis should continue in order to facilitate immediate cooperation when the Implementing Agreement is signed.

II. JAPAN

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A. Program Description and Status

In September 1977, the Atomic Energy Commission of Japan (AEC) released a Long-Term Atomic Energy Research, Development and Utilization Program for the next ten years, which emphasized the importance of the direct use of nuclear process heat and the need to develop the multi-purpose Very High Temperature Gas-Cooled Reactor (VHTR) to make the direct use of process heat possible. The AEC Program sets out the first stage for the development of the multi-purpose VHTR as an experimental reactor to start operation in the early part of the decade beginning from 1985. This would aim at about 1000°C temperature at the reactor outlet for nuclear energy to be used for steelmaking, hydrogen gas production, coal gasification, etc.

The Japan Atomic Energy Research Institute (JAERI) has long been aware of the need for the direct use of nuclear process heat, and has been engaged in research and development of the experimental VHTR since 1969. Nuclear process heat application technology has also developed in parallel with the VHTR design. The research and development of nuclear steelmaking was adopted by the Agency of Industrial Science and Technology (AIST) and the Ministry of International Trade and Industry (MITI) as a National Research and Development Program in 1973. The nuclear process heat application studies for steelmaking are being carried out by a consortium of twelve companies and a research institute which joined together in 1973 to form an association called Engineering Research Association of Nuclear Steelmaking (ERANS). The VHTR Project being carried out by JAERI and the nuclear process heat work project being performed by ERANS are described in the following sections on Japan's HTGR Projects.

Budget

The budget for 1980 was set at $17M U.S. Dollars and is directed toward support of the VHTR design efforts and for the continued support of the research and development programs. The total Japanese expenditures to date for the VHTR Program and the nuclear steelmaking process has been approximately $120 million U.S.

B. Major Projects

1. Design Study of Experimental VHTR

Studies on the design of the experimental VHTR began in 1969 and since then the main focus has been on designing the VHTR and the analysis of its characteristics. The first conceptual design was completed in 1975 and since that time, the design has been improved several times. The VHTR is a helium-cooled graphite-moderated reactor supplying the thermal output of 50 MWt, and the coolant temperature at the outlet of the reactor is specified as 1000°C. The VHTR must be provided with the functions as follows:

a) Feasibility test for nuclear process heat applications.

b) Irradiation test for development of fuel and material for high-temperature use.

c) Confirmation test for HTGR plant safety.

The plant system of the experimental VHTR concerns the design philosophy of how to transmit the reactor heat to process components or cooling apparatus. In this design, the reactor with the outlet temperature of 1000°C and its cooling system were emphasized rather than the process components in this plant system. Output power of 50 MWt is considered as an appropriate size. The reactor is provided with two systems of primary cooling circuit. Each of them is connected to the secondary cooling circuits with an intermediate heat exchanger. The steam reformer will be placed in one of two secondary cooling circuits. Emphasis was placed on providing the increase of outlet coolant temperature. Fuel element design was directed to the use of prismatic graphite blocks of hexagonal cross-section accommodating "the hollow or annular fuel pin" sheathed in a graphite sleeve. The core is composed of a regular array of these graphite blocks, stacked vertically.

2. FM-50 (Nuclear Steelmaking)

Studies on nuclear steelmaking were first undertaken in Japan by the Iron and Steel Institute of Japan in September 1968, and then taken over by the Agency of Industrial Science and Technology as a National Project in July 1973.

The conception of nuclear steelmaking connects a pilot plant with the experimental VHTR with a thermal output of 50 MW now being developed by JAERI. In order to enhance safety, the reactor process heat is to be transferred to a secondary helium gas loop through an intermediate heat exchanger. The primary helium gas emanating from the nuclear reactor is at 1000°C and 40 atmospheres of pressure, and it then returns to the nuclear reactor at 400°C. The secondary helium gas emanating through the intermediate heat exchanger is at 925°C and 45 atmospheres of pressure, and then returns to the intermediate heat exchanger at 300°C. On the high-temperature side of the secondary helium gas loop, the steam heater, the steam reformer and the reducing gas heater are arranged in parallel, and the steam generator is arranged on the low-temperature side. The material of the reducing gas is vacuum residue oil (asphalt), a byproduct of oil refining. After being cracked by steam, heated up to 850°C by the reactor process heat, the residual oil is transformed into reducing gas, a compound composed principally of hydrogen and carbon monoxide, produced through the process of either steam reforming or pitch gasification. After being heated to 800°C by a reducing gas heater, reducing gas is blasted into the shaft furnace. As exhaust gas from the top of the shaft furnace still has reducing power, a closed system is adopted so as to use it in circulation.

