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Non-electric applications of nuclear energy

Proceedings of an Advisory Group meeting held in Jakarta, Indonesia, 21–23 November 1995

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FOREWORD

Over half of the world's primary energy consumption is used for the production of hot water, steam and heat for various of industrial applications. This requirement is met almost exclusively through the use of fossil fuels. The emission of carbon dioxide and other gases resulting from the burning of fossil fuels poses serious challenges to our climate. Nuclear energy can help contribute to the solution of these problems. Clearly, only a small portion of its potential is being utilized. This technology which, to date, has been used almost exclusively in the production of electricity, has the capability of being a significant, clean alternative to fossil fuels for the production of hot water, steam and industrial process heat applications. It is with this focus that the IAEA convened the Advisory Group on "Non-Electric Applications of Nuclear Energy" in Jakarta, Indonesia.

This meeting, which included participants from eleven countries, brought together a group of international experts to review and assess the present status and recent progress made in systems and processes for nuclear heat applications and associated reactor development. The technical and economic potential of these systems and processes along with their related environmental and safety issues and requirements were explored and areas were identified for additional research and development necessary before they can be commercialized.

CONTENTS

SUMMARY

The Advisory Group Meeting (AGM) on Non-Electric Applications of Nuclear Energy was held in Jakarta, Republic of Indonesia, from 21-23 November 1995. This meeting was convened by the International Atomic Energy Agency (IAEA) and was hosted by the National Atomic Energy Agency of the Republic of Indonesia (BATAN). This meeting was organized as a forum for experts throughout the world to collectively review and evaluate the present status and international progress made in processes for non-electric nuclear heat application and associated reactor development; and to explore the technical and economic potential of these applications along with attendant environmental and safety aspects. The results of this AGM focused on identifying additional research and development needs and to determine pathways of opportunity for international cooperation in order for these non-electric applications of nuclear energy to achieve commercialization.

Attendance at this AGM included sixty participants and observers from eleven countries (Canada, China, Egypt, France, Germany, Indonesia, Israel, Japan, Republic of Korea, Russia and the United States). Twenty papers were presented by the participants on a myriad of non-electric nuclear heat utilization processes including seawater desalination, district heating, heavy oil recovery, petroleum refining, coal liquefaction and hydrogasification, steam and carbon dioxide reforming of methane to produce hydrogen and methanol, and thermochemical water splitting and high temperature electrolysis of steam for the production of hydrogen. Each presentation was followed by general discussion and the AGM concluded with a round-table evaluation of future technology development requirements and exploration of areas for enhanced international cooperation.

Indonesia is a country undergoing significant growth in its energy requirements and, although it has oil and gas resources, these are rapidly diminishing. Also, being composed of many thousands of islands with a wide variety of mining resources, significant differences in climate and potable water sources, large variations in population densities and long distances all contribute to an industrial development programme which has to be both unique and diversified. In order to provide prosperity and stimulate economic growth in an environment which is already experiencing increases in electricity demand of over 10% per year and total energy growth of 6-7% per year, it is necessary to secure a continuity in the supply of energy at affordable prices. Historically, oil has been the nation's primary source of commercial energy and, also, a major positive source of revenue as an export. However, as a resource which is no longer abundant, the continued reliance on oil to meet domestic needs is not appropriate. Indonesia's National Energy Policy is directed toward the measures of energy intensification, diversification and conservation. In order to help meet this policy, the role of nuclear power is to help stabilize the supply of electricity, conserve remaining gas and oil resources and to protect the environment. This includes nuclear energy for non-electric applications.

Major changes are projected over the next 25 years in the Indonesian primary energy supply mix. In 1990, the fossil fuels of oil, gas and coal represented 60.2%, 32.5% and 5.7% of Indonesia's primary energy share, respectively. By the year 2019, this is projected to change significantly to 34.3% for oil, with a major decrease to 3.4% for gas, and nearly a ten-fold increase to 54.3% for coal. During this same period, nuclear energy, which has yet to be established, is projected to account for $\sim$6.2% of the national energy share. In view of this anticipated major reallocation in Indonesia's energy supply, strategic non-electric applications of nuclear energy are under investigation by BATAN and other organizational entities in Indonesia. These applications were addressed by participants in the AGM and include coal liquefaction, desalination, enhanced oil recovery and hydrogen and methanol production.

Oil will continue to provide over 60% of Indonesia's energy share through the year 2000. However, even as these reserves are being depleted using primary and secondary recovery processes, there is still more than 50% of the original oil remaining in the reservoir. Thermally enhanced oil recovery utilizing steam flooding is a proven technology which can be applied to these reservoirs to assist in the recovery of this remaining oil. The feasibility of using the HTR as an energy source for the co-generation of this steam and electricity was the subject of a study conducted in the Duri Steam Flood Project. A comparison between the HTR and using a conventional oil-fired steam generator provided encouraging results for the HTR. However, this was highly dependent on a projected increase in the price of oil which has remained consistently low over the past several years.

Indonesia has abundant coal reserves, currently estimated at 30 billion tons. However, much of this coal is low quality lignite. As new liquid fuels must gradually be substituted for oil to avoid its early depletion, coal liquification is under consideration. A possibility, which requires further consideration, is to utilize the HTR for co-generation applications including process heat for the coal liquefaction plant. Also under consideration as a co-generation application of nuclear energy is the utilization of nuclear power for desalination and electricity production. The need for clean, fresh water for public, household and industrial uses is increasingly becoming a serious problem, particularly in the high population areas of Indonesia. However, because of the diverse conditions found throughout Indonesia, both large and small dual purpose nuclear power plants are being evaluated.

Investigation into the use of nuclear power for co-generation applications is becoming increasingly more prevalent. Only ~30% of the world's total primary energy is used in the production of electricity. Yet, nuclear power is predominantly applied to the generation of electricity with only a very small fraction allocated to those applications associated with district heating and process heat production for industrial use. The temperature requirements for these applications vary greatly from low temperature heat for district heating and desalination up to high temperature process heat for coal gasification and hydrogen production. Processes requiring temperatures of up to ~300°C can be supplied by water coled reactors while breeders may be applied to processes requiring up to 540°C. The high temperature gas cooled reactor can provide process heat temperatures of 950°C. Thus, nuclear energy has the potential to provide not only electricity, but also heat for many of the world's industrial heat applications. This broad spectrum of nuclear energy utilization is an important aspect in the IAEA's charter of promoting the development of atomic energy for peaceful uses throughout the world.

Nuclear seawater desalination has been a renewed topic of considerable emphasis within the IAEA since 1989. National and regional water shortages, especially in some Arab States, prompted an assessment of the technical and economic potential of nuclear reactors for seawater desalination. The initial phase of this assessment included a status report of the experiences gained in various countries throughout the past decade. A study was then undertaken to determine the economic viability of nuclear seawater desalination in comparison to the use of fossil fuels. An Options Identification Programme has now been initiated to determine the most feasible combinations of nuclear reactors and desalination processes for practical demonstration projects.

The emergence of seawater desalination as increasingly important energy utilization requirement was acknowledged by many meeting participants and was emphasised in presentations by many participants. The Korea Atomic Energy Research Institute is undertaking the development of a co-generation plant for electricity production and desalination. This plant is to be powered by an Integral PWR with an output of 330 MWt. Electricity and water production are to be 100 MWe and 40,000 cu.m/day, respectively. The schedule for this plant includes completion of the basic design in the year 2000 with the detailed design and construction phase following to ~2005.

In Canada, the *CANDESAL* nuclear desalination/cogeneration system has been developed to meet large scale water production requirements. This system integrates a nuclear energy source such as a CANDU reactor with a reverse osmosis (RO) desalination facility, capturing the waste heat from the electrical generation process to help improve the efficiency of the RO process. Coupling the reactor with the desalination system in this manner provides the flexibility of varying water production without adversely impacting the operation of the power plant.

The use of pool type light water reactors for thermal energy production is under consideration by the Research and Development Institute of Power Engineering (RDIPE) in Russia. RPIDE presented their design experience on two projects featuring the RUTA pool type reactor; the Nuclear Seawater Desalination Plant and the Apitity Underground Nuclear Heating Plant. This reactor is a simplified heat source supplying 55 MW of thermal energy as water at 85°C.

China is considering the use of water cooled reactors for nuclear heating. Their primary energy source is coal which results in two significant problems, the burden of transportation and the emission of environmental pollutants. A dominant consumer of China's primary energy is in the form of heat applications, of which district heating is a significant portion. The State is supporting the development of nuclear heating reactors for district heating purposes. The Institute of Nuclear Energy Technology (INET), with the support of the State, completed construction of a 5 MW test nuclear heating reactor in 1989. Since then, this reactor has been successfully operated for heating purposes, safety demonstration experiments and for tests on other applications. A 200 MW commercial nuclear heating demonstration plant has now been approved by the State Council and design and licensing on this plant is in progress at INET.

France has evaluated the use of nuclear power for district heating and other non-electric heat markets. Their industrial infrastructure evolves toward low energy usage. As a consequence, this concentration of energy usage would suggest a small nuclear plant which is not economically feasible. Similarly, nuclear plants for district heating are seen in France to be handicapped due to high heat transportation cost and only part-time usage which also makes them economically unattractive.

Many of the presentations focused on the high temperature applications available through the use of the HTR. The versitility offered by the gas cooled reactor allows for nuclear energy to be the source of heat for many industrial applications. This versitility was addressed by General Atomics in their Modular Helium Reactor (MHR). This plant can provide heat at temperatures of up to 950 °C for use in applications such as coal conversion where coal derived fuels such as high BTU gas, synthetic gas and methanol are possible. Also, the MHR coupled to a steam generator can provide high temperature steam for heavy oil recovery and coal liquefaction and gasification. Co-generation applications of the MHR would provide for the generation of electricity using a gas turbine with low temperature heat removal to support water desalination.

The high temperature gas cooled test reactors currently under construction in Japan and China are being built to demonstrate the technology for providing high temperature heat for industrial applications and for the generation of electricity utilizing the gas turbine. The High Temperature Engineering Test Reactor (HTTR) is scheduled for initial criticality in late 1997. It will be utilized to perform safety demonstration tests to validate the inherent safety features of the HTGR and to perform material and fuel irradiation tests. Specific heat utilization systems are to be connected to the HTTR for demonstration of temperatures to 950°C.

Examining the status, including the necessary research and development requirements, of high temperature heat utilization technologies for application to the HTTR is the subject of a Coordinated Research Programme establisbed by the IAEA on "Design and Evaluation of Heat Utilization Systems for the HTTR". Chief Scientific Investigators from seven countries are collaborating in this programme. Due principally to the state of technology advancement, the first priority candidates for demonstration are steam/carbon dioxide reforming of methane for the production of hydrogen and methanol and the use of the gas turbine for electrical generation.

The Institute of Nuclear Energy Technology is constructing the HTR-10 pebble-bed helium cooled test reactor at their research site outside of Beijing, China. This HTGR was chosen for its favorable safety features and its ability to provide high reactor outlet gas temperatures for efficient power generation and high quality process heat for industrial applications. This plant is being built within the Chinese High Technology Programme and will consist of two operational phases. The first phase will utilize a reactor outlet temperature of 700°C with a steam generator to a steam turbine cycle which works on an electrical/heat co-generation basis. The second phase is planned for core outlet temperatures of 900°C to investigate a steam cycle/gas turbine combined cycle system with a gas turbine and the steam cycle being independently parallel in the secondary side of the plant.

The technical feasibility of high temperature gas cooled reactors has been proven in a number of test and demonstration HTR plants. The AVR in Germany was successfully operated for many years with an average core outlet temperature of 950°C. The technical feasibility of high temperature heat consuming apparatus and components, in particular the helium heated steam reformer and the helium heated gas generator for the steam coal gasification process, and the intermediate heat loop have been proven by experimental facilities up to pilot plant scale. Also, the technical feasibility of the hydrogen coal gasification process has been proven by experimental facilities. Even though many of the non-electric heat applications discussed at the AGM have been successfully demonstrated in the laboratory or in small scale test apparatus, significant research and development is still required for their commercialization. The coupling of a nuclear high temperature heat source to the non-electric consuming process is still to be realized. Heat transfer requirements and reaction kinetics of the process and components such as catalysts must be established, and the operational, maintenance, safety and control aspects of the overall plant need to be well understood. Advanced applications, such as hydrogen production from thermochemical water splitting and high temperature electrolysis of steam, will require significant material development to assure reliable performance of the process components within their own specific operational environment. International cooperation between countries with research and development programmes on these applications is an essential ingredient in achieving their commercialization.

Carbon dioxide reforming of low hydrocarbons is a feasible process in both a "closed loop" operation for transport and storage of thermal energy in a chemical form, and in an "open loop" operation for the production of syngas. In Israel, the Weizmann Institute of Science has been operating a carbon dioxide/methane reforming loop throughout the past two years. This reforming loop has a 500 kWt capacity. Catalytic systems for both the reformer and for the methanator have been developed and are based on Ru/Al_2O_3. A computer code for calculating a complete loop has been developed and calculation results for a commercial size loop have been performed including chemical compositions, flows, heat loads and duties of the various heat exchangers. "Open Loop" tests have been performed with LPG and steam. Potential applications include: upgrading of residual oil; cracking of low hydrocarbons to produce ethylene and propylene; hydrogasification of coal; and, gasification of oil shales/coal mixtures.

A specific application of carbon dioxide reforming of low hydrocarbons through the use of the HTR is Indonesia's Natuna gas field. This vast gas field, with an estimated 35 trillion SCF, is very unusual in that its natural composite is ~71% carbon dioxide. This very high carbon dioxide content makes the Natuna gas an excellent candidate for high temperature reforming of the CO_2 and subsequent synthesis to methanol utilizing the HTR. The co-generation application of the HTR, with its broad process temperature range, could allow for carbon dioxide reforming to achieve methanol, desalination and electrical generation, all from a single nuclear energy source. Another high temperature application of nuclear energy being investigated in Indonesia is the prospect of using the HTR for the production of hydrogen. Processes including steam or CO_2 reforming of methane, thermochemical water splitting and electrolysis of steam are all achievable with the high temperatures available from the HTR.

Although unanimous agreement did not exist for international focus on a specific single heat utilization process, a majority consensus felt that the future high temperature application of nuclear energy should be directed to the development of hydrogen production techniques including steam and CO_2 reforming of methane. The need to move away from the burning of fossil fuels and to the use of hydrogen is felt by many to be a worldwide requirement for the future. The lower temperature application of desalination was also selected. Even though desalination via coupling to a light water reactor is now commercially available, it was generally felt that further development is necessary in the areas of safety, regulation and the synergisn of treating as a single plant, the coupling of different desalination processes with alternate nuclear heat sources. Other heat utilization processes such as heavy oil recovery, district heating and coal gasification and liquefaction should also receive international consideration.

The participants expressed the need for greater cohesion between national programmes. The prominent issues which need to be addressed in a collective international forum include evaluation of economic and technical feasibility of the total plant and the determination and resolution of the risks and associated safety in combining the different chemical porcesses with a nuclear heat source.

OPENING REMARKS

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It is indeed a great honour for Indonesia to be the host country for this IAEA-AGM on Non-Electric Applications of Nuclear Energy We consider this is a very important meeting, at the verge of nuclear era in Indonesia, when we will finish the Feasibility Study of the first Nuclear Power Plant (NPP) in Indonesia

We in Indonesia have limited amount of fossil energy resources We may become net importer of oil before 2010 Our gas resources may be sufficient for 60 years at the present production rate But fortunately we have more than 30 billions tons of coal reserves, 65% of this total amount is lignite This resource is the only fossil energy resource for the long term future of energy supply in Indonesia It is therefore very important for us to enhance the use of coal for electricity and fluid fuel supply through clean coal technology development And I am sure the experts here agree that nuclear energy has important role to contribute to clean coal technology dn to synergistic utilization of fissile and fossil energy

In order to increase the quality of life of the people, we not only need supply of sufficient energy to the society, but also supply of fresh water The supply of fresh water in Indonesia is lacking, due to damage of water resources and environmental pollution

Since nuclear reactors, particularly HTGRs, have the ability to produce heat at high temperatures up to 1000 degrees centigrade, they are amenable for various industrial process applications Fluid fuel is the most practicable form of fuel, due to simple way of transportation and distribution Unfortunately, fluid fuel is found to be more limited in nature compared to solid fuels such as coal Conversion from solid to fluid fuels requires technology that involves high temperature steam The utilization of HTGR technology therefore opens up new dimension in symbiotically using coal and nuclear energy to produce and guarantee the supply of fluid fuels Presently, road and air transportations are vulnerable to the supply of fluid fuels Except there is no new revolution in the technology of transportation, which is unlikely to happen in the next decades, the dependence on fluid fuels cannot be avoided Therefore the role of HTGR will show its power particularly by the time the fluid fuels from oil and gas are becoming scarce, which will occur less than 20 years from now

To anticipate the above situation, we have initiated an assessment working group that concentrates on coal fluidization technology and seawater desalination, CO_2 conversion to methanol, hydrogen production and enhanced oil recovery At present, we are considering to develop an assessment group on mini-scale Nuclear Power Plant (NPP) for isolated islands in eastern part of Indonesia This group will concentrate on light water reactor (LWR) type reactor for dual purpose (electric and heat applications), with a power between 5 and 50MWe

As I mentioned earlier, considering the capabilities of the high temperature reactor to produce heat for electricity generation and industrial processes, in August 1993 and Indonesia HTR team was established to conduct studies about HTR technology and applications The main purpose of this team is to study how to realize the HTR-project in Indonesia and you may guess that the main problem is funding! So, I also hope that the experts here can recommend funding schemes for the

HTR-project.

I would like also to touch upon the contract between Indonesia and EXXON (USA) on Natuna Gas exploitation with a price of 35 billion US dollars. Out of this amount, more than 10 billion US dollars is used for separation and re-injection of CO_2. The Natuna gas field is estimated at 120 TCF (trillion cubic feet) of gas reserve, 71% or 85 TCF of this gas reserve is CO_2. Therefore, it is indeed interesting and prospective to convert CO_2 and natural gas mixture to methanol using nuclear energy.

STATUS AND PLANS FOR THE INDONESIAN NUCLEAR POWER PROGRAMME

PROSPECT AND POTENTIAL OF NUCLEAR POWER PLANTS IN INDONESIA

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Abstract

In line with the national energy policy of Indonesia in promoting the intensification, diversification and conservation of energy, some important steps need to be taken in order to establish alternative energy strategies which will be decisive in the formulation and development of the national energy plan in the future. At present, Indonesia does not have any nuclear power plants. The introduction of nuclear power in Indonesia is not only to reach an optimum energy mix based on costs and the environment, but also to relieve the pressure arising from increasing domestic demand for oil and gas.

This paper addresses the present feasibility study being performed on the introduction of nuclear power plants in Indonesia. It is anticipated that nuclear power will contribute about 10% of Indonesia's electrical supply as of the year 2019. This represents approximately 12,600 MWe in capability. The paper describes the results, to date, of the Feasibility Study on nuclear power including the national energy market analysis, the electricity expansion plan and the associated role of nuclear power, the economics and financial plan, site studies on volcanology, seismology and the environment.

I. INTRODUCTION

The main objective of the Indonesian Long Term Development Programme is to give stress to development of the national economy, through developing a more active and advanced national industry, supported by a strong agriculture, which in turn will create a strong basis for a self-sustaining growth and development in the efforts toward social justice and welfare of the people based on our Five Principles (Pancasila) ideology.

Accordingly, the development of the national industries will need the supply of an abundant amount of energy. It must be noted, however, that the growth of this development should be maintained equally and widely spread, and to assure a self-sustaining development in accordance with the principle of social justice.

This principle is an important guideline in establishing the national energy policy for the future in supporting our second long term 25 year development programme, whereas the main objective would be the creation of a high quality people, a better standard of living, a healthier environment, and a prosperous and peaceful nation.

In line with the national energy policy in promoting intensification, diversification and conservation of energy, some important steps need to be taken in order to establish alternative energy strategies which will be decisive in the formulation and development of the national energy plan in the future. At present Indonesia does not have any nuclear power plants. The introduction of Nuclear Power Plants in Indonesia is not only to reach an *optimum energy mix* based on costs and environment, but also to relieve the pressure arising from increasing domestic demand for oil and gas. Therefore, oil and gas could be used for other strategies, such as for export and feedstocks to support the take-off era towards the 2nd

Long Term Development Programme. This strategy is an integral part of the overall energy strategy.

Even though Indonesia has some oil and gas resources, it has to be realized that these resources are not abundant and not unlimited. The role of Nuclear Power Plants is clearly to stabilize the supply of electricity, conserve strategic oil and gas resources and protect the environment from deleterious pollutants.

II. NATIONAL ENERGY POLICY

Indonesia has been implementing a National Development plan, whose goal is to create a just and prosperous nation. The first 25 years of the National Development plan was called the first long term national development programme. This programme was started in 1969 and consisted of Five-Year Development Programmes. One of the main objectives of the first long term national development programme is to broaden the basis of our economic structure, that is to strengthen and to promote national industrialization. The national programme on industrialization has given rise to substantial increase in the demand for energy. The energy sector is of particular importance in the development of the Indonesian economy, as Indonesia's current per capita energy consumption is relatively low compared to other ASEAN countries. The increase of population, especially in the rural areas do not yet have adequate access to electric power, an indication of an expected high growth rate of electricity generation. Most energy resources are located outside the Island of Java, yet Java, with its large population and industry constitutes the major area of energy demand. In a way which maximizes economic efficiency and provides employment and regional development opportunities, the Government has adopted a policy of promoting development of the energy resources with a view toward more diversification.