In order to implement the conception of a nuclear steelmaking pilot plant, first-stage research and development has been going on in the following six tasks over a seven-year program which began in 1973: (1) High-Temperature Heat Exchanger; (2) Heat Resistant Superalloys; (3) High-Temperature Heat Insulating Materials; (4) Reducing Gas Production Unit; (5) Reduced Iron Production System; and (6) Total System for Nuclear Steelmaking.

These six tasks make up the principal research and development elements in nuclear steelmaking, which have been undertaken by ERANS and the National Research Institute for Metals, where more than 500 engineers and researchers are engaged in the projects. The conceptual design is now proceeding for a nuclear steelmaking pilot plant system, FM-50, to be connected to the experimental VHTR of 50 MWt being developed by JAERI. Based on the FM-50 configuration chosen after studying both the material balance and the thermal balance, studies and assessments will be performed on the following points: (1) plans for arrangement of facilities; (2) layout; (3) utility; and (4) performance of operation, safety and control by dynamic simulation models. In addition, designing and safety analyses of the instrumentation and control systems of the pilot plant are going on.

These six design tasks, along with the above described research and development effort, represent the first phase of the nuclear steelmaking project and were completed this year. The second FM-50 project phase is now under way and is expected to lead to plant construction. It is anticipated that by about 1990 the nuclear steelmaking pilot plant, FM-50, can be connected directly with the experimental VHTR of 50 MWt and begin operation.

Descriptions of the Organization of ERANS and the Organization of the Japanese Nuclear Steelmaking Program are given in Figures 2 and 3, respectively.

C. Major VHTR Facilities

1. HENDEL Loop Test Facility

The Helium Engineering Demonstration Loop (HENDEL) will begin operation in 1981. It is a large-scale model testing facility for the demonstrative operation of high-temperature components such as the intermediate heat exchanger, high-temperature piping, emergency isolation valve and core support structure of the experimental VHTR. It will demonstrate the performance and integrity of the components of the experimental VHTR from the standpoint of licensing.

Test conditions of HENDEL test sections should permit the extrapolation of HENDEL experiments to the experimental VHTR conditions on a large-scale and should, at the lowest possible costs, correspond to one channel and one block column model for fuel stack tests, three region core bottom model for in-core structural tests, three seven-region mock-up for in-core flow tests, and 1/3-scale high-temperature components for heat removal tests.

The HENDEL loop consists of a parent loop section, an adapter section and various test sections. The parent loop section circulates helium gas of the specified flow rate (0.4 and 4.0 kg/s), pressure (40 kg/cm^2g) and purity. It consists of helium circulators, heater, cooler, mixing tank and filter, connected with helium purification, helium storage and cooling water systems which are designed for the respective purposes of purification, storage and cooling of primary helium gas. The adapter section heats

FIGURE 2

ORGANIZATION OF ERANS

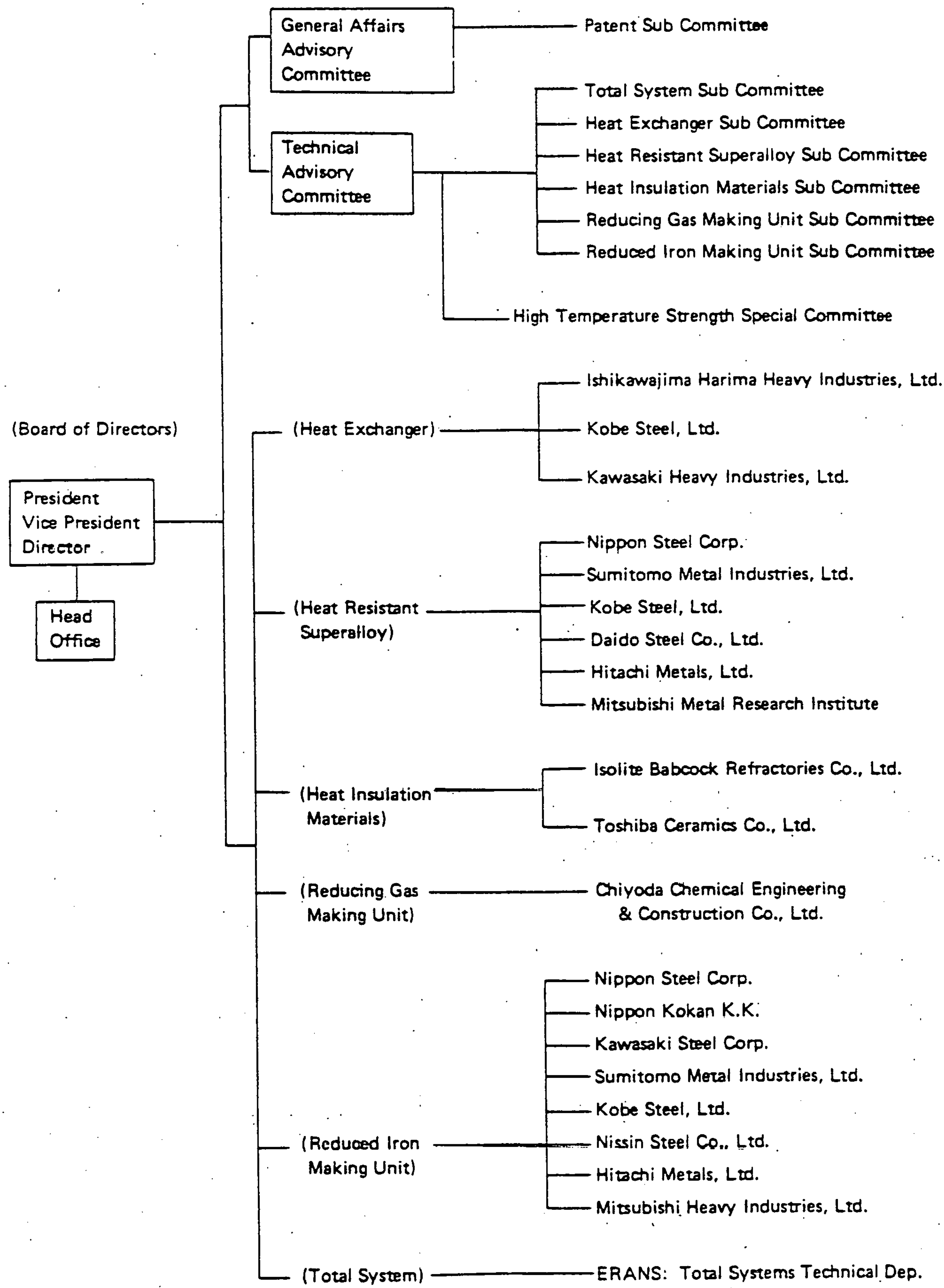