Historically, Indonesia's energy policy and petroleum policy were synonymous. Oil had the dual role of being the nation's prime source of commercial energy and of providing both foreign exchange and Government revenue to finance economic development. By the late 1970's however, domestic consumption grew at an annual rate of up to 15 %. Domestic consumption began to divert oil from the export market. In the late 1970's, the Government embarked on an ambitious programme to move domestic energy consumption away from crude oil in order to maximize the amount of oil production available for export. The indirect result of this diversification effort was the construction of electrical generation facilities which utilize non-oil energy resources such as coal. Cement plants were converted from burning oil to using coal. Diversification also led to increasing use of liquefied petroleum gas (from gas reserves) by households. There were also plans for increasing utilization of natural gas in domestic industry and for electricity generation.

Briefly, our National Energy Policy has four main objectives. These objectives include :

1. To secure the continuity of supply of energy for domestic use at prices affordable to the public,
2. To enhance the quality of life of the people,
3. To stimulate economic growth, and
4. To reserve an adequate supply of oil and gas for export, in order to provide an important source of foreign exchange to fund national development programs.

There are three policy measures adopted by the government to meet these objectives :

1. Intensification, i e. to increase and expand exploration of energy sources available in the country.
2. Diversification, i.e. to reduce dependence on only afew sources of energy (i.e. gas and petroleum), and later to replace it with other available sources.
3. Conservation, i.e, to economize on the energy use and to increase the efficiency of energy production.

Implementation of the energy policy covers several aspects such as issuance of regulations, standards, energy pricing incentives and disincentives, and the application of appropriate technologies. The technologies that would be considered are identified as follows :

a. Technology to produce substitutes for oil, as oil is non-renewable. Gasification and liquefaction of coal could well meet the fuel needs of the future.
b. Technologies to support a more sustainable energy supply, through the harnessing of available and renewable energy sources.
c. Clean and efficient energy technologies to support environmental concerns.

III. The Present Feasibility Study for The First NPP In Indonesia

In September 1989 the Indonesian Government through the National Energy Co-ordination Board (BAKOREN) decided to perform anew the NPP feasibility study including a comprehensive investigation of the Muria site. The study itself should be carried out by the National Atomic Energy Agency (BATAN), under the directives of the Energy Technical Committee (PTE) of the Department of Mines and Energy, and in cooperation with other institutions.

On August 23, 1991, an agreement was signed in Jakarta between the Indonesian Ministry of Finance and BATAN on behalf of Indonesia, and the consultancy company NEWJEC Inc. This agreement contracts NEWJEC for a four and a half year period to perform a site selection and evaluation, as well as a comprehensive nuclear power plant feasibility study. The principal part of the contract value will be spent on studies related to the site, which is to be sought in the northern coast of the Muria Peninsula in Central Java.

The scope of the feasibility study includes two main components

1. The non-site studies, covering energy economics and financing, technical and safety aspects, the fuel cycle and waste management, and general management aspects, among other things.

2. Site and environmental studies, covering field investigations and assessment of site selection, site qualification/evaluation, and environmental, socio-economic and socio-cultural impacts.

On December 30, 1993, two years after the starting date (22 November 199 1), NEWJEC submitted the feasibility study report (FSR) and preliminary site data report (PSDR) to BATAN. At the end of the four and half year contract, a final report will be provided, including a site and environmental report, and a preliminary safety analysis report. These documents will provide the information necessary for site permit application, for the design engineering basis and other industrial infrastructure preparations. The attached Figure-I shows the overall schedule of the feasibility study.

In this chapter a more general description concerning the results of the Feasibility Studies including National Energy Market Analysis, Electric Expansion Plan and the role of NPP, Economics and Financial Study, as well as Site Studies on Earthquake, Volcanology and Environmental Impacts shall be presented.

III.1 National Energy Market Analysis

The objectives of the National Energy Market Analysis are to conduct a study of the national energy development to support the long term energy demand, and to conduct analysis of the energy system, specifically the electrical energy sector by the use of the ENPEP (Energy aNd Power Evaluation Program).

This report includes an analysis of the evolution of the energy market, evaluation of energy resources, forecast of energy demand, analysis of energy demand management options, and the formulation of an energy supply planning.

Following are some tables showing results of the Macro Economic, Energy Demand and Energy Supply projections.

a. Macro Economic Projection

	GDP GROWTH TOTAL (%/year)	POPULATION GROWTH (%/year)
1990 - 2000	6.50	1.87
2000 - 2010	6.00	1.35
2010 - 2019	5.00	0.85

b. Energy Demand

The energy demand will increased by 6 - 7% per year during the study period of 30 years (1990 - 2019).

	GROWTH OF TOTAL ENERGY DEMAND (%/year)	ELECTRICITY DEMAND GROWTH (%/year)
1990 - 2000	6.27	10.30
2000 - 2010	7.20	9.64
2010 - 2019	7.09	8.27
AVERAGE GROWTH	7.18	9.41

c. **Energy Supply**

- Share of Primary Energy Supply during the Study Period

PRIMARY ENERGY	1990	2000	2010	2019
OIL	60.21	60.79	51.14	34.34
GAS	32.52	18.60	7.01	3.41
COAL	5.72	18.21	35.55	54.29
NUCLEAR	0.00	0.00	3.92	6.18
OTHERS (hydro, geothermal)	1.55	2.40	2.38	1.79

d. **Crude Oil Projection (%)**

- Crude Oil Projection during the Study Period

PRIMARY ENERGY	1990	2000	2010	2019
OIL	60.20	60.80	51.10	34.3
(DOMESTIC PROD.)	(92.1)	(48.0)	(21.4)	(12.8)
(IMPORT)	(7.9)	(52.0)	(78.6)	(87.2)
(EXPORT)	(51.1)	(32.5)	(17.0)	(11.4)

III.2 Electric Expansion Plan and The Role of NPP

The Electric expansion studies include studies on the Electric System Analysis and Choice of Unit Size.

a. Electric System Analysis

The objective of the Electric System Analysis, is to determine an optimum configuration for the Java-Bali electric generation system with the introduction of Nuclear Power Plants including the size and its main features.

The results obtained through the optimization study in the development of the Java-Bali electric generation system with the use of the ELECTRIC module (WASP III) of the ENPEP program, shows that the introduction of nuclear power plants in the early 2000s to the Java-Bali electric system represents an optimal solution.

b. Choice of Unit Size

The objective of Choice of Unit Size study, is to determine the nuclear power plant unit size, taking into consideration the capability and reliability of the electric network system in relation to the load flow, short circuit capacity and the stability of the network.

The results show that commencing in the early 2000s and supported by development of the electrical network, the introduction of the 600 to 900 class nuclear power plants into the Java-Bali electric system is absolutely possible, furthermore based on economic aspects, the introduction of the 900 unit size class is a better option. Meanwhile, to anticipate the increasing demand of electricity in the future, it is very necessary to conduct updating studies of the electric network system.

Based on the above studies, the following may be concluded :

Coal fired plants will dominate the electricity generation system. Nuclear power plants will be feasible to be in operation in the early 2000s (based on current projection studies). Nuclear power plants will increase in accordance with the demand. The result of the analysis of this scope of work is used as reference for optimization studies in the development of the Java-Bali electric system.

In the year 2019 the role of nuclear power plants will give a contribution of 10% to the electricity supply, an amount equal to about 12600 MW.

III.3 Economics and Financial Study

a. Nuclear Cost Estimate

This study covers an analysis of capital cost (based on vendor's overnight cost, in April 1992 US dollars) for each type of nuclear power plant, as offered by various vendors: Mitsubishi Heavy Industries (Japan), Atomic Energy of Canada Limited, Nuclear Power International (German - French Consortium), Westinghouse Electric Company (USA), General Electric Company (USA). Comparisons of maintenance and decommissioning costs of the various designs, based on NEWJEC's method and experience are given.

The results of the analysis and information acquired are as follows :

1. The capital costs (vendors budgetary estimate) of various types and capacities of conventional NPP (600 - 1000 MW) is around **1530 - 2200 US$/kWe** and **1530 - 2020 US$/kWe** for advanced designs.

2. The operation and maintenance cost of various types and power of NPP averages about US$ 70/kWa.
3. The estimated decommissioning cost is around 10% of the capital cost.
4. The data and information from points 1, 2 dan 3 have been used as a basis for Generation Cost calculation of nuclear power plants.

b. Financial Study

The objective of the Financial Review Study, is to obtain various options and sources of viable financing for the construction of Nuclear Power Plants in Indonesia. The scope of the study consists of : 1) Conventional Financing, and 2) BOO/BOT Financing Scheme. Following are the results of the study :

1. Conventional Financing

Implementing conventional financing for the construction of 600 or 900 MW units can be done like any other construction of power plants. Feasible or viable sources of financing can be conducted for example : US component 50%-Japanese component 50%, US component 100%, French component 50%-German component 50%, and Canadian component 100%.

The results show that the energy price of the 600 and 900 MW class Nuclear Power Plant units are competitive to the energy price of similiar capacity of Coal Fired Plants using deSOx and deNOx equipment.

2. BOO/BOT Financing Scheme

The study is still very preliminary in nature.

The implementation of the BOO/BOT financing scheme for 600 and 900 MW unit nuclear power projects in Indonesia should be supported by the Government through the following instruments :

- The need of a bilateral agreement between the Government of Indonesia and the related country concerning the use of nuclear energy for peaceful uses.
- Activities related to the decommissioning and back end of the fuel cycle.
- Guarantee of fuel supply.
- Third Party Liability insurance from nuclear hazards.

Furthermore a power purchase agreement is necessary between PLN with the company, covering the following guarantees and requirements :

a. The obligation of PLN to remit payments according to the requirements, using the agreed determined exchange rates.

b. A guarantee by the Government to return loans, dividends, and other financial arrangements in the determined exchange rate and currency.

III.4 Site and Environmental Studies

Site and Environment Study (SES) for the NPP in the Muria Peninsula has been going on since end of 1991. The study consisting of general site survey, site evaluation, and site confirmation currently has reached its third or final stage. The completion of the study is scheduled for May 1996, with the submission of complete report of Site Data Report (SDR), Preliminary Safety Analysis (PSAR), Environmental Impact Analysis Report (EIAR), and the Final Report of Site and Environmental Study (FR-SES).

By far, preliminary conclusions drawn from data and information of the study show that the candidate site, Ujung Lemahabang (ULA), an area of approximately 500 hectares at the Northern part of Peninsula, is the best choice for the siting of NPP from both technical and economical point of views. There is no immediate hazard that could affect the NPP integrity and its operation.

The Site Studies concern many aspects, however, only the results of the volcanology, seismology and environmental studies will be briefly described here, as follows :

a. Volcanology and Seismology

These two aspects of SES receive special attention during the study. Networks of Microearthquake Telemetring System (MTS) consists of 5 and 3 seismometers are installed in the area. This system records every single earthquake with the magnitude of < 3 Richter. To record earthquake having $M > 3\text{-}5$, A Strong Motion Accelerometer (SMA) system is installed at the Ujung Lemahabang site. By far, no single earthquake that could trigger this SMA system is ever recorded.

There are two volcano systems in the area, they are, the Genuk and Muria volcanos. Mount Genuk (719 m) had activities in the age between 3.29 to 1.65 ma, and had lasted till about 0.49 ma. Mounth Muria (1602 m) that is situated in the center of Peninsula had activities between 2.1 to 0.8 ma. The last volcanic eruption is judged to have occured about 0.32 ma ago. The candidate Site, Ujung Lemahabang, has never been affected by lava or pyroclastic flows from either volcano. Careful assessment of the phreatic and gas emission phenomena at flank of Muria is still underway.

b. Environmental Studies

As mentioned before, most of environment studies in the candidate site Ujung Lemahabang are still underway. However, preliminary results in some aspects of studies further confirm the acceptability of Ujung Lemahabang.

The following parts is the highlight of preliminary results in the environment studies:

1. Evaluation based on the screening distance value (SDV) shows that none of sources of Man-Induced Event identified in near the site may affect the safety of the site.
2. No extreme meteorological phenomena such as tropical cyclone that may threaten the site is foreseen.
3. No sensitive ecological systems and communities are found within the 5 km radius from the site.

III.5 The Prospect and Public Concern of NPP in Indonesia

The prospect of Nuclear Power in Indonesia is very good both in the medium and long term future. Indonesian geography, resource distribution and population distribution have a great influence on the nuclear prospect besides environmental consideration. From the political point of view, we have got a new and stronger momentum from President Soeharto, who stated on 5 May 1995 that Indonesia should carefully plan for the nuclear power plant construction with due attention to its safety. We are now working on two main issues in nuclear power introduction, namely :

1. Public acceptance, where few important figures are still influenced by the negative information from anti-nuclear group.

2. Financing scheme, where we should choose the right scheme to make the NPP's really viable economically.

a. Public Acceptance

There have been growing concerns coming from the Indonesian public on the use of nuclear energy, especially concerning issues of NPP. Non Governmental organization and environmentalist have come up, making the public acceptance programme more challenging.

To enhance the public on the peaceful uses of nuclear technology including the aspects of nuclear power plants, an interdepartmental organization has been established since the year 1990. This interdepartmental organization, coordinated by National Atomic Energy Agency, has made efforts in promoting, giving information, and discussing openly to the public on the peaceful uses of nuclear energy and especially to the immediate environment where the feasibility site studies are being conducted. Efforts such as these will be a continuing program, as also practiced by many other countries.

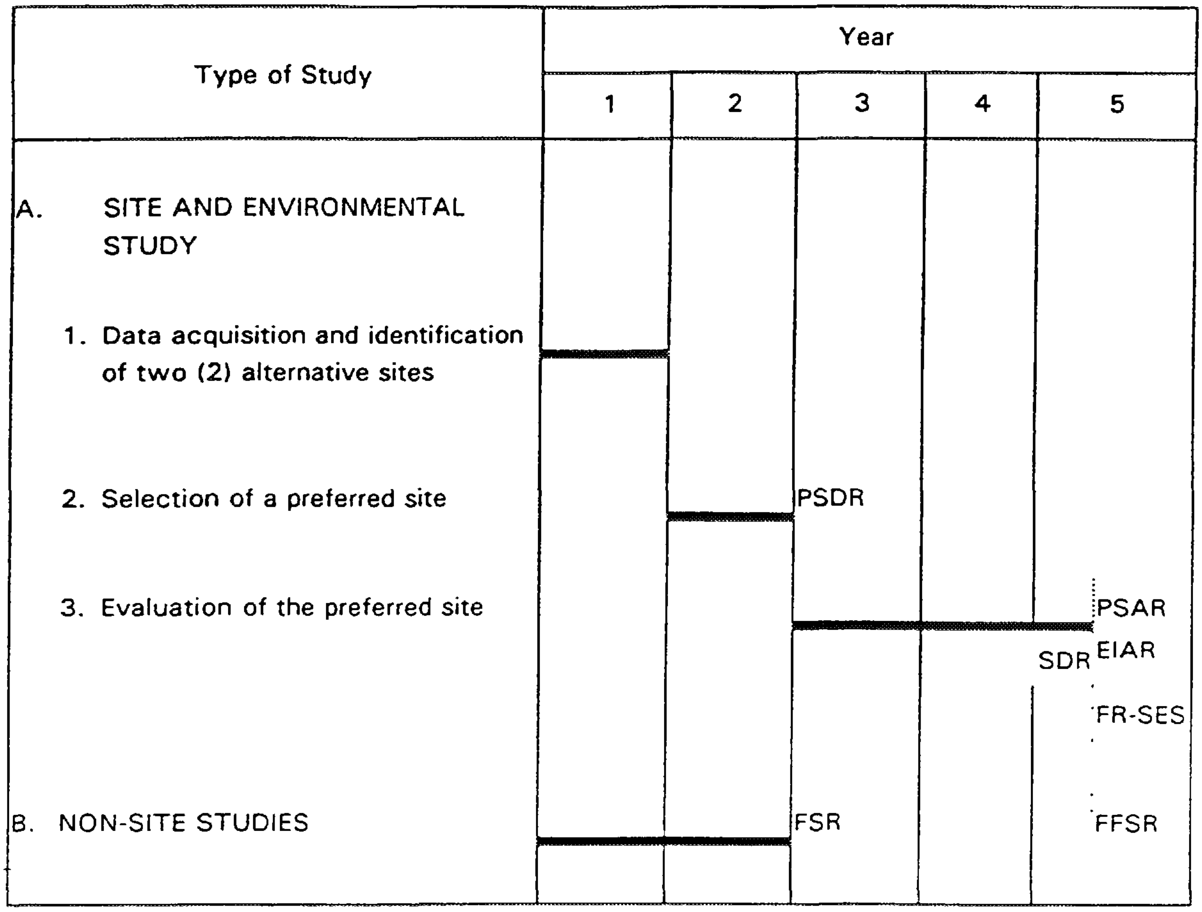
This endeavor may not be enough. However, experiences from industrial countries that already have a history of NPP, may contribute positively to our endeavor, and cooperation among countries in this respect may also add to global concern on the need of NPP.

b. Financing of Nuclear Power Plants

As financing of nuclear power plants require large amounts of funding, it is necessary that funding of NPP must be considered as sound investments and being economically beneficial, not only to the NPP itself, but to expand the industrial capability and participation. Domestic industrial participation in the NPP construction assessed so far would represent around 25 % for the first units, and can increase progressively to 35 % for the third units. This means that large business opportunities will emerge in parallel with the required capabilities in the domestic industries themselves.

In case of expected substantial share of domestic participation, related domestic investments should be made available sufficiently and timely to support the required increased capabilities. These investments include also the development of human resources.

However, it will become more difficult to aqcuire funding in the future, which will be a challenge in the endeavor to build high scale projects having long investments periods. In order to prevent financial matters in becoming a hindrance, it is very important to anticipate this matter as early as possible by efforts to increase cooperation among nuclear concerned countries so that financial institutions will support and be in favour of building of nuclear power plants.



PSDR - Preliminary Site Data Report
FSR - Feasibility Study Report
SDR - Site Data Report
PSAR - Preliminary Safety Analysis Report (Site Part)
EIAR - Environmental Impact Analysis Report
FR-SES - Final Report of Site and Environmental Study
FFSR - Final Feasibility Study Report

Figure-1. Time Schedule of the Feasibility Study for a Nuclear Power Plant in the Muria Peninsula Region

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STRATEGIC AREAS FOR NON-ELECTRIC APPLICATION OF NUCLEAR ENERGY IN INDONESIA

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Abstract

An attemp is made to identify strategic areas, whereby non–electric application of nuclear energy may be justified Subject to further evaluation, particularly on the economic aspects, non–electric application of nuclear energy in Indonesia may have justfiable strategic role in the long term sustainability of the development of the country The key arguments are (a) within not too far distant future, domestic resources constraints of oil and natural gas will strongly be felt, especially if the current trend in the rate of production of the two commodities has to be maintained to satisfy the growing demand for energy and to secure foreign exchange earning, (b) nuclear option, in concurrent with coal and biomass options, can provide the need for heat supply required to undertake strategic schemes for (i) improving oil production capacity, (ii) prolong the availability of oil and natural gas by displacing their uses as heat sources in industry, whenever appropriate, (iii) coal conversion to synthetic natural gas (SNG), or synthesis gas, to substitute or at least supplement the use of natural gas as industrial chemical feedstock, and (iv) sea water desalination by evaporation, to overcome shortage of fresh drinking and industrial water supply, as well as to secure its reliability and availability In terms of carbon emission to the atmosphere, the nuclear option offers an interesting choice
In view of those, serious consideration for futher technical assessment, and thorough evaluation on the economic viability and social acceptability for the option is recommended

INTRODUCTION

Within not too far distant future, domestic oil and natural gas resource constraints will strongly be felt by Indonesia, especially if current trend in its rate of production has to be maintained to satisfy domestic oil and gas demand and generation of foreign exchange revenue Coal is anticipated to be the lead fuel of the Indonesian energy mix in the next century

The above picture can be appreciated by recognation and observation of the following

(a) the endowed energy resources of Indonesia, as is shown in Table 1, coal is the most abundant among the prime fossil fuels (i e excluding peat)

Table 1 Estimated energy resources of Indonesia (*)

Oil	*48 4 billion barrel*
Gas	*216 8 TSCF *)*
Coal	*36 billion tons*
Peat	*200 billion tons*
Geothermal	*16000 – 19000 MW*
Hydropower	*75,000 MW*
Biomass	*1 035 x 10^6 km^2 forest area, and 52 37 mtoe/yr (1990) agro & silviculure wastes*
Tidal, wave and ocean thermal	*identified*
Wind	*prospective*
Radio active minerals	*indicated*

(*)Source CRE–ITB Energy Data, colleted from various sources

(b) the development of the share of oil and natural gas in the Indonesian energy system for the past 25 years and in the projected 6th Five Year Development Plan, as can be seen in Figure 1 and Figure 2 the two energy commodities occupy a dominant role;

(c) the determining role of oil and natural gas to the sustenance of the Indonesian economy in the past 25 years, i e with an annual average GDP growth of 6.8%, the share of the oil and gas sector to the GDP was 24% in 1981 and declined to 13% in 1992, while the export share was 80% to total export earnings in 1981, and dropped to 25% in 1992 (1), even though it is declining, the shares are still very substantial, and in the immediate future, oil and gas will still be determining factors to the economic development of the country.