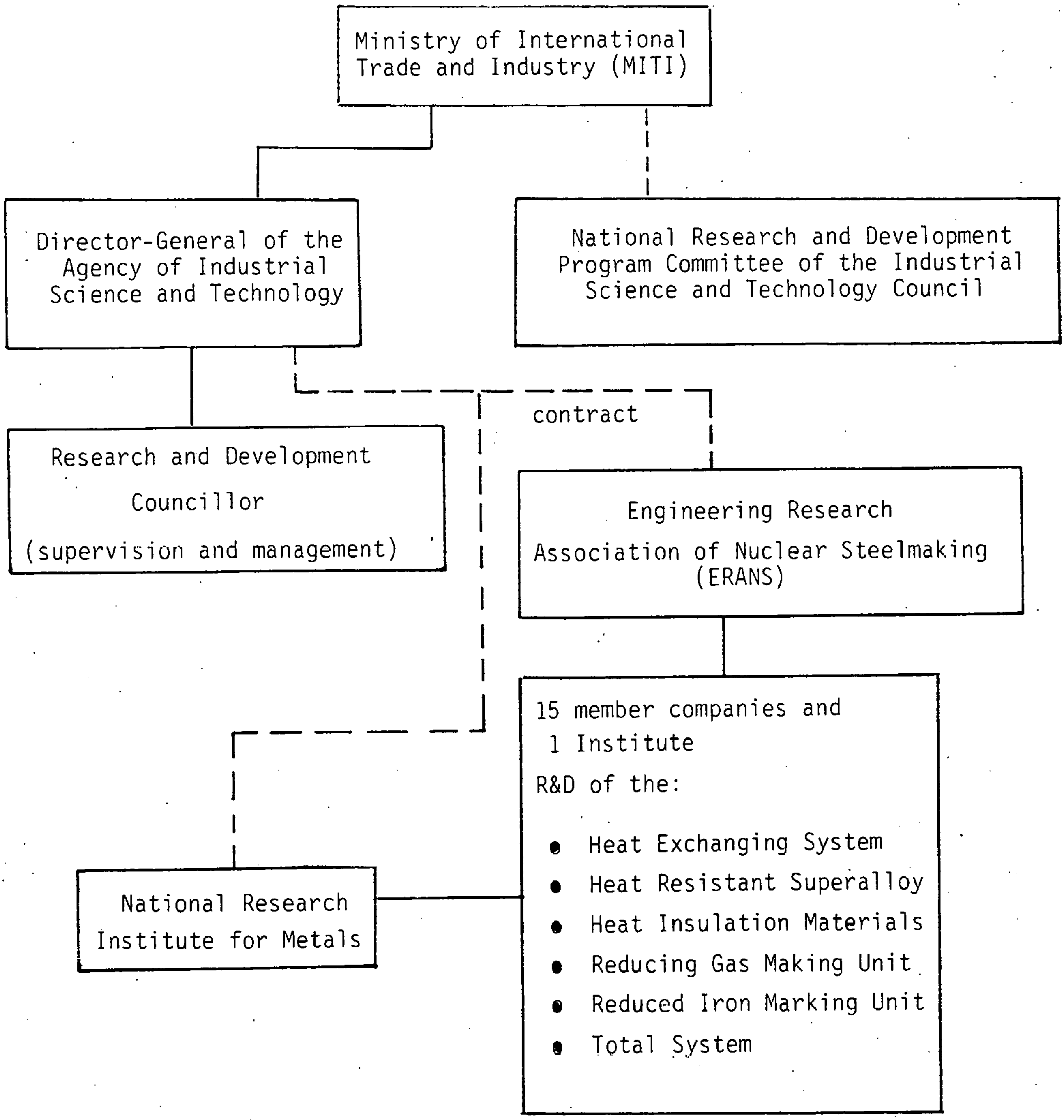