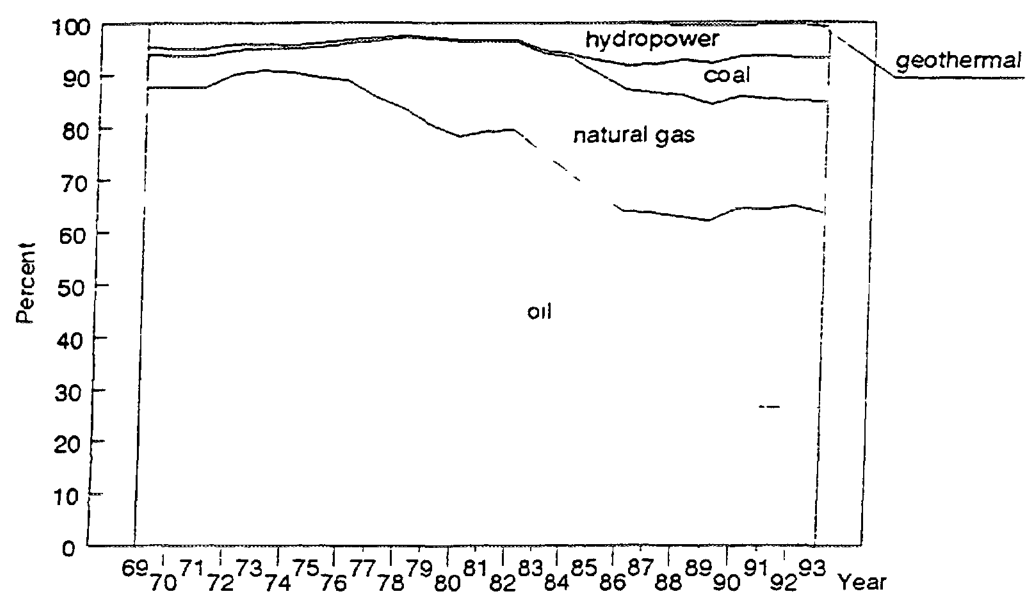

Figure 1 Primary (commercial) energy consumption in the 1st Long Term Development Cycle, 1969–1994
Source DJLPE, 1994

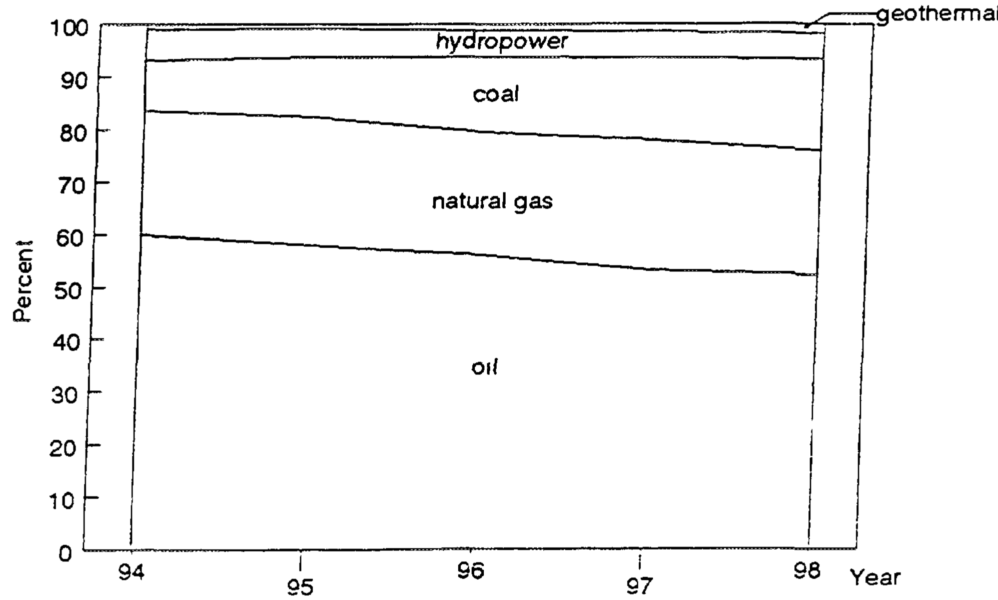

Figure 2 Projected (commercial) primary energy consumption in the 6th Five Year Development Plan 1994/95–1998/99
Source DJLPE, 1994

(d) the results of various studies on the Indonesian possible energy futures (2,3), from which one can see that, typically the projected energy mix has a pattern as shown in Figure 3, where the share of coal is wedging as one moves futher into the future, the projected scenario also indicates a fast decline of oil and natural gas resources if current export rates of oil and natural gas is maintained, as can be seen in Figure 4 and Figure 5

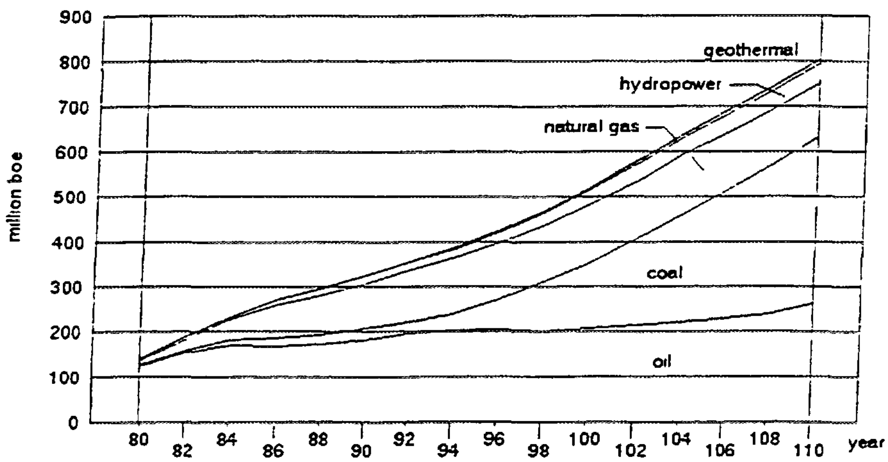

Figure 3 Scenario projection of primary energy supply
Source Reference 2

In view of the above observation, aside from conservation measures, investigating and finding avenues to control the rate of use of oil and gas by way of introducing alternative resources to replace their role in the energy and non–energy uses is therefore very relevant with respect to the sustainability of the development of the country and its energy security

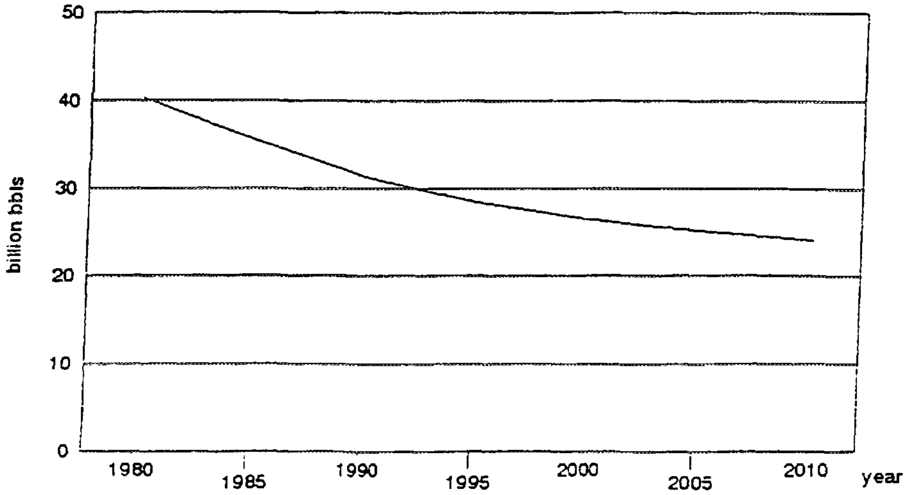

Figure 4. Scenario projection: decline in oil resource
Source: Reference 2.

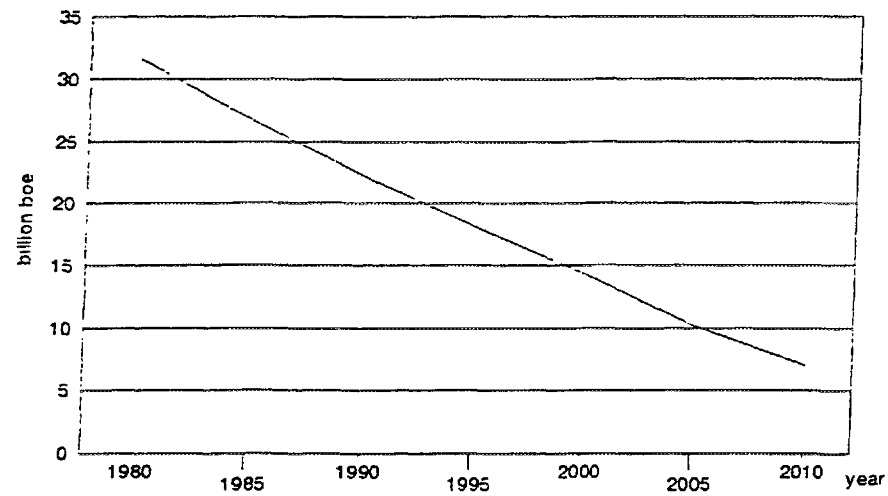

Figure 5. Scenario projection, decline in natural gas resource
Source: Reference 2.

STRATEGIC AREAS FOR APPLICATION OF NUCLEAR HEAT

Although coal can be expected to assume the role as the future major energy supply of Indonesia, there will still be gaps in satisfying the needs of the industry for natural gas as chemical feedstock, and the demand for liquid fuel in the transportation sector. Furthermore there is a global concern on the increasing carbon accumulation in the atmosphere that to some extent impose constraints to direct coal burning.

In response to those developments, there are alternative means that Indonesia can consider and prepare herself to undertake:

a. Implementing enhanced oil recovery procedures to extract remaining oil that are still in place, when such undertaking can be carried out more economically compared to other options, like import of oil.

b. Prolong the availability of oil an gas by way of diversification and conserving the use of oil and gas, not only through demand management and efficiency measures, but also by replacing their functions as sources of heat supply to the industry;

c Substitute or supplement the use of natural gas as feedstock to the chemical industry, by way of coal conversion to synthetic natrural gas (SNG), or synthesis gas that presently are produced through reforming of natural gas

All of the mentioned schemes would require substantial heat sources to implement The use of oil or natural gas to supply such demand even though could be justified from purely economic consideration is a self defeating excercise with respect to the underlying motives that was taken as the base for the listed undertakings

Since for all the above purposes, relatively high temperature heat is required, alternative options that technologically can be considered are to use coal, biomass nuclear, and solar energy. The technology for the solar energy option, however, is a much more remote choice as compared to the first three Without implying the elimination of the coal and biomass options, only the nuclear option will be discussed, for the obvious reason that this presentation is addressed to a meeting on non-electric uses of nuclear energy

Aside from the mentioned area, there is another area whereby non-electric application of nuclear energy could be justifiably considered, namely the supply of clean, fresh water Clean water supply, either for household, public uses, and industrial uses, as well as in steam power plants is increasingly becoming a serious problem, particularly in densely populated areas in Indonesia, like in the island of Java, as well as in areas where large industrial complexes are developed and operated.

The water supply problem is partly due to lack of adequate infrastructure for water supply in urban and other settlements. This has triggered wider problem, since the situation leads to wide spread exploitation of deep ground water to fill the large gap in need for water. Another reason is plainly the unavilability of a reliable rate of water supply for large scale and continuous water use of industrial complexes. The problem is also aggravated with the accelerating rate of pollution of surface inland water (rivers, lakes, water ways), and certain costal sea water.

Before massive cleaning operation of those polluted waters can be successfully undertaken, which is not only costly but also socially complex, desalination of sea water is practically the only available option(*) As was previously the case, nuclear generated heat supply is an option that one can justifiably choose, since the need for fresh clean water is a basic need. All steam power stations in Java, as well as refinery and fertilizer plants in East Kalimantan and some other places rely on such installation for their water needs Oil and gas are currenty used. In some cases, with proper configuration, the supply of heat for water desalination can be a downstream operation of a high temperature process, like reforming or power plant operated on supercritical steam

POTENTIAL DEMAND FOR POSSIBLE APPLICATION OF NUCLEAR HEAT

Refering to the identified strategic areas for the application of non-electric nuclear heat in the previous section, some preliminary rough estimates of a few selected areas and their potental demand is made, and presented in Table 2

(*) This does not imply, however that massive cleaning program of inland surface waters (lake, rivers, water ways) and coastal sea waters should be put aside In fact the sea water desalinaton scheme could become a facilitating action in support of that program as this may reduce deep ground water exploitation and relieve some pressure on the demand for inland waters

Table 2. Estimated potential demand for possible non-electric application of nuclear energy

Application area	Specific energy consumption [TJ/m^3]	Throughput volume [m^3/yr]	Estimated heat demand(*) [TJ/yr]	Estimated CO_2 emission reduction(*) [tons/yr]
Enhanced oil recovery (Duri)	0.00738816	12,712,000	93,918	7,269,284
Reforming of natural gas				
a.in fertilizer production (1991)	0.00023	403,191,883	92,517	5,190,215
b.in steel production, ton/yr				
c.in methanol synthesis				
Water supply to power plants (Java) (assuming 1% make up rate)	0.00000225	1,952,654	4.41	341
Water supply to ind'l complexes (Kaltim) (assuming 50 % make up rate)	0.00011293	54,750	6.18	479
Coal gasification				
a. for gaseous fuel				
b. for synthesis gas				
c. for SNG				
Total			186,446	12,460,319

The estimated demand figure, even though of limited coverage, indicates that at least there is potential demand at the level of 186,446 TJ per year, which is equivalent to savings in natural gas at the rate of 176,726,750 MSCF per year. The corresponding CO_2 emission reduction potential due to avoided combustion of oil and natural gas is 12,460,320 tons per year(*).

The tabulated estimates were made by assuming that the heat supply of current and firmly planned installations are to be replaced by nuclear generated heat from HTGR.

If one takes a 20–30 years perspective into the future, one may also consider the potentials of implementaing a scheme whereby coal gasification is undertaken to produce gaseous fuel (medium or high BTU gas), synthesis gas to replace or complementing the need for urea fertilizer production, methonol synthesis, etc.

CONCLUDING NOTES

The spectrum of the areas, whereby non-electric application of nuclear heat can be identified, and the preliminary estimates on the possible demand for such application, indicated that such application has some prospect to Indonesia. The brief analysis on the likely beneficial effects with respect to the prolonged availability for domestic oil and gas supply, implies that such nuclear option would have beneficial effect to the sustainability of the Indonesia economic development and energy security. Furthermore, the approach would contribute to carbon emission reduction, that is currently taken as a global objective. Serious consideration for further technical assessment, and thorough evaluation on the economic viability and social acceptability of the mentioned nuclear option is therefore recommended.

(*) Based on the IPCC most recent published emission coefficients.

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PROSPECT OF COAL LIQUEFACTION IN INDONESIA

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Abstract

With the current known oil reserves of about 11 billion barrel and annual production of approximately 500 million barrel, the country's oil reserves will be depleted by 2010, and Indonesia would have become net oil importer if no major oil fields be found somewhere in the archipelago. Under such circumtances the development of new sources of liquid fuel becomes a must, and coal liquefaction can be one possible solution for the future energy problem in Indonesia, particularly in the transportation sector due to the availability of coal in huge amount.

This paper present the prospect of coal liquefaction in Indonesia and look at the possibility of integrating the process with HTR as a heat supplier. Evaluation of liquidability of several low grade Indonesian coals will also be presented. Coal from South Banko-Tanjung Enim is found to be one of the most suitable coal for liquefaction. Several studies show that an advanced coal liquefaction technology recently developed has the potential to reduce not only the environmental impact but also the production cost. The price of oil produced in the year 2000 is expected to reach US S 17.5~19.2/barrel and this will compete with the current oil price.

Not much conclusion can be drawn from the idea of integrating HTR with coal liquefaction plant due to limited information available.

I. INTRODUCTION

A key and continuing thrust of the national energy strategy is to optimize the use of non-exportable energy and therefore to conserve exportable surplus of crude oil and thereby to slow down the pace of Indonesia's transition to net oil importer status (Ramlan, 1994).

With the current known oil reserves (11 billion barrels) and annual production of about 500 million barrel oil (Ramlan, 1994), the country's oil reserves will be depleted in the middle of PJP-II's period, and that time (2010) Indonesia would have become net oil importer if no major oil fields be found somewhere in the archipelago. Under such circumtances, the development of new sources of liquid fuel becomes a must.

Coal, on the other hand, offers the potential for stable supply and therefore relatively stable price. At present, its reserves in Indonesia is estimated to reach 36.6 billion tons. Unfortunately, more than 70 % of that coal reserves are mainly in the form of low rank coal or lignite. The unfavourable nature of this low quality coal makes it difficult to be stored and transported, for example it has so many holes and consists of considerable water; when it is exposed to air, there is a strong possibility of self-igniting. Besides, the utilization technology of this low grade coal is still limited at the moment.

To secure the future of energy supply while preserving the oil reserves, the country must find an alternative energy by utilizing such huge amount of low quality coal. Regrettable, modern life relies very much on the use of oil and other liquid fuels particularly in the transportation sector that coal is not suitable. Therefore, coal must be converted into oil through a process known as coal liquefaction. The process produces synfuel for transportation such as gas oil, gasoline and kerosine.

This paper presents the prospect of coal liquefaction technology in Indonesia. First, it discusses what coal liquefaction process is and its latest development status, followed by brief overview of coal liquefaction research in Indonesia and results from evaluation of liquidability of several low rank Indonesian coals conducted at LSDE-BPPT and Takasago Laboratory, Japan. Finally, the economic evaluation of a coal liquefaction plant is presented. Advanced brown coal liquefaction technology is used more in this analysis due to the availability of the data (Source of data : NBCL, Japan).

II. WHAT IS COAL LIQUEFACTION?

Coal liquefaction can be divided into two processes, i.e. direct and indirect coal liquefaction. *Indirect Coal Liquefaction* is the production of hydrocarbons from carbon monoxide and hydrogen in the presence of Fischer-Tropsch catalyst (Lee, 1979). The process was originally develop by Fischer and his partners. Full scale commercial plant built in 1950s in South Africa by Sasol is the only commercial liquefaction plant ever built in the world today. Despite it is very expensive in terms of thermal effisiency, the process itself is quite flexible. By adjusting the composition of catalyst, hydrogen/carbon ratio and operating conditions, a wide variety of products can be obtained. Moreover, other products such as methanol and acetone can also be produced by using different catalysts.

Direct coal liquefaction is a process which decomposes high molecular structured coal into lower molecular structured oil in the presence of hydrogen solvent and catalyst at a certain operating condition. Clearly, by blending coal, as a hydrocarbon compound like petroleum (but exists in solid form because of its greater molecular weight and lower hydrogen to carbon ratio), with catalyst and a hydrogen donor solvent at a very high temperature and pressure, the coal's polymer chains can be broken down, causing it to liquefy into an artifial petroleum. Direct Coal liquefaction is considered to take place into two consecutive steps : conversion to a soluble form (dissolution or depolymerization), and reduction in molecular weight and removal of heteroatoms, which is often called as up grading process (Fernandez et.al., 1995)

Numerous coal liquefaction projects are currently under development, and most of them are using direct coal liquefaction process as shown in the following schematic diagram (Figure 1). The energy efficiency of several coal liquefaction processes, which varies between 57 - 71%, is presented in the table 1. EDS, SRC-II and ITSL of USA use bituminous and sub-bituminous coals, while *Advance Brown Coal Liquefaction* process (BCL) uses low grade coal or lignite as a feedstock. Research on advanced BCL process using Indonesian low quality coal from Tajung Enim (South Banko) conducted by NBCL-Takasago Laboratory shows that its energy efficiency is higher than Victorian coal.

The study of advanced BCL process was commenced in 1993 as an improvement of the original concept design of 50 ton/day pilot plant built in Morwell, Victoria-Australia, The Victorian Brown Coal Liquefaction was intended to obtain technical data needed for scale-up to a commercial plant. Modification was made from the following points of view : less energy consumption, less construction cost, higher oil yield and more up graded products. The advantages offered by advanced BCL process compared with the original conceptual design are presented in table 2, while the difference between the two processes are shown in Figure 2 and 3.

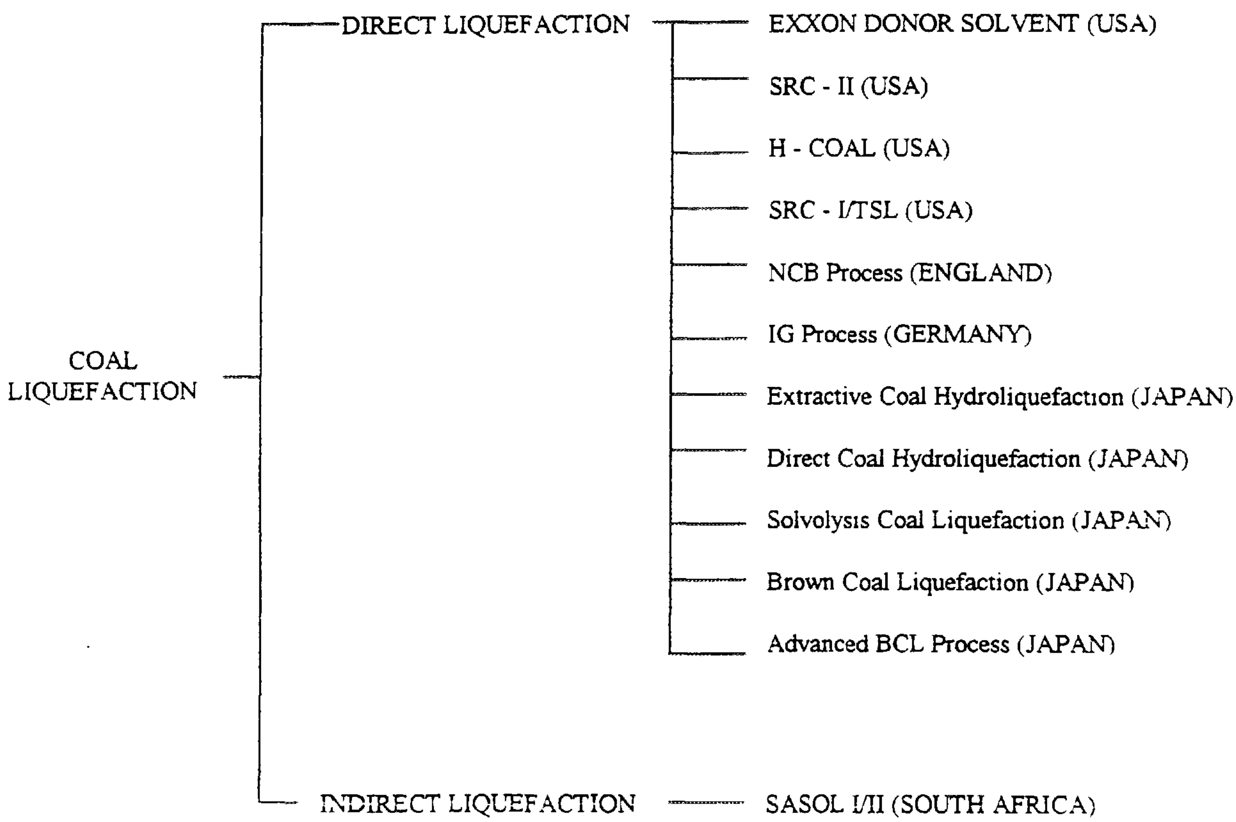

Figure 1. Coal liquefaction projects in the world

TABLE 1. ENERGY EFFICIENCY OF COAL LIQUEFACTION PROCESS

Original Conceptual Design	**57.3%**
Advanced BCL Vic. Coal with Hydrotreator	**60.4%**
Advanced BCL Vic. Coal	**66.9%**
Advanced BCL Ind. Coal with Hydrotreator	**65.8%**
Advanced BCL Ind. Coal	**70.2%**

Other Processes

EDS	**Sub-Bituminous Coal**	**57~58.5%**
SRC-II	**Bituminous Coal**	**66~71.0%**
CC-ITSL	**Bituminous Coal**	**67.9%**

TABLE 2. ADVANCED BCL PROCESS OFFERS SIGNIFICANT ADVANTAGES

1. **Simplified Liquefaction Process Makes High Efficiency With Low Cost.**
   Primary Hydrogenation With Half Scale Deashing Unit.
   Inline Vapour Phase Hydrotreator Instead Of Secondary Hydrogenation Unit.
2. **Low S/C Ratio & High Plant Efficiency By "Dual Peaks Solvent System".**
3. **Inline Hydrotreator To Improve Product Quality.**
4. **DAO (De-Ashed CLB) Recycle Operation Lightens Erosion Troubles.**
5. **High Reactive Iron Catalyst To Improve Oil Yield & Operational Reliability.**
6. **Introduction Of De-Carboxylation In Slurry Phase To Reduce Scale Formation.**
7. **No Preheater Operation Required During Normal Operation.**
8. **Multiple Reaction Temperature Profiles Would Change Yield Structures.**
9. **Hot And High Pressure Bottom Recycle.**
10. **Slurry Preparation Without Ball Mills.**
11. **CLB Direct Feed To Deashing Unit.**
12. **Max. Power Recovery From Gas & Liquid**
13. **C_3, C_4 Recovery From Plant Off Gases.**
14. **Optimization Of Plant Fuel Systems.**

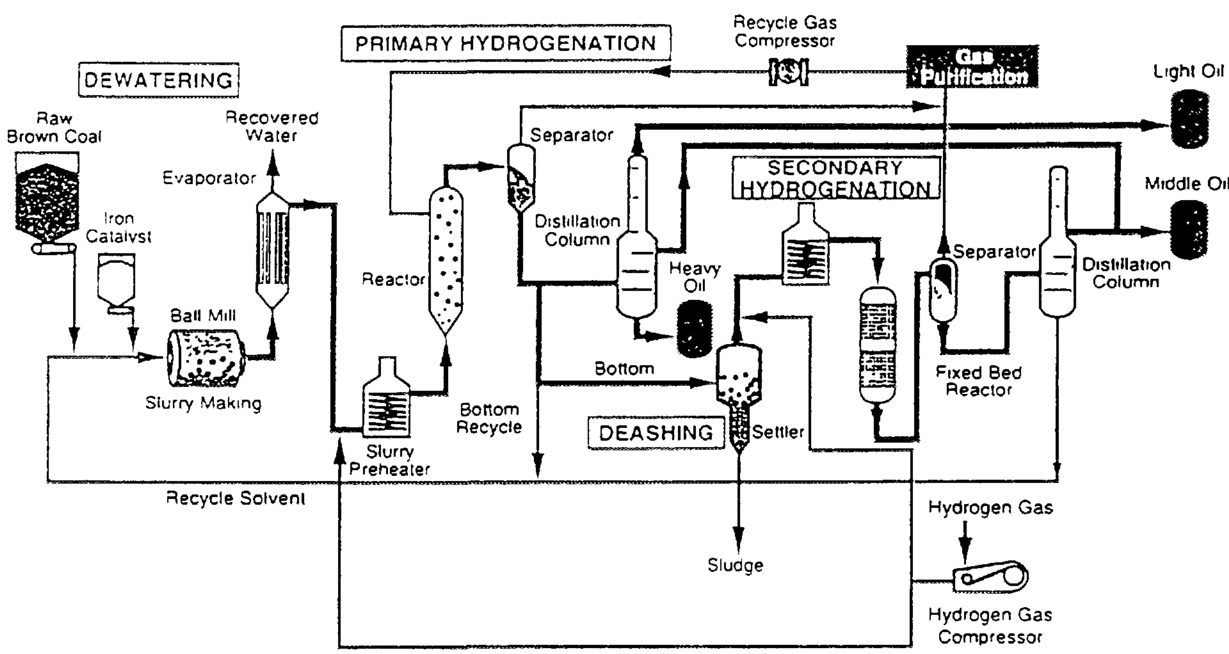

Figure 2 : Brown Coal Liquefaction Plant

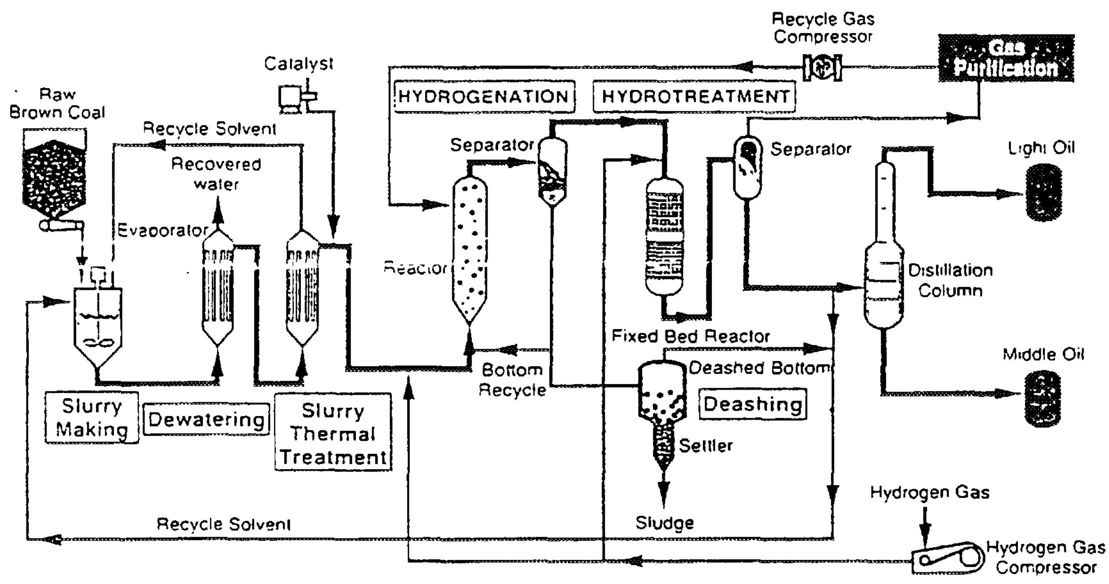

Figure 3 : Advanced Brown Coal Liquefaction Plant

III. OVERVIEW OF COAL LIQUEFACTION RESEARCH IN INDONESIA

Coal liquefaction research has been carried on in Indonesia since early 1990s. at MTRDC (Mineral Technology Research and Deveoment Centre-Bandung) and ITB (Bandung Institute of Technology using small scale reactor (autoclave). In 1993, BPP Teknologi, in cooperation with NEDO-Japan, commenced Indonesian brown coal Liquefaction colaboration study to investigate the liquidability of Indonesian coals and the economic of the process.

Coal samples from five different mining areas (Cerenti, Adaro, Pasir. Berau and South Banko) have been tested at NBCL-Takasago Laboratory, Japan and at LSDE - BPPT, Puspiptek, Serpong. The laboratory study using 0.5L autoclave, shown that lignite from South Banko in Tanjung Enim, Palembang, South Sumatra has the highest coversion effisiency, produces approximately 70% of liquid fuel. As a comparasion, 1 ton of Victorian raw coal (with 60% moisture) produces only about 1 barrel of liquid fuel, while each ton of raw South Banko coal (with about 35 % moisture) can produce approximately 3 barrel of oil. Figures 4 and 5 show the comparison of hydrogen, carbon. oxygen and sulfur contents of Indonesian coals and coal from Yallourn (Victorian), and the liquefaction results of those coals using 0.5 liter autoclave.

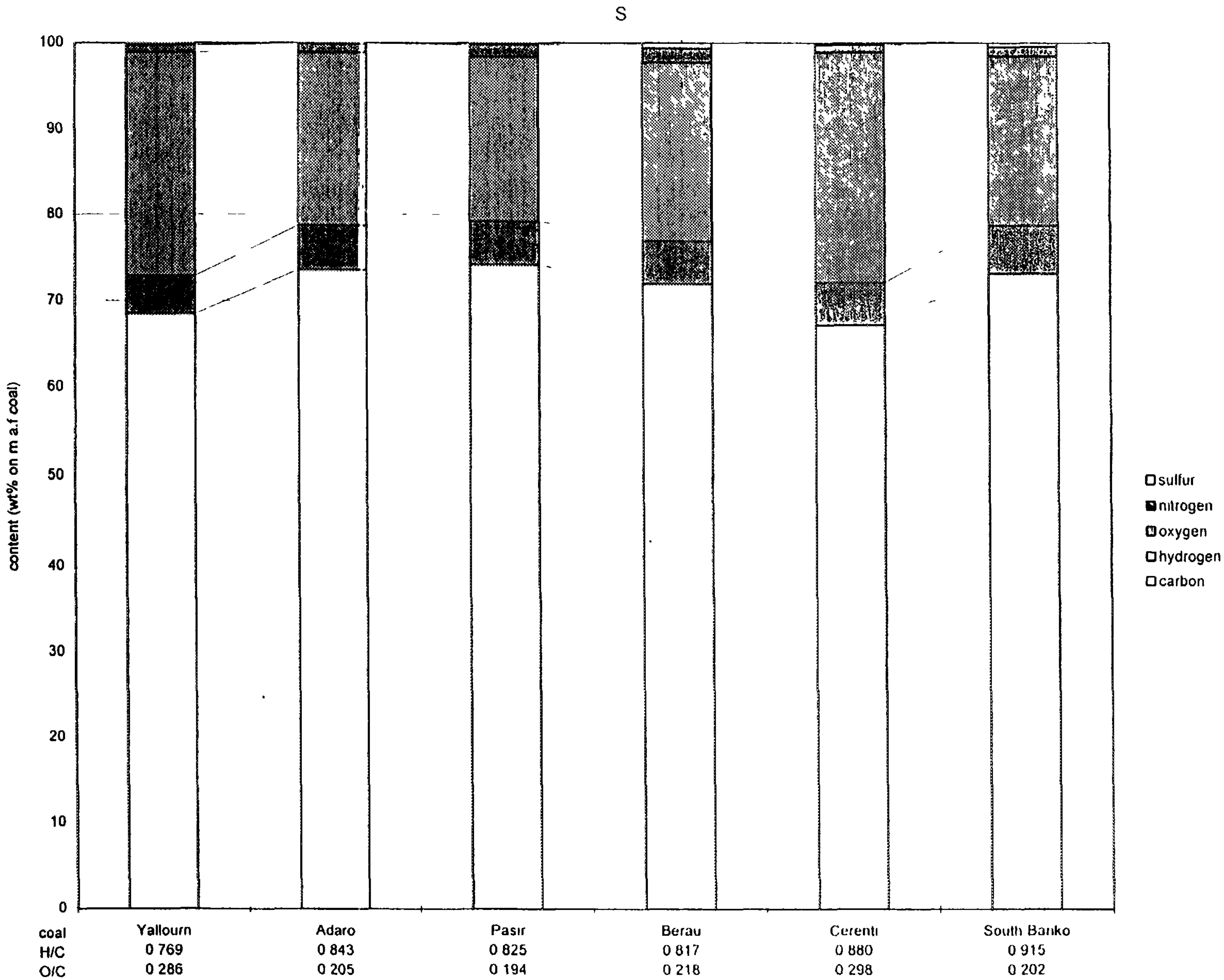

Figure 4. Comparison of the contents of component

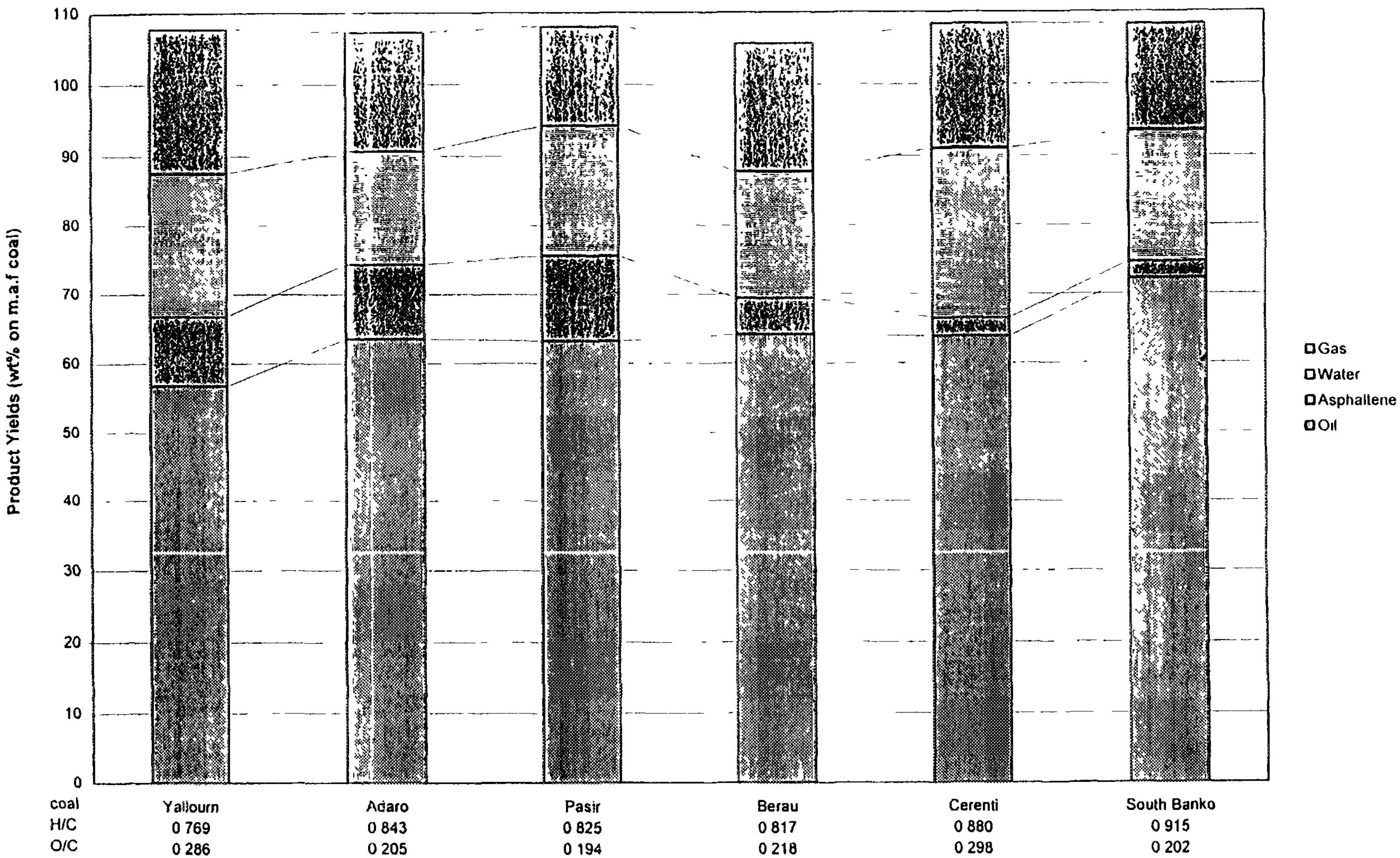

Figure 5. Comparison of the liquefaction product yields at 450°C/2~24 Mpa

Figure 6 and 7 show the concept of coal liquefaction process and proceeding of AC experiment, respectively. First, coal is dried and pulverized, and then mixed with pulverized iron ore as a catalyst and solvent hydrogen. The slurry mixture is heated and pressurized at about 430-450 °C and 15-25 Mpa performing liquefaction. Second, before it is destillated, liquified coal is hydrogenated (up-graded) in the present of catalyst. To produce marketable products liquefied coal needs to be rifined.