FIGURE 3

ORGANIZATION OF JAPANESE NUCLEAR STEELMAKING PROGRAM



helium gas up to 1000°C. It consists of high-temperature heaters and coolers. The operation of the parent plus adapter sections will be started late in 1981 and the test section in 1982-83. Test results obtained will be used for licensing of experimental VHTR and improvement of manufacturing, performance and design.

D. Industrial Participants in the VHTR Program

The following Japanese industrial organizations have participated with JAERI since the initiation of design work in 1970. In addition, many have conducted their own HTGR research and development programs. A brief description of these R&D programs is given after each participant.

Fuji Electric Co., Ltd.

Fuji Electric Co., Ltd. has been interested in the gas-cooled reactor beginning with the UK's Calder-Hall Magnox reactor type. This company's research and development work includes methods development and materials studies of the effects of the environment of high-temperature metal and creep of tube metals at high temperature. The mechanical and physical properties of graphite, and the effects of corrosion have been measured up to 1200°C.

Hitachi, Ltd.

Hitachi, Ltd. has performed general research and development activities in support of the VHTR.

Ishikawajima-Harima, Ltd.

Ishikawajima-Harima, Ltd. has done research and development work for AIST through the ERANS project 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 valves and bypass valves; (5) Development of He circulators; and (6) Experimental study on helical coil heat exchangers.

Kawasaki Heavy Industries, Ltd.

Kawasaki Heavy Industries, Ltd. has been conducting studies in various fields of the HTGR such as: bellows, ceramic coating thermal insulation materials, adhesion properties, and high-temperature metals including welding techniques. Also, using its own test loop facilities, valves and heat exchangers are being developed.

Mitsubishi Heavy Industries, Ltd.

Mitsubishi Heavy Industries, Ltd. has constructed its own helium loop test facility to perform materials tests and other high-temperature technological tests.

Toshiba, Ltd.

Toshiba, Ltd. has performed general research and development activities in support of the JAERI VHTR Program.

III. OTHER COUNTRIES

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A. Switzerland

The Swiss Office of Science and Research (BBW, formerly AWF) through its Nuclear Research Institute (EIR) has participated with Germany in the HHT Project since 1973. The Swiss must now re-evaluate their role in the Program as a result of the delay in the HHT Project and the current reassessment of the German HTGR Program direction. The Swiss had been strong supporters of the HHT Project because of the Swiss industrial interest in both the gas turbine and dry-cooling technologies. The EIR had contributed 15% of the total project cost by funding the Swiss companies that were performing work for the HHT Projects, such as BBC-CH, and Sulzer Brothers. The total expenditures of the Swiss HHT-Partners from 1973 to 1980 amount to some 78 million sFr (approximately $50M U.S.). The budget for 1980 was 13.3 million sFr.

A brief description of a few of the industry participants and their roles follows:

Bonnard and Gardel Consulting Engineers, Ltd.

Bonnard and Gardel is involved in PCRV design, testing and analysis and is a significant contributor to the program in this area. Work at the present time is in collaboration with HRB.

Brown, Boveri & Cie AG of Baden (BBC-CH)

BBC-CH was responsible for the design and construction of the turbomachinery for the HHT Project.

Gebruder Sulzer (Sulzer Brothers of Winterthur)

Sulzer Brothers Ltd. participated as a member of the HHT industrial consortium. It was to design and manufacture the recuperator and precooler for the HHT.

Sulzer-General Atomic Heat Exchangers Ltd. (SGX)

This company is owned 50% by GAC and 50% by Sulzer Brothers Ltd. Both companies have licensed SGX to their respective gas reactor heat exchanger technology. It is planned that SGX will become a major supplier of heat exchanger equipment.

B. France

The French government decided to terminate their participation in the HTGR Program during the latter part of 1979. Although the French remain interested in the HTGR technology, large cost overruns in other nuclear programs, principally the Superphenix effort, require the discontinuation of their efforts in the HTGR field. The French, through their Atomic Energy Commission (CEA) had been part of the Umbrella Agreement since 1977. They also had had an industrial agreement with GAC and the French nuclear industry which would allow licensing of the GAC design for fuel and NHS components in France. Through this exchange with GAC and later under the Umbrella Agreement, extensive fuel and primary circuit component testing had been conducted by the CEA. The French possess some of the best gas-reactor testing facilities in the world, such as the Carmen flow loop, COMEDIE fission product loop and Spitfire fuel irradiation test loop, and efforts are being made to continue use of these facilities. However, since the French have discontinued their HTGR Program, these efforts have been hampered because of their previous association with the Program through the multi-national Umbrella Agreement.

C. United Kingdom

The United Kingdom has considerable experience with gas-cooled reactors. It has 26 Magnox reactors and five Advanced Gas Reactors (AGR's) in operation with an additional ten AGR's under construction or planned. The British were early pioneers in the field of gas reactors and made significant contribution to the HTGR development, especially in the areas of fuel, core and gas transfer technology. The U.K.'s Dragon reactor was one of the principal HTGR test facilities until its decommissioning during the early 1970's. The British HTGR Program was discontinued in the mid-1970's principally as a result of reduced forecasts for future electrical energy demands. They have, however, continued with the AGR as the mainstay of their current nuclear reactor program.