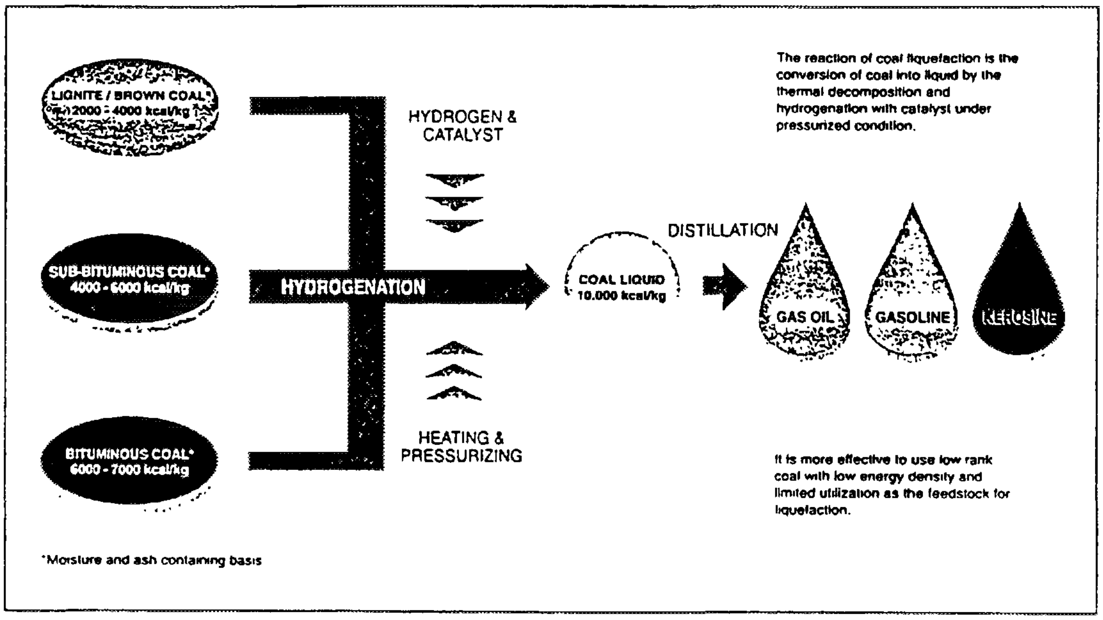

Figure 6 : Concept of Coal Liquefaction Process

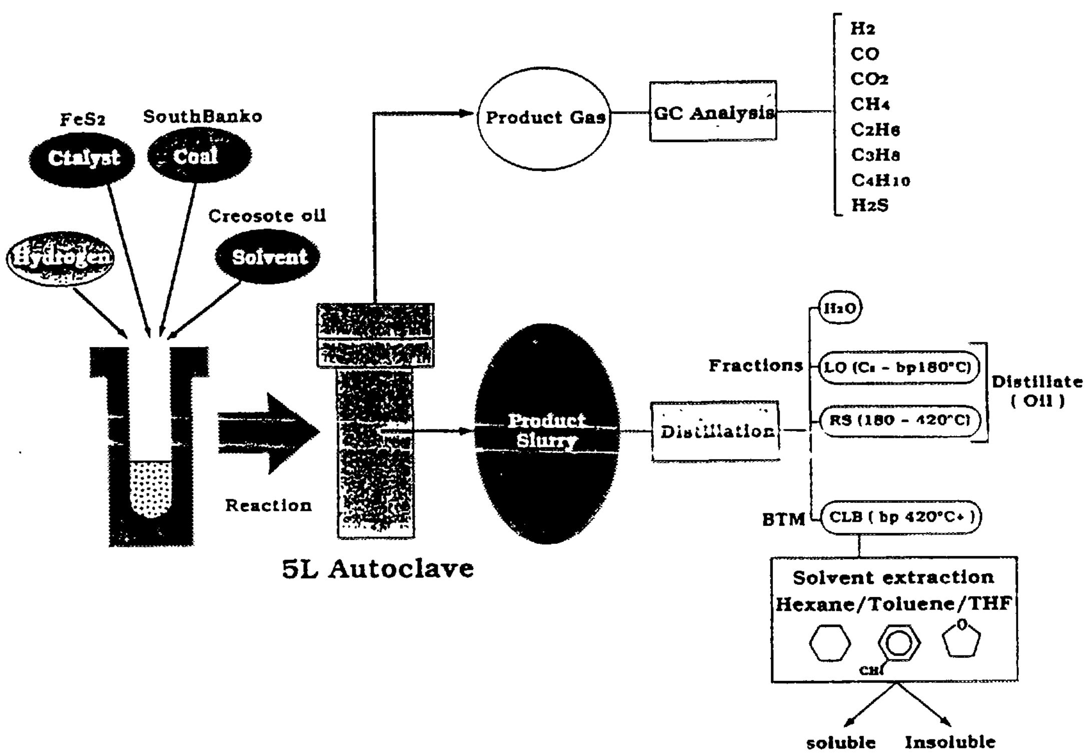

Figure 7 : Proceeding of Autoclave (AC) Experiment

The phase one of the research cooperation between BPPT and NEDO is planned to be completed by March 1996. At the moment about 10 tons coal sample from South Banko-Tanjung Enim is being tested in Takasago using a 1 ton BSU (continous) coal liquefaction. One Indonesian Engineer is working at the Laboratory together with the NBCL's experts to carry out the liquefaction research of South Banko coal which is expected to finish by medio 1996. Following this, a preliminary feasibility study will be conducted to determine the economy feasibility of brown coal liquefaction in Indonesia. Detail feasibility study is planned to be carried out for three years starting from 1996 to 1999.

IV ECONOMIC EVALUATION OF A COAL LIQUEFACTION PLANT

Study conducted by Gray and Tomlinson (1988) showed that the cost of hydrotreated product (oil) from Illinois coal for ITSL and H-coal plants or EDS plant are more than US \$ 40/barrel in 1986. This price of course, are too expensive and can not compete with the current price of crude oil which is vary between \$ 16 to \$18/barrel.

As previously mentioned, modification for further improvement was made in Brown Coal Liquefaction, and it is called with *Advanced BCL* process. Some significant process improvements can significantly reduce investment cost and operating cost. By adoption of the dual peaks solvent, for example, solvent to coal ratio will be reduced from 2.5 to 1.8. Moreover, as light fraction corresponding with S/C= 0.74 would move to vapor phase in the reactor, actual slurry quantity decreases from 337 m^3/h in the conceptual design case to 169 m^3/h which means significant improvement of space efficiency on reactor section. This will affect not only the reactor but also slurry handling system, and reduce the number of slurry feed pumps to about 50%. As a result, the investment cost as well as operating cost will be reduced significantly.

Other process improvements have also been made in the Advanced Brown Coal Liquefaction. They are :

1. Mixing the pulverized coal directly with the recycle solvent in slurry mixing tank can eliminate the ball mill plants.

2. The reactor effluent slurry depressurized to 5 Mpa by the single pressure letdown valve contains a very small amount of light fraction which allows direct feed of CLB *(Coal Liquid Bottom)* to the deashing unit operated at 3.5 Mpa. This will eliminate the secondary pressure letdown valve system and CLB separation under the full vacuum.

3. At without hydrotreating case, adding a gas separation plant allows a recovery surplus of C3 and C4 of about 4.2% on mafc in total, resulting an improvement of product yields.

4. No CLB production and small quatity of waste sludge from the advanced process leads to the elimination of the waste sludge incinerator. The waste sludge can be incinerated in the coal fired boiler.

Those improvements lead to the substantial reduction in all costs of the plant. Results of the economic analysis, which was carried out using the discounted cash flow rate of return, shows in the case that design and construction for a commercial plant would commence in 1996 and begin to sell product from 2000, the product oil price (with hydrotreating case) would be US $19.2/barrel (no infration), a 25% decrease compared with US $ 25.5/barrel (no infration) for the conceptual design case. For without hydrotreating case, product oil price would also again be reduced to US $ 17.5/barrel, a 31% decrease. The price of oil produced by advanced coal liquefaction process could be competitive with these forecasts even with such a very low forecast as US $ 15/barrel in 1994 and 1.5% per year escalation.

Evaluation of the advanced coal liquefaction process was carried out in the scale of 30,000 ton maf coal/day that consists of 5 parallel trains with the capacity of 6,000 ton/day each train. The plant location is sited near a coal mining area in the Latrobe Valley Victoria. The production capacity of this plant is approximately 124,000 barrel/day (with hydrotreator) to 132,000 barrel/day (without hydrotreator). The construction cost of the commercial plant is based on the conceptual design for 6,000 ton/day demonstration plant with some modification.

V GAS EMISSIONS

Table 3 shows the emission of Carbon Dioxide released by several Coal Liquefaction processes and Advanced Brown Coal Liquefaction has the lowest emission, although it uses lower rank coal compared with other process such as ESD Direct Liquefaction and F-T Synthetic Indirect Liquefaction..

VI INTEGRATED PROCESS

One possibility of supplying energy required for coal liquefaction process is by having an integrated process which combines *High Temperature Reactor* (HTR) with the the coal liquefaction plant. The role of *High Temperature Reactor* (HTR) is to supply heat for coal liquefaction process. The heat produced in the reactor core is transferred by helium gas as coolant circulated gas. The outlet gas from HTR has temperature more than 900 °C, promise a wide application in process. This energy can be used to provide heat required at the dewatering process, thermal treatment unit to increase the slurry temperature up to 350-420 °C before is fed to the coal liquefaction reactor, and distillation

TABLE 3. GREEN HOUSE GAS EMISSIONS

Original Conceptual Design	**21.5g-C/Mj-product**
Advanced BCL Vic. Coal with Hydrotreator	**20.3g-C/Mj-product**
Advanced BCL Vic. Coal	**17.2g-C/Mj-product**
Advanced BCL Ind. Coal with Hydrotreator	**14.1g-C/Mj-product**
Advanced BCL Ind. Coal	**12.7g-C/Mj-product**

Other Processes (Wandoan Coal)

EDS Direct Liquefaction	**26.6g-C/Mj-product**
Methanol Indirect Liquefaction	**26.3g-C/Mj-product**
F-T Synthetic Indirect Liquefaction	**41.0g-C/Mj-product**
MTG Gasoline Indirect Liquefaction	**35.8g-C/Mj-product**

column. Theoritically, this concept can possibly be done, but the heat waste generated from HTR must be well utilized for other purposes, for example, to generate electricity or provide energy for other process. Unless the energy supplied by HTR is effiently utilized, this approach may not be attractive. Unfortunately, there is not much information available regarding the integration of HTR and coal liquefaction plant. Futher detail study is required.

VII CONCLUSION

1. Coal liquefaction can be one possible solution for the future energy problem in Indonesia, particularly in the transportation sector.

2. Coal from South Banko-Tanjung Enim is found to be one of the most suitable coal for coal liquefaction, in fact, it offers the highest energy efficiency.

3. Advanced brown coal liquefaction has the potential not only to reduce the environmental impact but also reduce the production cost.

4. The oil produced from Advanced BCL process in the year 2000 would be US \$ 17.5~19.2/barrel. This will be competitive against the current oil price.

5. Not much conclusion can be drawn from the idea of integrating HTR with coal liquefaction plantdue to limited information available.

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PROSPECT ON DESALINATION BY USING NUCLEAR ENERGY IN INDONESIA

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Abstract

Due to the population growth and its effect on the environment and hydrological cycle make the need of water in drinking water. hydro power, household water etc., increase. Not only in eastern parts of Indonesia with low wetness level compare with other part, but also in many provinces with high population, the lack of water becomes a serious problem. Based on this, a suitable method of desalination plant that converts sea water into fresh water as method with a good promising will be described. A probable future method of coupling a small nuclear power with desalination plants in Indonesia also will be explained.

I. INTRODUCTION

Water is the priority for human life. Even earth planet is contain of 75 per cent of water (including sea water resources), but still too many places of the world are feeling scarcity of fresh water resources, not only for drinking water but also for agricultural, industrial and residential uses. The world is becoming more and more aware of its shortage of fresh water.

Indonesia is located between two oceans and two continents. It's in wet tropical zones. It is an archipelago country and consists of thousands of big and small islands, distributed along the equator with many volcanoes and mountain among them. Depend on the number of rainfall, eastern part of Indonesia has a low wetness level compare with other part. So, there are naturally lack of water in dry season and abundant water in raining season. It is an irony that most of peoples who lives in areas along the seashore in Indonesia are also suffer from the enough quantity of fresh water.

Since industry and population growth of 7% and 1.57% per year respectively, will arise the amount of water demands and side effect on environmental damage. Many of water resources such river, ground water, lake or dam has been polluted. These water resources could not be used as raw water. In some part, the intrusions of sea water become a serious problem, which has happened in Jakarta, Medan, Semarang, Surabaya and Ujung Pandang.

Based on this situation, it is considered to look for another alternative method of producing fresh water. Similar as in middle east and North Africa, Indonesia also has abundant of sea water with various concentrations of salt. Therefore, desalination process and a possible coupling with small nuclear power have been considered to be appropriate method.

In this paper, a preliminary report on water supply, demand, desalination technology, a probable coupling with small nuclear power and economical aspects in Indonesia will be described.

II. WATER SUPPLY AND WATER DEMAND

WATER SUPPLY

The existence of water in the earth is managed by the hydrological cycle, where the waters move from continent and sea water surface into space and then fall down again to the earth surface eternally. That's never stopped energy source that activated that cycle is the heat from sun. The water from space, pours out to the earth as rainfall, dew, snow and ice. In the continent, they move in 3 ways, in soil surface as a stream, pond etc., comes up into leaves or space and intrude into soil to become ground water. Finally, they will gather in the lowest place as sea water. A part of sea water will evaporate and combine with the evaporated water come from continent and so on, to start a new hydrological cycle.

Principally, the amount of water in the earth is constant. However, the water balance (the amount of water in different type of water resources) from one region to another region in the world is different and can change in the dimension of time.

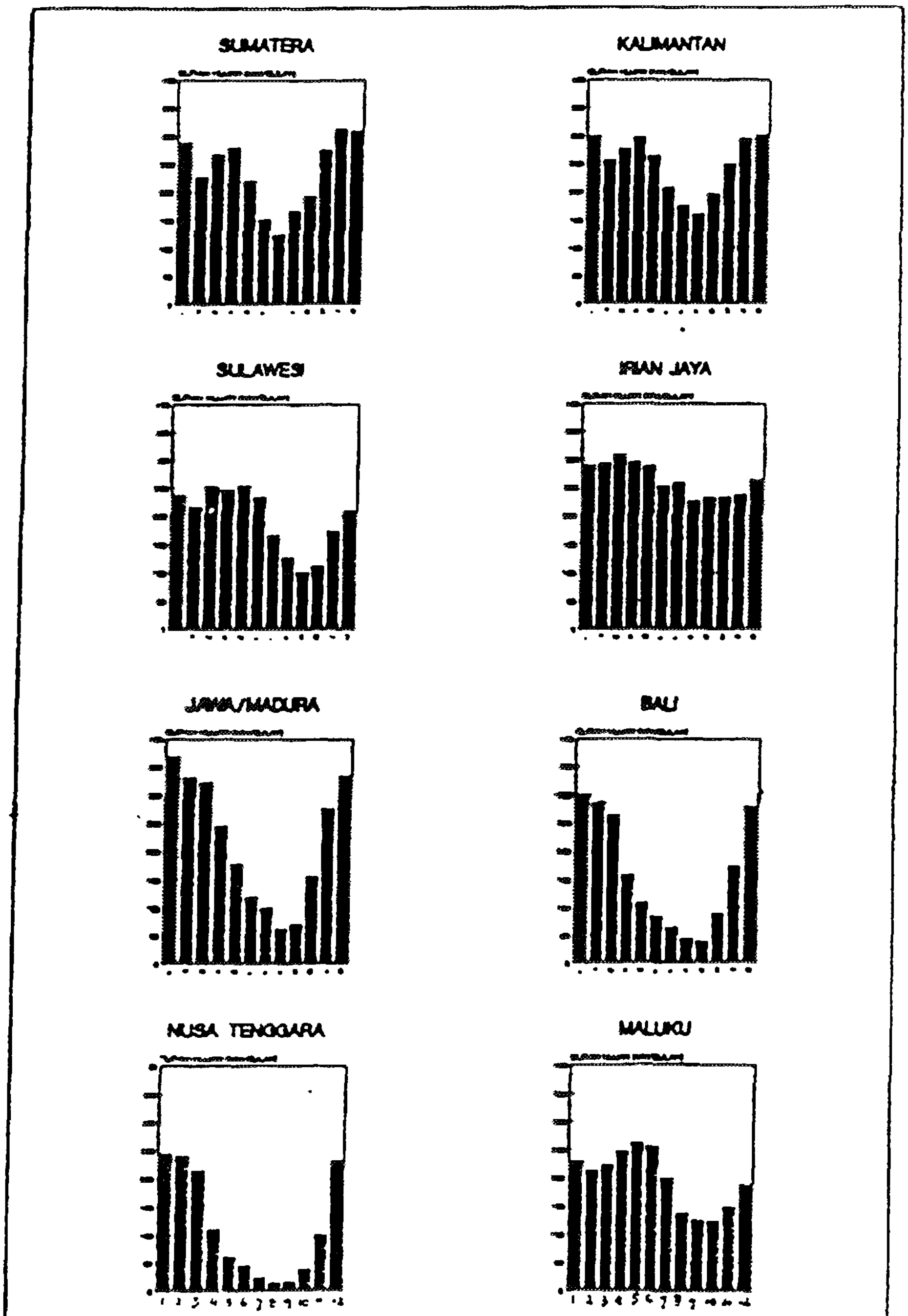
The water resources can be divided into primary and secondary water sources. Lava water and atmosphere water are called as a primary water source, because they are a primary type of earth water. Surface water and ground water are a secondary water source since they are made from the primary water as a pouring out products.

Rainfall

Indonesia is located between two oceans, two continents and in tropical zone. So, different with North Africa and Middle east, Indonesia is a tropical country with high number of rainfall. Therefore, the pouring out of rainwater seems to be a primary water source instead of sea water. The availability of primary water sources is usually expressed as a number of rainfall per month or year, so it will be in the dimension of times (rainy and dry season) and locations. In the dimension of time (Figure 1) cause a drastic change in water resources in some part of Indonesia, where it become very dry during dry season (from March until August) and reversely have abundant water in rainy season (from September until February), then can cause flooding and consequently cause damaging all things. The number of rainfall in one part is different with the other part, but it seems to have a similar pattern.

The balance of rainfall number and evaporation number during a year cause a various level of wetness in Indonesia (Figure 2). The provinces with higher rainfall number compare with evaporation number is called surplus region with high wetness level. Inversely, the lower rainfall numbers cause low wetness level region. It is clear from the Figure, that almost one thirth of part in Indonesia has low wetness level with lack of water specially in dry season.

Recently, as an effect of industrial development that do not care with the environment causes a decreasing of rainwater pH. It will lead a broad effect on the other secondary water resources and decrease in quality.



Sumber Direktorat Bina Program, Direktorat Jenderal Penyiapan Pemukiman Departemen Transmigrasi, 1990

Figure 1. Monthly rainfall fluctuation in some part of Indonesia

Rivers

As a consequence of rainfall, Indonesia has many rivers as a secondary water resource. The availability of surface flow water resources can be calculated as an

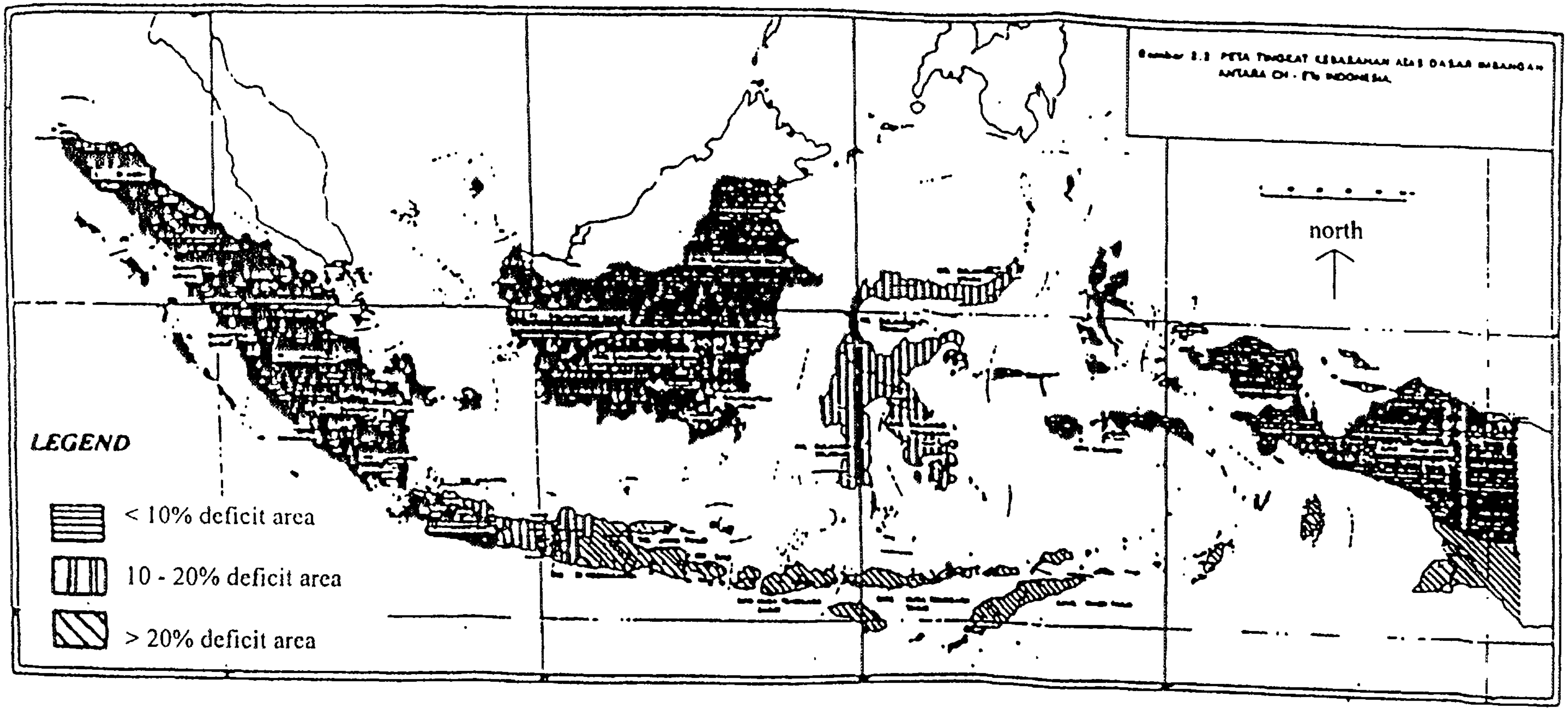


Figure 2. The map of wetness level in Indonesia

empirical analysis (equation 1) between a number of rainfall and a flowing surface water in a year.

$$R = 0.94 \times P - 1000 \qquad (1)$$

Where R is the average flow in a year (mm/year)
P is the average rainfall (mm/year)

By using the equation (1), the potential of average flow in a year in every province can be predicted. However, since the varied pattern of rainfall in a year, not all of that potential is useful specially in dry season that shows a minimum capacity of flowing surface water resources.

Lakes and Dams

Instead of rivers as a secondary water resource, Indonesia also has lakes and water reservoir of dams (53 water reservoirs that was built from 1914 up to 1992) with a total volume of 9,171.8 million m^3, where almost all are located in Java island (7,807 million m^3). Those dams are very useful for fresh water resources, irrigation, industry, fishery, electric and to prevent flooding.

Ground water

Indonesia is an archipelago country with 5 big islands and thousands of small islands with many mountains and volcanoes among them. The characteristic of ground water is defined by the climate, physiography and geohydrology. Therefore, Indonesian ground water is different with other country.

Almost part in Indonesia has fresh water supply that comes from ground surface water wells. So, during the last dry season, which was relatively longer, caused drying out of ground water well which can lead the intrusion of sea water. The human activities' results also affect the balance of hydrological cycle where can cause lack of ground water amount.

Environmental damage

As described above that the conventional water resources which depend on the hydrological cycle are rainfall, rivers, lakes, dams and ground water (deep or shallow).

Since the human activities, the quality and quantity of those water resources will decrease in time and become unusefull in the near future. In this section will be described how far the human activities affect the environment.

The uncontrolled air pollution comes from the industry (NOx and SOx compounds), since the difficulties on the source preventive action and the expensive cost to install the converter, will cause a condensation of them in the air and then fall down to the earth as acid rain. Even this effect seems be done only in industrial area and not in the large part of Indonesia specially in the eastern part of Indonesia (since a low number of rainfall), the desalination treatments become an appropriate method to be applied.

The industrial pollution and domestic pollution that seem to increase year by year in accordance with the increasing of the industrial facility's number will suppress the quality of water river. Even the government already built the PROKASIH (Clean River Program) to manage the waste water from industries. the water pollution concentrations still hold the main problem since the domestic waste water contribution. One of the important reason that should be covered is the high concentration of organic waste water treatment and a toxic component. Up to now, the PDAM JAYA (Water supply Enterprise - Jakarta) use the river water as their main water resources. Since the increasing of water pollution that can lead the high price of fresh water treatment installation, PDAM should find another cheap water resources alternative in the near future, where the sea water could be considered as a priority for it through desalination process.

The getting worst of water river causes the lower water quality in lakes and dams where swamps and lake's water resources are the source of ground water aquifer. So the farther effect is the lower quality of ground water.

The fresh water supply, especially in dwelling region such as Jakarta, mostly use ground surface water wells. Since there is no sewerage system in Jakarta, the utilization of septic tank in each house will cause a serious problem and named as a biggest septic tank. Recently, the uses of ground surface water well are not appropriate anymore, because the side by side position of those ground water wells with septic tank that can seduce the increasing of colliform bacteria has been applying. So, that shallow ground water surface becomes unusefull water without any farther processes. From the recent data shows that from 252 shallow water wells (1-15m depth), more than its 45% has already polluted by organic pollutant and 100% by colliform bacteria. Beside shallow water wells, the utilization of deep water ground surface also has been applying. However that usage should be stopped immediately. It will provoke some damages in land subsidence and breakage many buildings and roads (such as Bangkok issues and northern Jakarta). Far away, the excess of using a deep ground water surface will accelerate the sea water intrusion. To repair the breakage of deep ground soil structure, making the ground rechange area is needed. However, since the sort of soil in Jakarta (silt clay), the ground rechange area for preventing the lack of water resources is not an appropriate method. It has not a capability to absorb the water surface deeply to refill the space that has already intruded by sea water. The suit place for ground rechange area is in the slope of mountain, so the protection of that place is very important.

From all of the environmental damage description above can be concluded that instead of applying the expensive cost of recycling or reusing water treatment, it is better to look for another abundant alternative water resource such as sea water. Therefore, in the near future, desalination process is considered to be an appropriate method not only for Jakarta as a capital city but also all part of Indonesia especially in eastern part.

WATER DEMAND

According to Indonesian law No. 20, 1990, there are four categories of water service in Indonesia, such as follow:

Category A : direct potable water

Category B : raw water for drinking water

Category C : fishery water and farm water

Category D : agriculture water, cityfield water, industry and hydropower.

The advantages of water for domestic, industry and urban including small cities are capacity of production of 56.2 m^3/sec. including small cities. 64% of the amount of water are coming from surface water and the rest of 36% is ground water. This fact shows the dependency of potable water on surface water debit that is influenced by the season fluctuation and the water quality. In dry season there is a decreasing of water debit that cause the quality of water. Since the population in the capital city is bigger than in the rural district, so the water demand in the capital city is higher than in the rural district. Similarly, the water demand in the capital city in Java island is higher, more than five times, than the city outside Java island (Figure 3). In the year 2000 the water demands become twice than 1990 (totally almost 200 m^3/sec.).

Irrigation

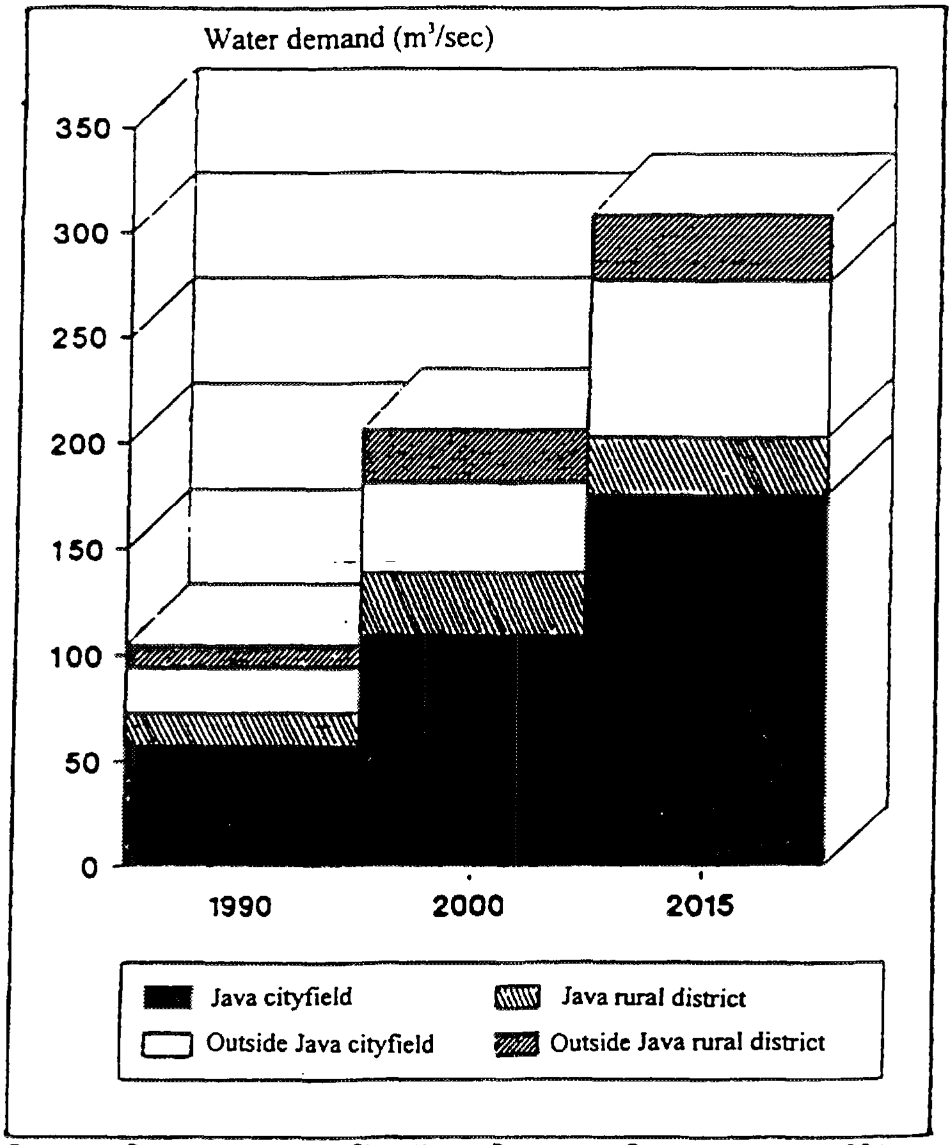
Indonesia is an agriculture country, so the irrigation becomes a dominant thing that should be thought. The total irrigation area in Indonesia is more than 4.5 million hectares, where more than half is located in Java island. It shows that the water demands for irrigation also hold an important role. The needs of water for irrigation in the year 2015 become 150% compare with in the year 1990 or 2000.

Fishery

Besides agriculture, the fisheries also become a dominant occupation in Indonesia. The area for dam's fishery is five times bigger than in water basin and four times bigger than in rice-field in 1986. The need of water for developing of fishery in the year 2000 will increase 10% and 25% in 2015 that is around $4{,}856.9 \times 10^6$ m^3/year.

Hydro power

The potential of hydro power is 75,624MW and 1,743.9MW has been installed only in Java island. Keeping the water debit is a problem specially in dry season, because instead of hydropower, the damÕs water has to be distributed for domestic, fishery, irrigation and other purpose.



Sumber : Direktorat Jenderal Cipta Karya, Departemen Pekerjaan Umum, 1991

Figure 3. The projection of domestic water city and industry for city field and rural district in Java and outside Java.

Based on the water supply come from rivers, rainfall, dams and groundwater the average water availability per year can be listed as shown in Table 1. Together with that, the water supply during dry season is also shown. The water demand tends to increase in the year of 1990. 2000 and 2015 that vary for each province and depend on the population and industrial growth (Table 1). The water balances which are defined by the balance of water supply during dry season minus water demands are also listed in that table. In accordance with the water demands, the water getting smaller by year. Specially in high populated islands of Java (including DKI Jakarta and DI Jogjakarta) and several eastern islands such as Bali, Nusatenggara have a

Table 1 . Water balance with its projection in Indonesia

NO	PROVINCE	AVAILABILITY		WATER DEMAND			WATER BALANCE		
		AVERAGE $10^6 m^3$/year	Dry season $10^6 m^3$/month	1990	2000	2015	1990	2000	2015
				$10^6 m^3$/month			$10^6 m^3$/month		
1	DI.Aceh	87,024	725	199	328	297	526	487	428
2	North Sumatra	105,558	880	377	440	526	503	440	254
3	West Sumatra	93,643	780	212	234	263	568	547	517
4	Riau	128,953	1,075	35	124	260	1,040	950	815
5	Jambi	76,385	637	56	90	141	581	546	496
6	South Sumatra	149,087	1,242	87	237	458	1,155	1,005	785
7	Bengkulu	51,150	426	62	72	88	364	354	338
8	Lampung	46,238	385	174	199	231	212	186	154
9	DKI Jakarta	440	4	50	71	88	-47	-67	-84
10	West Java	81,413	678	1,293	1,409	1,561	-615	-730	-883
11	Central Java	56,188	468	1,172	1,255	1,356	-703	-786	-888
12	DI Jogjakarta	2,903	24	77	84	88	-53	-59	-64
13	East Java	46,277	386	1,339	1,415	1,502	-953	-1,030	-1,116
14	Bali	5,454	45	132	138	144	-87	-92	-99
15	West Nusatenggara	12,774	106	204	215	229	-97	-106	-122
16	East Nusatenggara	28,798	240	86	99	116	154	141	-124
17	East Timor	12,907	108	8	20	37	99	87	70
18	West Kalimantan	326,083	2,717	131	190	277	2,586	2,527	2,441
19	Central Kalimantan	307,826	2,565	62	163	313	2,503	2,403	2,252
20	South Kalimantan	48,766	406	53	144	278	354	263	128
21	East Kalimantan	325,380	2,712	15	91	204	2,696	2,621	2,507
22	North Sulawesi	38,630	322	67	75	85	255	247	237
23	Central Sulawesi	81,907	683	127	140	160	555	542	523
24	South Sulawesi	89,005	742	521	585	674	221	156	68
25	Southeast Sulawesi	37,240	310	40	52	70	270	258	240
26	Maluku	104,660	872	15	47	941	857	825	778
27	Irian Jaya	876,309	7,303	5	332	823	7,298	6,970	6,480
	TOTAL	3,220,977	26,842	6,600	8,159	10,363	20,242	18,683	16,478

minus water balance. This is a severe problem that should be covered. It is noted that those values are based on the constant water availability without considering the environmental damage that can cause the water quality.

Jakarta as metropolitan city

In 1996, the residents of Jakarta in the fresh water service area, will be around 8.2 million people and those who will be served are around 4.5 million people. Every zone has different condition, where Central Jakarta and a part of North Jakarta have the biggest population in the service area (2.4 million people).

The projected production will have its impact on the projected operating cost of fresh water production as a result of the usage or consumption of pure water, chemicals, electricity and others. In practice the projected operating cost will also depend on the quality of pure water to be processed, climate, type and system of processing, capacity and etc.

The population, its development and it's living demands, influences the needs of service in any field, specially the fresh water supply that is the basic need for living being.

Principally the development of fresh water supply system in Indonesia and specially in Jakarta, will keep increase because the need of fresh water will paralelly increase with the growing standard of living in the Jakarta Community. At present PAM JAYA own 12 fresh water treatment installation with total capacity of 12.230 litre/sec. and 1 spring water in Ciomas Bogor with the capacity of 150 litre/sec.

The capability of PAM Jakarta in producing the maximum capacity of the fresh water will influence the various main supporting factor such as pure water, electricity power, chemicals, equipment and all the treatment machine itself. At present, the pure water condition as the basic material in PAM JAYA is supplied from the different surface water wells, Jatiluhur Dam passing Tarum Barat Canal, Ciliwung River, Krukut River, Pesanggrahan River and Secondary Bekasi Canal.

The water balance

Water balance is defined as a percentage between water demand and water supply. In Figure 4 shows the percentage of water balance in the year 1990, 2000 and 2015 in many provinces of Indonesia.

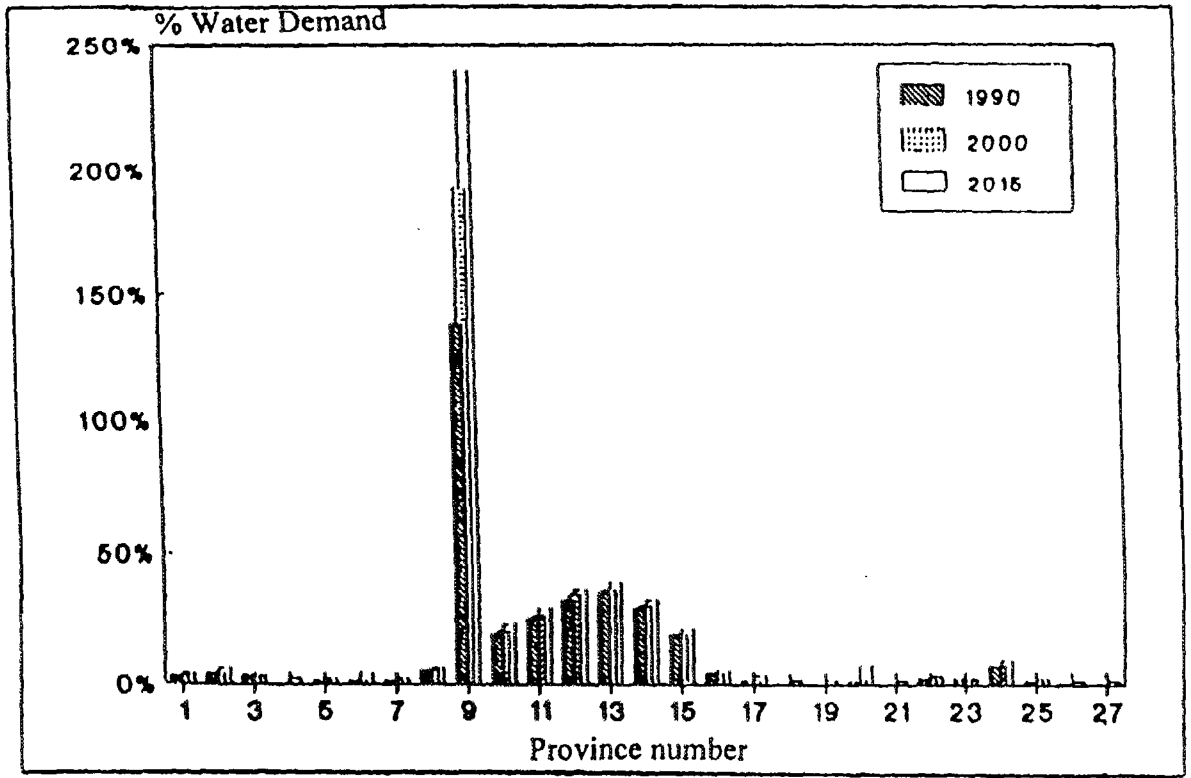
Clearly there is an increase in percentage of water balance in year, specially in Jakarta as a metropolitan city where covering the area of 650 km^2. Another province in Java island relatively has a high number compare with other province outside Java. However, there still has a small number compare with Jakarta (around one fifth).

The needs of water in Jakarta become five times higher than water supply. This is a serious problem. Intending to prepare Jakarta as a "service city" the improvement of fresh water services should be continuously encouraged by PAM JAYA (Water Supply Enterprise) as described above.

Due to the shortage of fresh water distribution in DKI Jakarta area, besides build new facilities, many efforts are also being made to buy fresh water from areas outside Jakarta such Cisadane Treatment Installation that is managed by PDAM Tangerang. The Cisadane Installation has a capacity of 3,000 litre/sec., 2,800 litre/sec. from Cisadane Installation and 5,000 litre/sec. from Buaran Installation. Consequently, the total supply capacity of PAM JAYA will be 18,292 litre/sec. This figure has not yet taken into account the capacity of the mini installations, amounting 630 litre/sec.

To handle the increasing of water demand in Jakarta, PAM JAYA has been developing and implementing "PAM JAYA SYSTEM IMPROVEMENT_PROJECT", abbreviated as PJSIP. By completion of the project that is scheduled to be in the year 2000. It is expected to be able to serve 5.7 million inhabitants out of total population of 8.9 million. A lot of improvement on piping, a good team and ample experience are required.

Long range program will mean nothing without following up the facts in the effort to reduce water losses and improving fresh water services to the population of Jakarta quantitatively and qualitatively.



Sumber : Direktorat Bina Program Pengairan, Ditjen Pengairan, Departemen Pekerjaan Umum 1991

No	Province
1.	Daerah Istimewa Aceh
2	Sumatera Utara
3.	Sumatera Barat
4.	Riau
5	Jambi
6	Sumatera Selatan
7	Bengkulu
8	Lampung
9.	DKI Jakarta
10.	Jawa Barat
11.	Jawa Tengah
12.	DI Yogyakarta
13.	Jawa Timur
14.	Bali
15.	Nusa Tenggara Barat
16.	Nusa Tenggara Timur
17.	Timor Timur
18.	Kalimantan Timur
19.	Kalimantan Barat
20.	Kalimantan Tengah
21.	Kalimantan Selatan
22.	Sulawesi Utara
23.	Sulawesi Tengah
24.	Sulawesi Selatan
25.	Sulawesi Tenggara
26.	Maluku
27.	Irian Jaya

Figure 4. Water balance as a percentage between water demand and water supply during a year.

III. DESALINATION TECHNOLOGY FOR WATER SUPPLY IN INDONESIA

The population growth and development in many sectors that cause an environment damage will be a serious problem in the near future. At the same moment, they will require a large amount of water to sustain their life. Therefore, instead of keeping the environment, looking forward another alternate technology of fresh water production is important. Indonesia has an advantage in geographical location, because two-third of its area is sea, therefore, desalination of sea water is one of the logical choice. The principle of desalination process is to reduce the dissolved salt concentration in water. Base on the salt concentration dissolved, can be arranged as brine water (>35.000mg/l), sea water (35.000mg/l), brackish water (1000-35.000mg/l) and fresh water (<1000mg/l). The water produced by nearly all sea water desalination process can not be utilized directly as drinking water, because the mineral concentration is relatively small. So the well-developed treatment is needed.

Various processes for sea water desalination can be categorized as heat consuming processes and processes using mechanical or electrical energy. The heats consuming process include the flash evaporation (such as MSF), boiling and film evaporation. The processes by using mechanical or electrical energy are reversed osmoses (RO), electrodialysis, heat consuming processes combined with vapor compression and freezing processes. The RO and MSF are the first generation desalination systems which still too expensive cost. Therefore, the desalination with low cost production is needed. The second generation desalting systems is RO with advanced membranes and Multi Effect Distillation (MED) combined with Vapor Compression (VC). However, further R&D activities are still required to get a low cost desalting system.

Basically, the process involves heating brine water progressively up to maximum operation temperature of 90 to 130°C, and then the vapor produced is condensed by heat exchange with incoming feed water. A main problem in heating process is scale formation that is eliminated by adding acid. The energy required is heat with the ratio of 10 to 65 kW.h/m^3 water produced. The Multi Effect Distillation (MED) is the oldest type of heat consuming process. The different between MED and

MSF is in the components and materials used. The most promising one of MED is using the Horizontal Tube Multiple Effect Desalination.