A brief description of the British Magnox and AGR's follows:

Magnox

Magnox reactors are the first generation of gas-cooled reactors. The fuel elements consist of natural uranium rods while the fuel element cladding is made of magnesium alloy (referred to as Magnox). The CO_2 coolant is heated from 250°C to 360°C at 30 bars. The heat generated is removed via forced circulation steam generators. The most recent Magnox reactors have PCRV's.

There are 36 Magnox systems now in operation throughout the world with a combined electrical rating of 9100 MWe and approximately 570 reactor years of operating experience (see Table 1). The mean availability for all these reactors through 1975 was 60%.

AGR (Advanced Gas-Cooled Reactors)

The United Kingdom pioneered advances in the Magnox reactors to develop the AGR. The most significant change is a new fuel element. AGR fuel contains low-enriched uranium oxide in steel cladding which allows gas outlet temperatures of 650°C. In addition, the fuel element burn-up rate is five times the rate of Magnox reactors and the power density is three times as great. The AGR also has a graphite moderator, integrated steam generators within the PCRV, and core reloading under load which are the same as Magnox.

Under Britain's newly launched nuclear program, two new AGR power stations have been authorized. Start of construction of the two stations, each with two 660 MWe reactors, at Torness in Scotland and Heysham in northwest

Table 1

Magnox and Advanced Gas-Cooled Reactors

Facility	Number of Reactors	Net Electrical Rating in MW	Commercial Operation Date
Magnox Reactors			
Calder Hall	4	200	9/56
Chapel Cross	4	200	11/58
Marcoule G2,G3	2	80	4/59, 5/60
Berkely	2	276	6/62, 10/62
Bradwell	2	300	6/62, 11/62
Latina	1	150	1/64
Hunterston A	2	320	5/64, 9/64
Chinon 2	1	210	2/65
Trawsfynydd	2	500	2/65, 3/65
Hinkley Point A	2	500	5/65
Dungeness A	2	550	9/65, 12/65
Sizewell A	2	580	1/66, 3/66
Tokai 1	1	159	7/66
Chinon 3	1	400	8/67
Oldbury	2	600	1/68
St.-Laurent-des-Eaux 1	1	460	3/69
St.-Laurent-des-Eaux 2	1	515	8/71
Wylfa	2	1180	11/71, 1/72
Bugey 1	1	540	4/72
Vandellos	1	480	7/72
AGR			
Windscale	1	32	2/63
Hinkley Point B	2	1250	6/76, 1/77
Hunterston B	2	1250	6/76, 5/77
Dungeness B	2	1200	80/81
Hartlepool	2	1250	81/82
Heysham I	2	1250	81/82
Heysham II	2	1320	TBA
Torness	2	1320	TBA

England, is expected to begin in 1981. These will then make a total of fifteen AGR reactors completed or under construction for a combined electrical rating of 8875 MWe (see Table 1).

D. Miscellaneous

Belgium, the USSR, and more recently China, have some interest in the HTGR, but have not entered into any formal agreements with other countries.

In addition, IAEA has recently organized an International Working Group on HTR (IWGHTR) which will provide technical meetings and information exchange on HTGR's. Current member countries are the U.S., Germany, France, Switzerland, Japan, U.K., Belgium, Italy, Austria, Netherlands, Poland and the USSR.

IV. FOREIGN HTGR PROGRAM INDEX

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ADAM	Test loop in Germany designed to test the feasibility of transporting the energy of the HTGR as latent bound chemical energy. This process is intended to be used in the hydrogasification portion of the PNP plant.
AGR	Advanced Gas-Cooled Reactor - United Kingdom's advanced design gas reactor. There are fifteen completed, under construction, or planned.
AIST	Agency of Industrial Science and Technology - Part of the Japanese Ministry of International Trade and Industry which funds the Japanese FM-50 Nuclear Steelmaking Project.
AVR	Arbeitsgemeinschaft Versuchsreaktor, GmbH - the name of the 15 MWe demonstration HTGR in FRG. Also the utility group which contracted for the construction of the AVR nuclear power station.
AWF	Swiss Office of Science and Research - It was the Swiss counterpart of DOE, now renamed Bundesamt fur Bildung und Wissenschaft (see BBW).
BBC-CH	Brown, Boveri & Cie AG of Baden - A Swiss partner under the HHT Project which was responsible for turbomachinery design.
BBC-D	Brown, Boveri & Cie AG of Mannheim - A German partner under the HHT Project which was responsible for construction and BOP engineering/contracting.
BF	Bergbauforschung GmbH - German industrial member of the PNP Project working on the materials program. It operates the WKV-I pilot hydrogasification plant in Essen.
BMFT	Bundes Ministeriat fur Forschung und Technologie - Federal Ministry for Research and Technology in Germany. Equivalent to U.S. DOE.
BBW	Bundesamt fur Bildung und Wissenschaft - Swiss office of Science and Research. It is the Swiss counterpart of the U.S. DOE (see AWF).
CCM	Compagnie de Constructions Mecaniques - This company is a French subsidiary of Sulzer Brothers. This company may be utilized by SGX to manufacture heat exchangers for the early HTGR Projects.
CEA	Commisariat a L'Energie Atomique - The French Atomic Energy Commission.
EdF	Electricite de France - The sole French utility (nationally owned).
EG	Entwicklungsgemeinschaft HTR - This "Development Partnership" is the R&D organization of the German HTR Program formed by HRB, GHT, and KFA.

EIR	Eidgenossisches Institut fur Reaktorforschung of Wurenlingen - The Swiss national reactor research laboratory and is a participant in the German HTGR Program. It is the Swiss counterpart of KFA and ORNL.
EKEM	Elektromark, Kommunales Elektrizitatswerk Mar AG - Municipal utility located in Hagen.
ERANS	Engineering Research Association of Nuclear Steelmaking - An organization of Japanese companies doing R&D and project management on the FM-50 Project in Japan.
EVA	This KFA Project is designed to test the feasibility of a helium heated steam reformer. The EVA I loop at KFA produces 200 m^3 methane/hour. EVA II is under construction with 30 methane steam reformer tubes. It will be a part of the joint ADAM II/EVA II facility.
EVO	Energie-Versorgungsanlage Oberhausen - A 50 MWe plant at Oberhausen, Germany, which is a fossil-heated helium-driven closed cycle gas turbine system. Also known as Oberhausen II.
EVU	Former utility group formed to provide technical guidance to the HHT Program.
GEWK	Gas-Elektrizitatswerke-und Wasserwerke Koln AG - Municipal utility of Koln.
GHT	Gesellschaft fur Hochtemperaturreaktortechnik mbH - A subsidiary of Kraftwerk Union (KWU) and Interatom. It has been the NHS system designer for the PNP Project.
HBK	Hocktemperaturreaktor Brennelement Kreislauf - The High Temperature Reactor Fuel Cycle Project being headed by KFA. All German activities on the HTR fuel cycle are coordinated under HBK.
HEW	Hamburgishe Elektrizitatswerke AG - Municipal utility of Hamburg.
HHT	Hochtemperaturreactor mit Helium Turbine - The joint German/Swiss Project to design and build a high temperature reactor with a helium turbine rated 600 MWe.
HHV	Hochtemperatur Helium Versuchsanlage - This hot helium test loop is designed to test turbomachinery components and design, hot duct materials and performance and auxiliary system designs.
HKG	Hochtemperatur Kernkraftwerk GmbH - Utility operating group for the HTR-300.
HKV	Hydrierende Kohlevergasung - The hydrogasification of coal process.
HOBEG	Hochtemperaturreaktor-Brennelment GmbH - A subsidiary of NUKEM. It has received NUKEM's existing HTGR fuel production facilities, personnel and technology and is supplying fuel for AVR and THTR.

HRB — Hochtemperatur Reaktorbau GmbH with main offices in Mannheim - HRB has been the industrial partner in the HHT Program responsible for the design of the nuclear heat supply system and is also the NSS supplier for the THTR Project. It is 55% owned by BBC-D and 45% owned by General Atomic. It has joined with GHT to form the "Konsortium HTR."