Reversed Osmosis (RO) can be thought of as a filtration process at the molecular/ionic size level by using semi permeable membrane and pressure higher than the osmotic pressure. The energy required is mechanical power, the total energy requirement is about 7 to 10 kW(e).h/m^3 of product water. The RO desalination industrial scale having capacity up to 56,800 m^3/day (the largest plant in the world at Jeddah. Saudi Arabia. constructed by Japanese Company, 1989).

The other thermal process is freezing process and the other membrane process is electrodialysis, membrane distillation, pervaporation and etc.

Coupling Nuclear Plants with Desalination

Principally, the energy used for desalination process is thermal power or mechanical power. All desalination processes need mechanical work for pumping, and electricity for auxiliaries and services. Therefore, one nuclear unit can energize that process.

By applying single purpose coupling water cooling nuclear plants with desalination plants for thermal desalting, RO, MED, MSF and etc., of 365 Mwt (around 100MWe) will produce 530,000 m^3/day water product, 4.23kWe.h/m^3 for liquid metal cooling reactor and 7.2kWe.h/m^3 for HTGR, etc. It shows that the usage of small nuclear power for desalination plants is probable to service an arid area in Indonesia.

IV. ECONOMICAL ASPECTS

An important consideration in choosing a desalination plant is a financial cost evaluation. For long term lifetime, What type of desalination process, What type of energy source and how much required output is factors that affect the cost. In the pervious section the various method of desalination has described. In general, the MSF method has a specific higher unit costs compare with the MED, MED/VC and RO (for EC or WHO standard) as 1800 , 1440 - 1680, 1650 and 1350 & 1125 US

$/m^3/d, respectively. The amount of output volume per day for MSF and MED is similar (48,000 m^3/d). MED/VC and RO processes have a lower output volume as 24,000 m^3/day.

As described above, every kind of desalination method has a different kind of energized energy, electrical/mechanical or thermal. Both of them could be produced by fossil or nuclear plant. For single purpose plant, the nuclear power plant has a higher cost construction, operation-maintenance and electrical production cost compare with fossil plants. However, the fuel cost in US $/MW.h for NPP is lower than fossil plants, and both of them has a similar water cost production around US $ 0.7~2.0 per m^3.

Considering the lack of electricity and water availability in some part of Indonesia, and high cost in some cost aspect for NPP, so it is suggested to use NPP coupling with desalination in dual purpose. However, for economical benefit, while using dual purpose plants, coupling with desalination plants applies only to thermal (destillation) process such as MSF or MED. Therefore, electricity is the main product and not more than 10% of thermal output for desalination process.

Jakarta has PDAM that produces clean water in many cross subsidence consumers. The water production cost range is US $ 0.2~2.23 / m^3. Comparing with desalination process coupling with NPP (US $ 0.7~2.0 / m^3, depend on the technology), the cost is competitive. It could be noted that the potable water produced by desalination process has a lower cost compare with mineral water that produced by a private company (produced water named "aqua") in Indonesia (US $ 467.25 / m^3).

V. SUMMARY

Due to the population growth and its effect on the environment make the need of water in many purposes increase. Especially in eastern parts of Indonesia, the lack of water becomes a serious problem since they have a low wetness level compare with other part. To handle that problem, a suitable method of desalination plant that converts sea water into fresh water is considered to be an appropriate alternate. By coupling a small nuclear power with desalination plants in dual purpose has been assessed to be an economical benefit for future plants in Indonesia.

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PROSPECT OF HTGRs FOR HYDROGEN PRODUCTION IN INDONESIA

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Abstract

Hydrogen energy system is interesting to many peoples of the world that because of hydrogen promised to save our planet earth from destroying of burning of fossil fuels The selected development of hydrogen production from water such as electrolysis and thermochemical cycles are evaluated These processes are allowed to split the water at lower temperature. still in the range of HTGRs' working temperature. An overview of related studies in recent years enables the development of research to be followed, studied and evaluated are mentioned The prospect of hydrogen market in Indonesia and economic consideration based on previous studied are also analyzed and evaluated

1. INTRODUCTION

1.1 Background

Today. more than 80% of the world's energy demand and supply are depending on fossil energy resources (coal, oil, natural gas) The rate of using fossil energy resources tends to increase sharply Soon or later energy crisis will come. likely what happened in oil embargo experience in 1973 The embargo itself has a good impact to the people of the world that the oil is not abundant and need to do some saving for the next generation

The above consequences are also valid for Indonesia even as member of OPEC. In the last Bali's OPEC conference has achieved some agreements of oil production balance in each country's members. Indonesia has allowed to produce its oil up 1.4 million barrel per day [1,4] But unfortunately the non-renewable energy reserved of Indonesia (included oil reserved) are so limited as shown in Table 1 And it is estimated that in the beginning of 21st century Indonesia will be become net importer oil country

It is also considered that gradually the level of pollutant contents (CO, CO_2, SO_x, NO_x etc) in the atmosphere are increasing as because of burning of fossil fuels[2,3,7,8] All these pollutants are resulting global warming, acid rain, and seriously damaging the biosphere of the earth

Table 1 The availability of energy resources in Indonesia

No	Energy source	Proven Reserved	Production rate per year	Final reserve estimation - [4]
1	Natural gas	$91x10^{12}$ SCF - [1]	6%	2026
2	Oil	$10\ 9x10^{9}$ barrel - [1]	0%	2006
3	Coal	$36x10^{9}$ ton - [2]	12 4%	2166
4	Peat moss	$8x10^{9}$ ton - [3]	-	-
5	Solar	-	-	-
6	Wind	-	-	-
7	Water	$75x10^{3}$ MW	-	-
8	Geothermal	$16x10^{3}$MW	-	-
9	Biomass	-	-	-
10	Marine	-	-	-

[1]) Petroleum report, 1993
[2]) Coal Directorate, Ministry of Mine and Energy, 1992
[3]) New and Renewable energy resources Conference, Kenya, 1981
[4]) Markal study, BPPT, 1993

1.2 Future clean energy system

In the concept of future energy system, the primary energy source should be high abundant and limitless Nuclear with its fast breeder - fusion and solar energy are considered as two candidates for long-time primary energy sources [1,3,7]

In order to increase the flexibility using of the primary energy sources, it need an energy store that acts as a go-between (or intermediary) between the primary energy sources and the consumers (industry, transportation, household) This intermediary energy is comply with all requirement of the present and future conditions such us

It must be storable and transportable,
It must be fuel for use in transport systems, home and industry,
It must be clean and inexhaustible

It is only hydrogen and electricity meet with all the above requirements Hydrogen is certainty one of the keys to "clean energy" Hydrogen is able to replace all the positions of fossil fuels It can operate cars, homes and various businesses from environmental clean, renewable energy source on large scale

1.3 Nuclear heat as energy source

HTGR is potential to used to non-electric applications as well as the electricity generation as a high temperature heat source up to 1000°C Heat energy is possible to use in hydrogen and methanol productions, enhance oil recovery, coal liquefaction and desalination processes

At present, Japan and China are constructing HTGR with its thermal out put 30 MW and 10 MW respectively. The Japanese HTGR (popular as HTTR) is planned to be first critically in 1998 and to be connected to heat utilization processes in the year 2003. Of this HTTR thermal out put of 30 MW, 10 MW is transferred to be heat utilization system through a helium -to- helium intermediate heat exchanger as shown in Figure 1.

The purpose of this paper is to report the current status hydrogen production and utilization in Indonesia. It is also described the role hydrogen energy in the future related to the application nuclear heat (HTGRs) as input energy source.

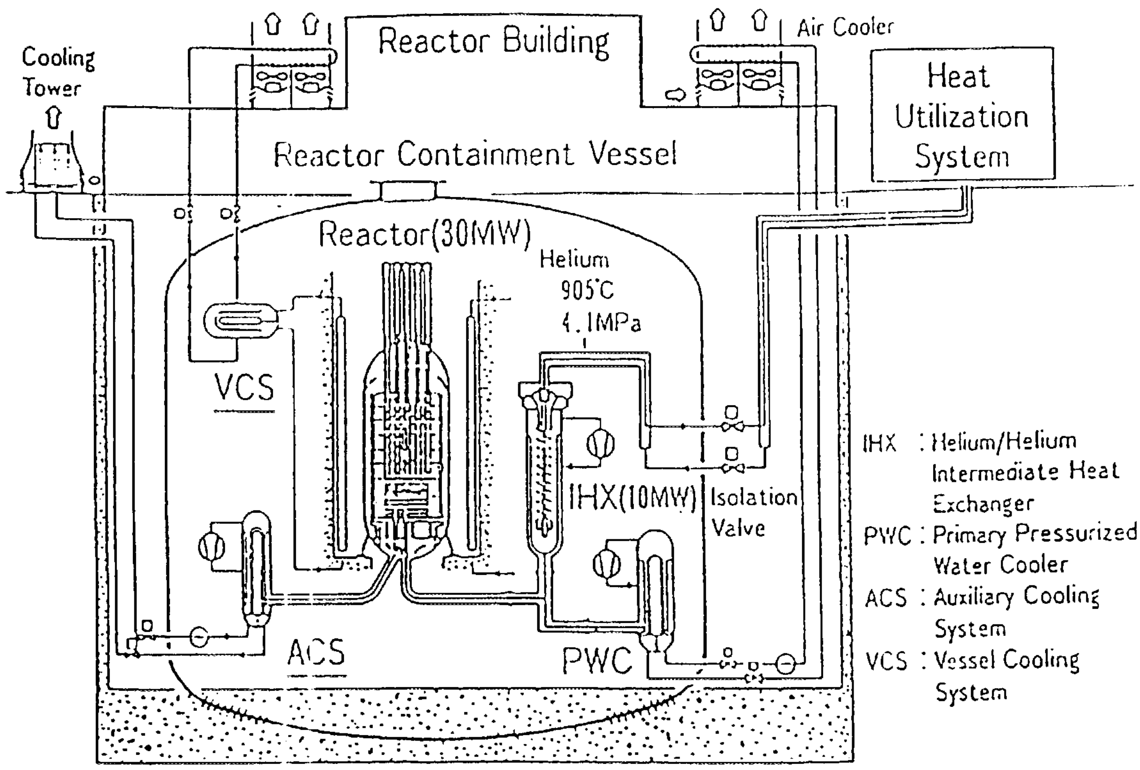

Fig. 1 Connection of heat utilization system to the HTTR reactor cooling system [6]

2. HYDROGEN PRODUCTION

2.1 Conventional hydrogen production

The world's hydrogen production is still derived from fossil, almost the total hydrogen demand is met by hydrogen made from fossil fuels, by steam reforming and by partial oxidation of natural gas or oil fractions.

Briefly outlined, these include [1,2,4,]

(1) Removal of methane and other constituents from refinery tail gases or coke oven gas at low temperatures.

(2) Reforming of natural gas (or other hydrocarbons)

$$CH_4 + H_2O = CO + 3H_2 \tag{1}$$

followed by water-gas shift:

$$CO + H_2O = CO_2 + H_2 \tag{2}$$

This is followed by carbon dioxide removal using physical or chemical absorption techniques.

(3) Direct production of synthesis gas by reaction of coal with oxygen and steam

$$3C + O_2 + H_2O = CO + H_2 \tag{3}$$

followed by water-gas shift and carbon dioxide removal

(4) Partial oxidation of hydrocarbons

$$CH_4 + 0.5\ O_2 = CO + H_2 \tag{4}$$

followed by water-gas shift and carbon dioxide removal.

Of these methods, that of (2) is the most widely employed. Desulphurized natural gas is steam reformed in the presence of a nickel oxide catalyst. After cooling to about 375°C, the product gases undergo the water-gas shift reaction, usually with an iron/chromium catalyst. And this shift reaction may be carried out at about 200°C over a copper/zinc catalyst The carbon dioxide is removed by physical or chemical adsorption. Overall, the thermal efficiency of the process approaches 70%.

Hydrogen plants in Indonesia are commonly located closed to oil and gas fields such as Balik papan and Dumai plants as shown in Table 2. Hydrogen produced in these plants are used in oil refinery for hydrocracking, hydrotreating and hydrorefining, ammonia plant for urea fertilizer industry, hydrogen peroxide and methanol production etc. [1,10,11]

2.2 Future interested hydrogen production system

In comparison, the hydrogen production from water as raw material is more interesting than fossils Among of those reasons are the water has high abundant. 75 per cent of the earth planet consist of water. Water also could be recycled from the burning of hydrogen fuels. And water is relatively clean, a hundred per cent free carbon element.

The production of hydrogen from water could be done by thermolysis, thermochemical cycle, electrolysis and photolysis. Based on the present technology, electrolysis and thermochemical cycle are more reasonable ways and promised a good prospect in the future for hydrogen production.

Table 2 Hydrogen production plant in Indonesia

No	Location	Capacity (MMSCF)[5]
1	Balik papan	68,000
2	Dumai	79,000

[5]) Lemigas, 1994

a) Electrolysis

To split water by electrolysis means has been known long time a go. In this method cells similar to cell of battery in the car are used to produce hydrogen and oxygen from water. Each cell consists of two electrodes immersed in an electrolyte of water plus some chemicals that conduct electricity well, and is connected to a direct current (DC) electricity supply. About one per cent of worldwide hydrogen demand is produced electrolytically. Hydrogen production cost by this electrolytically is much higher than that fossil fuels.

In the development of electrolysis, the advanced concepts of electrolytic hydrogen production have been proposed to improve hydrogen production efficiency and to reach high hydrogen production density from view point of saving electricity. A solid polymer of water (SPE) and high-temperature electrolysis of steam (HTES) using ceramic electrolysis cell are representative of new advanced technologies. Figure 2 shows the structure of ceramic cell, developed in JAERI [6].

b) Thermochemical cycle

In direct thermolysis, its need temperature around 2,500 to 3,000 °C to split water to hydrogen and oxygen. But using of thermochemical cycle means allow the operating temperatures lower than 1,000 °C.

Thousands of thermochemical cycles have been proposed in USA, Europe and Asia. But only few per cent of those cycles are continuously studied to bench-scale and pilot plant. Among these cycles which have a good promised to the future hydrogen production are sulfur family (IS cycle, Mark cycle) and bromine family (UT-3 cycle).

IS Cycle:

Iodine-sulfur cycle (IS-cycle) consist of three steps reactions as follow:

$$I_2 + SO_2 + 2H_2O = H_2SO_4 + 2HI \quad (5)$$
$$2HI = H_2 + I_2 \quad (6)$$
$$H_2SO_4 = H_2O + SO_2 + 0.5\ O_2 \quad (7)$$

thickness of each layer 0.1~0.25mm
thickness of support tube 3mm
the same configuration and materials as the SOFC

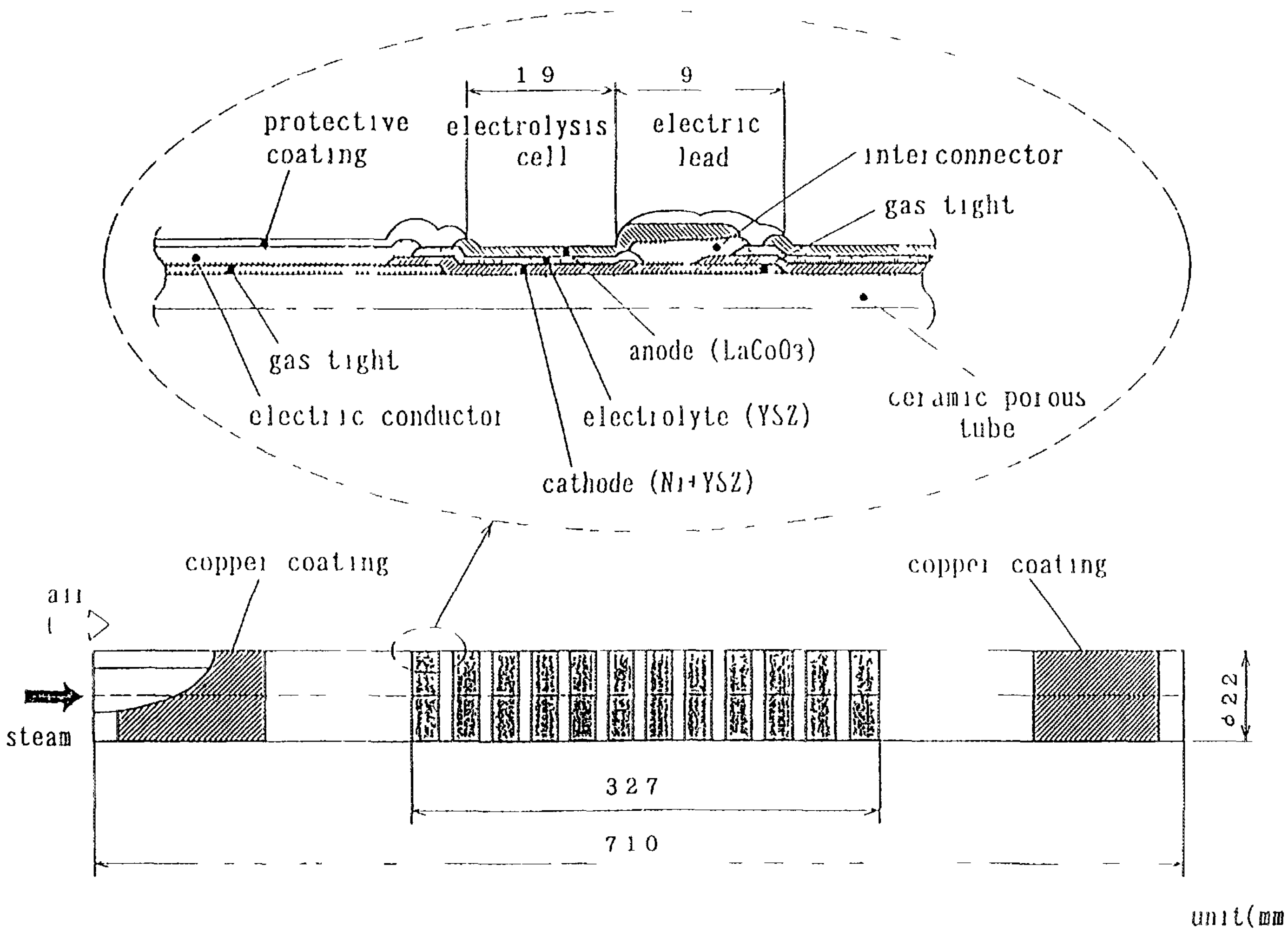

Fig. 2 Electrolysis tube with 12 cells [6]

IS cycle first proposed by General Atomic-USA. Since that KFA Julich-Germany and JAERI-Japan are continuously studying this cycle and successful operated at laboratory bench-scale plant with its total hydrogen production 16.4 liter. Figure 3 shows a simplified flow-sheet of the experimental apparatus which was designed to realized to the basic function of the process The apparatus was designed to have the capacity Of 1-10 liter H_2/hour, is made of quartz, glass and Teflon

UT-3 Cycle:

The third generation of Tokyo University cycle (UT-3 cycle) consists of fourth steps reactions as follow

$$CaBr_2 + H_2O = CaO + 2HBr \quad (8)$$
$$CaO + Br_2 = CaBr_2 + 0\ 5O_2 \quad (9)$$
$$Fe_3O_4 + 8HBr = 3FeBr_2 + 4H_2O + Br_2 \quad (10)$$
$$3FeBr_2 + 4H_2O = Fe_3O_4 + H_2 \quad (11)$$

UT-3 cycle was proposed by Kameyama et al. (Japan) in 1978 Ten research groups and nine Universities have successful operated a UT-3 bench-scale (MASCOT) with the capacity of 3 liter/hour Toyo Engineering under the contract with JAERI has finished the feasibility study of commercial UT-3 hydrogen production plant capacity 20,000 Nm^3/hour Figure 4 shows the flowsheet of the UT-3 hydrogen plant HTGR is considered as the heat source Helium gas is assumed to be introduced to the UT-3 hydrogen plant at 850 °C and supplies the necessary heat for the reactions The result shows that the thermal efficiency is 40% and hydrogen production cost is 42 yen/Nm^3, based on assumption of the cost of nuclear heat from HTGR is 0 91 Yen/MJ

3. HYDROGEN MARKET ANALYSIS

Most of hydrogen produced are used in the chemical industry for the production of ammonia, plastics, foodstuffs, rubbers and pharmaceuticals, and also as a reducing agent in the metallurgical and scrap-metal recovery industry Table 3 shows the number of the world's hydrogen consumption in various industries in 1970 This number will increase in the next future as industry growth sharply Table 4 shows the number of hydrogen requirements in each types of industries

3.1 Petrochemical industry

The oil refining industries in Indonesia are located in Sumatra, Kalimantan and Java as shown in Table 5 Refinery need for hydrogen in Indonesia are currently met by hydrogen plants in Table 2 and by recycling by-product hydrogen made in the industry The capability to produce hydrogen by conventional steam reforming of natural gas does exist, but to minimize cost, by-product hydrogen is used whenever possible In order for hydrogen supplementation of natural gas with hydrogen separation to penetrate the refinery hydrogen market in Indonesia, it must at very least, be competitive with steam reforming of natural gas