HRG — Newly formed German Utility organization composed of eight electric generating companies. This organization is lead by H. Suchanek of PREAG, and replaces EVU as the Utility organization supporting the HTGR development in Germany (see section IE1.a).

HTMP — High Temperature Materials Program.

IAW — Isar-Amperwerke AG - Municipal utility of Munich.

JAERI — Japanese Atomic Energy Research Institute - It is the Japanese counterpart of KFA and ORNL.

JANP — Japan Association for Nuclear Process Heat - A consortium of eight industrial companies in Japan headed by Mitsui Co. It will promote and act as a program manager for the Japanese VHTR process heat reactor.

JUPITER — Julicher Pilotanlage zum Thorium Element Reprocessing - A pilot reprocessing plant scheduled to become "hot" operational in 1985. It is designed to process spent AVR fuel elements with a throughput of 2 kg heavy metal/day.

KFA — Kernforschungsanlage Julich - The Julich Nuclear Research Center is Germany's national laboratory for nuclear-related research. It has been one of the HHT and PNP Project participants and has a very strong influence on the HTR Program.

Konsortium HTR — This consortium is a combination of the HHT and PNP Projects' nuclear heat source system suppliers: HRB and GHT. It was formed to do the design and tender bids for the HHT and PNP Projects.

MAGNOX — First type of gas-cooled reactor. See Magnox section under United Kingdom.

MITI — Ministry of International Trade and Industry - Department of the Japanese government which is funding the FM-50 nuclear steelmaking project.

NFE — Nukleare Fernenergie - A project undertaken by KFA and RBW to show the feasibility of a chemical heatpipe system for transporting the energy of an HTR in the form of latent bound chemical energy. It is also called EVA II.

NRW — Nordrhein Westfalen - German state government which is contributing financing to the THTR and PNP Projects through the Ministry of Economics (MWMV) due to its large coal reserves and interest in coal gasification.

NUKEM	Nuclear-Chemie und Metallurgie GmbH of Wolfgang - Member of the HHT Project. It is the leading German nuclear fuel cycle company and it owns HOBEG.
NW	Neckarwerke Electrizitatsversorgungs AG - Municipal utility of Esslingen.
NWK	Nordwestdeutsche Kraftwerk AG - NWK is a utility member of HRG and has operating experience with several LWR's.
PNP	Prototypanlage Nucleare Prozesswarme - Prototype Nuclear Process Heat System Project supported by BMFT and the State of North Rhine Westphalia (NRW) to produce a nuclear coal gasification plant.
PPNP	Projektgesellschaft Prototypanlage Nuclearer Prozesswarme - The operating company for the PNP plant formed by RBW and Ruhrkohle, two coal companies.
PREAG	Preussiche Electrizitats - AG - PREAG is the utility organization taking the lead among the German utilities in organizing HRG.
PTH	Projekttrager HTR - The Project Office of BMFT located at KFA responsible for monitoring the government funding and the project progress.
RWE	Rheinish-Westfalisches Elektrizitatswerk AG - German utility member of HRG. The largest utility in FRG.
SGX	Sulzer-General Atomic Heat Exchangers Ltd. - General Atomic has a 50% equity with Sulzer Brothers, the Swiss heat exchanger manufacturer.
SHR	Stadtwerke Duisberg AG - Municipal utility of Duisberg.
STEAG	STEAG Aktiengesellschaft - Private electricity generating company located in Essen.
Sulzer	Sulzer Brothers of Winterthur, Switzerland - Swiss manufacturer of heat exchangers and member of HHT industrial consortium.
SWD	Stadwerke Dusseldorf AG - Municipal utility of Dusseldorf.
THTR-300	A 300 MWe prototype HTGR-SC plant with pebble bed core being built in Germany by BBC, HRB and NUKEM under contract to HKG.
TWS	Technische Werke der Stadt Stuttgart AG - Municipal utility of Stuttgart.
VEW	German Utility. THTR-300 is on VEW's grid.
WKV	Wasserdampf Kohlevergasung - The steam gasification of coal process envisaged to be used in the PNP plant.