3.2 Fertilizer industry

Ammonia production accounts for the largest industrial use of hydrogen in Indonesia, and is produced by the catalytic reaction of nitrogen and hydrogen at high temperature and pressure

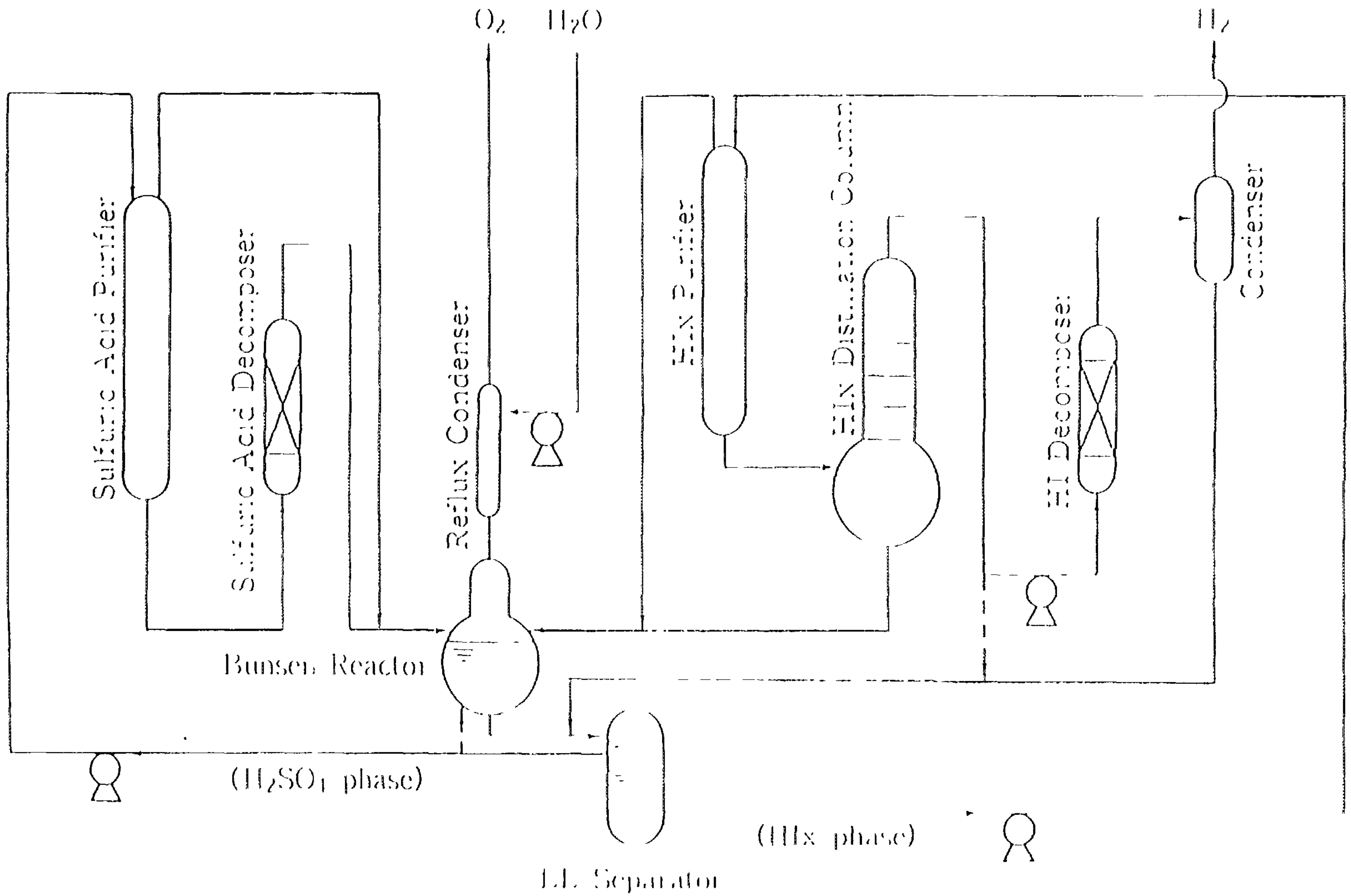

Fig. 3 Schematic flowsheet of the laboratory scale demonstration apparatus [6]

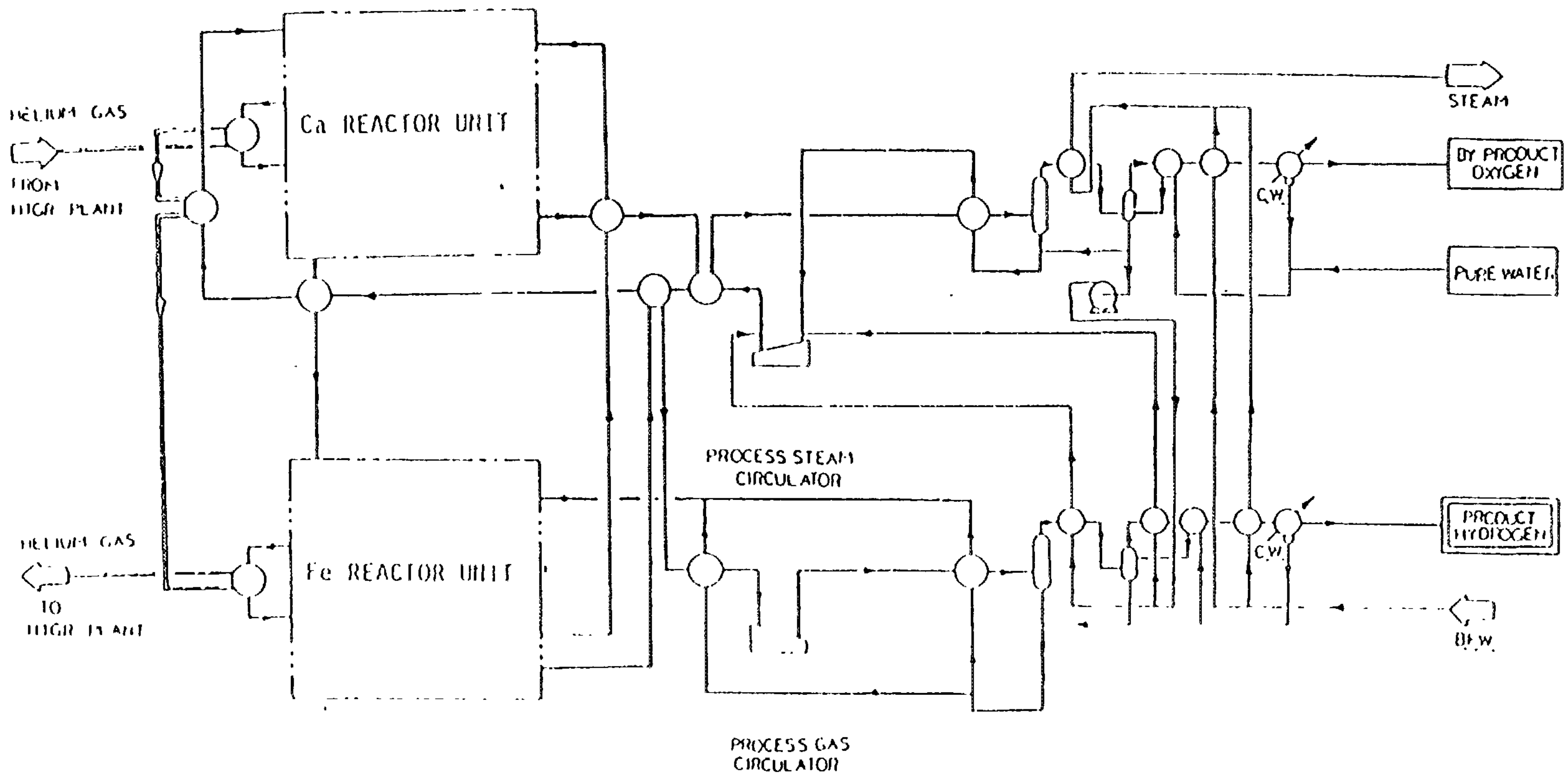

Fig. 4 Flowsheet to UT-3 hydrogen plant [2,3]

Table 3 World consumption of hydrogen (1970)

Application	Consumption (Gm^3)[1]
Ammonia synthesis	100
Methanol synthesis	25
Synthesis of other chemicals	10
Hydrotreating desulphurization	30
Hydrocracking	30
Refinery fuel (low grade H2)	10
Total	205

[1] Energy -Present and Future Options, Vol.3, John Wiley & Son Ltd., 1984

Table 4 Typical industrial hydrogen requirements

Use	H_2 requirement per unit of product (m^3)[1]
Ammonia synthesis	1950 - 2230/ton NH_3
Methanol synthesis	2.25/kg MeOH
Petroleum refining	109/m^3 crude oil
Hydrotreating.	
naphta	12/m^3
coking distillates	180/m^3
Hydrocracking	475 - 595/m^3
Coal conversion to	
liquid fuel	1070 - 1250/m^3
gaseous fuel	- 1560/(10^3 SCM of synthesis gas)
Oil shale conversion to	
liquid fuel	230/m^3 of synthetic oil
gaseous fuel	1200/(10^3 SCM of synthetic gas)
Iron ore production	560/(ton of iron)
Process heat	82.4/GJ or 169/10^3 kg process steam

[1] Energy -Present and Future Options, Vol.3, John Wiley & Son Ltd., 1984

Table 5 Pertamina's oil refinery plant in Indonesia (barrel/day)[1]

No	Location	Atm./Vac. Distill.	Hydro-cracking	Hydro-treating	Hydro-refining	Other-process
1	Balik papan	348,800	51,200	20,000		20,000
2	Cilacap	338200		18100	13500	68400
3	Dumai	202200	47000	15400		40700
4	Musi	158500				18100
5	P Brandan	4800				
6	S Pakning	46,100				

[1] World Refinery survey, Business Review 1, April/1992

Then introduced to urea plants as shown in Table 6. It seems that the demand of urea fertilizer in Indonesia is continuously increased in the future as population and agriculture industries' growth as shown in Table 7 Hydrogen is manufactured by steam reforming of natural gas in essential all ammonia plant in Indonesia. Future ammonia plants in Indonesia might also employ coal gasification because of the high price of natural gas and concern over its long-term future supply Beside ammonia and urea production (Figure 5), there is a sizable chemical industry located closed to oil and gas fields in Indonesia

3.3 Steel industry

Hydrogen is currently used in steel industry to maintain a controlled reducing atmosphere for annealing and heat treating steel. Heat treating shops that purchase merchant hydrogen to meet their relatively small needs of roughly 1000 SCF/day are not particularly suitable for

Table 6 Fertilizer plants in Indonesia

No	Company	Capacity (ton/year)[2]
1	PT Aceh Fertilizer	625,000
2	PT.Pupuk Iskandar Muda	570000
3	PT Pusri (I,II,II,IV)	1,732,000
4	PT Pupuk Kujang	570000
5	PT Pupuk Kaltim (I,II)	1710000
6	PT Petrokimia Gresik	460000

[2] Department of Industry RI, 1990

Table 7 The projection urea fertilizer supply and demand in Indonesia (thousand ton/year)[1)]

No	Parameter	1989	1994	1999	2004
1	Production	4,248	6,452	7,762	9,901
2	Demand	3184	4657	6087	7901

[1)] Department of Industry RI, 1990

hydrogen separation from supplemental natural gas because of their small, intermittent, and widely dispersed requirement for hydrogen. Plants that use hydrogen for annealing obtain it by purchasing merchant hydrogen and by on-site methane steam reforming

A potential future uses of hydrogen in the steel industry is in the direct reduction of iron ore, a process that chemically reduces iron ore at temperatures well below its melting point. The reductants commonly used are carbon monoxide and hydrogen, which can be produced from fossil fuel. The direct reduction process produces a lowcost substitute for ferrous scrap and blast furnace iron at lower capital cost and reduced pollution than the blast furnace, which is conventional means of pig iron production The blast furnace is extremely capital intensive, and in the current economic situation of the domestic steel industry, it is unlikely that new blast furnace will be built in the near future

PT Krakatau Steel is one of the largest steel industry in Indonesia. Its total steel production in various forms reached to 868,633 tons per year in last fiscal years. These number are projected to be 2.5 million tons per year in 1998 and 4 million tons per year in the year of 2000. Other steel industries are distributed in Java, Sumatra, Kalimantan etc with its production capacity increase day by day.

3.4 Other future applications

Hydrogen plays a key role in the manufacture of many important materials and in many industrial processes. It provides a reducing atmosphere in the manufacture of float glass and the fabrication of electronic components Hydrogen is used as raw material for hydrogen peroxide and methanol. Hydrogen is also used as a cooling medium in electric generators and large electric motors It serves as fuel for space vehicle and is used to manufacture pharmaceuticals and hydrogenated fats and oils.

Depending on such factors as the size of the plant, the amount of hydrogen needed. daily fluctuation in this amount and the purity level required, the hydrogen for these smaller industrial uses can be produced on site by conventional steam reforming of methane, water electrolysis or thermochemical cycles, ammonia decomposition, or it can be purchased and delivered by pipeline, tank truck, or in compressed gas cylinders (merchant hydrogen) In the future hydrogen is projected to replace all the positions of fossil fuels in industrial process, transportation and household as shown in Table 8

Source: Directorate general of oil and gas RI, 1990
Note : - Proven reserved 50% potential reserved
- Production: 80% proven reserved

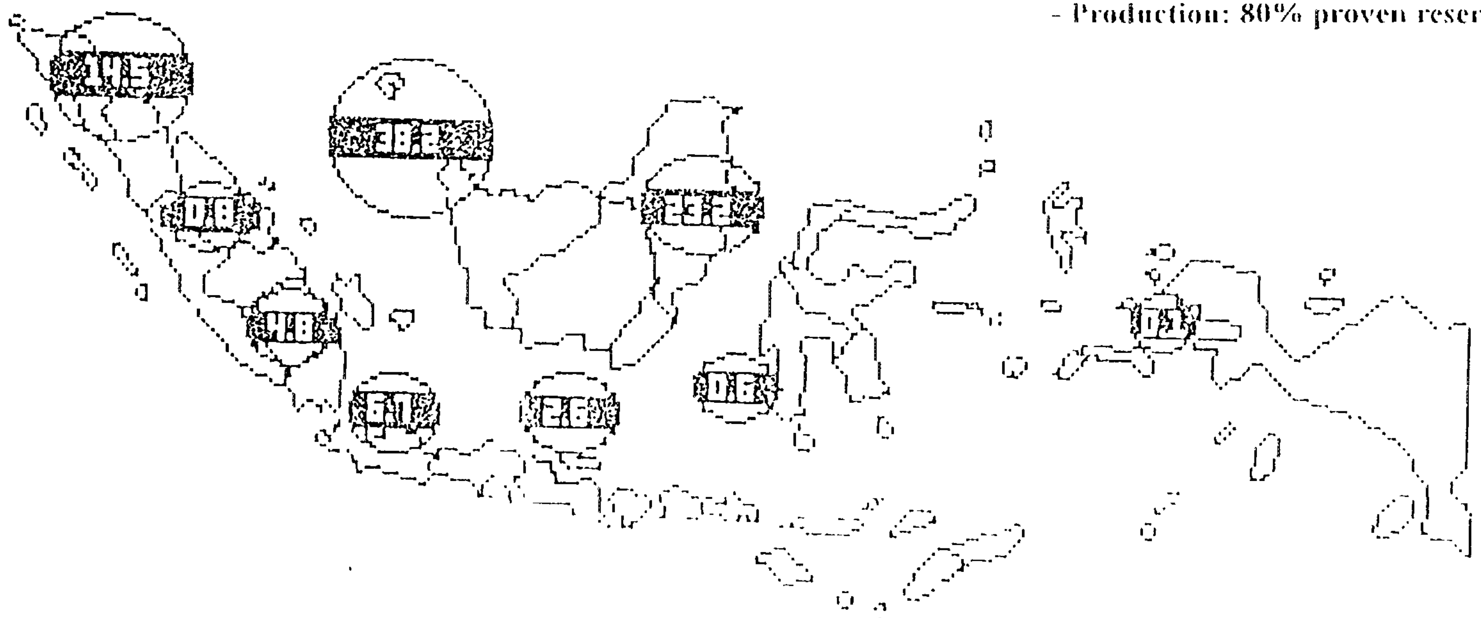

Fig. 5 Potential map of natural gas reserved in Indonesia (TSCF) [11]

Table 8 Other future potential application of hydrogen

No	User	H_2 efficiency[1)]	Fossil efficiency (Comparison)
1	Converter machine		
	- Gas turbine		
	- Steam turbine		
	- Fuel cell	40 - 85%	
2	Household		
	- Cooking		
	- Catalytic combustor	>85%	
	- Gas burner	70%	60%
	- Space heating and cooling		
	- Lighting		
	- Water heating	70%	60%
	- Refrigeration	long life,	
	- Home appliances and equipment	low O-M	
3	Transportation		
	- Airplane, Aerospace		
	- Train		
	- Car		Petrol: 25%
	- Ship	60%	

1) Solar hydrogen, the power to save the earth, Macdonald Optima, 1991

4. THE ROLE HYDROGEN IN THE FUTURE

4.1 Government policy

The demand of oil fuel increase year by year. During Last five-year plans the average of oil of demand is increased by 8.5% per year. Various diversification, conservation program have proposed by Government of Indonesia to reduce domestic consumption of oil fuel in the frame work of increasing or keeping oil export. Even Indonesia have some oil refining plants with the total capacity 1 million barrel per day or with the capacity of oil fuel 43.1 million kl/year. Still Indonesia has a deficit of 27.5 million barrel/year. This deficit will increase in the next future, and it is estimated that the deficit will be 44.3 million barrel/year in 1999 and 104 million barrel/year in 2004. A new plant should be build to meet with the deposit of oil. The large number hydrogen will be required for oil refinery plants in the near future. For oil and gas saving contributions, it is also considered to consume the produced hydrogen from other sources such as water.

To support the implementation of the Government policy of Indonesia in conservation and diversification of fossil energy, particularly in oil and natural gas, some efforts have been done such as audit energy program for saving energy (Table 9), Indonesia cleaner industrial production program, and adopted the ideas of foreign environmental regulations such as carbon tax, air ambient quality standard etc One of the more extreme ideas is by introducing nuclear energy to industry processes to save fossil energy in Indonesia Based on our experience a simple calculation was made to show how much the fossil fuel could be saved in industrial fields as shown in Table 10. It shows that around 117 7 BSCF of natural gas could be saved each year in urea ferlizer industry. A larger amount of natural gas and oil will be saved if this assumption may be applied to other industrial processes in Indonesia.

Table 9 Potential energy saving of some industries in Indonesia

No	Industry	Potential saving[1]
1	Fertilizer	25%
2	Textile	10%
3	Cement	10%
4	Ceramic	15 5%
5	Iron/Steel	20%
6	Tire	10%
7	Tea	18%
8	Manufacture	25%
9	Glass	20%
10	Building	20%

[1] Surveyed by PT KONEBA

Table 10 Potential energy saving of natural gas for heat process in fertilizer industry in Indonesia

No	Company	Capacity (ton/year)	Potential saving in heat process (BSCFY) [1]
1	PT Aceh Fertilizer	625,000	12 0
2	PT Pupuk Iskandar Muda	570,000	10 9
3	PT Pusri (I,II,III,IV)	1,732,000	33 3
4	PT Pupuk Kujang (I,II)	570,000	10 9
5	PT Pupuk Kaltim (I,II)	1,710,000	32 8
6	PT Petrokimia Gresik	460,000	8 8
		Total	117 7

[1] Based on estimation (Lemigas) to produced 1,500 ton of urea/day or 570,000 ton of urea/year is required 60 MMSCFD of natural gas (50% of this amount is used to consume in heating process)

4.2 Changing in our fuel system

In the future or post fossil era, two main candidates' energy sources are considered by the scientist and engineers. One is synthetic fossil fuels (syngas, SNG) and the other one is solar hydrogen energy system. Among the gas synthetics, SNG is the cheapest, while among the liquid synthetics, liquid hydrogen from hydro electric power is the cheapest as shown in Table 11, especially after adding with the cost of environmental damage to cost production of synthetic fuels.

Probably, the breaking away from polluting fossil fuels will not be carried out on the initiative of the Governments their selves, but the pressure should come from the all the peoples of the world. Even though hydrogen has been used as a fuel in NASA's and EUROPE's space program for many years, much more research needs to be carried out to bring this technology to a common market, to make it more affordable and usable. The areas of research still to be conducted are storage and leakage.

Demonstration projects have been run on hydrogen; cars, motorcycles, planes and coal-mining vehicle have all been run on clean hydrogen. To mass produce of these cars, motorcycles, planes etc. that use fossil fuels so that, instead, they operate on hydrogen, and to convert the pipeline infrastructure so that hydrogen can be transported, still need to spend hundreds millions of dollars per years. This is a trivial sum when we consider the cost of the awesome damage caused by pollution, that cost is estimated in hundreds of billions of dollars per year. As an example, Jakarta with its population eight million peoples has been paid about US $ 500 million per year for human health because of heavy air pollution in this area, according to World Bank surveyed.

Table 11 Synthetic fuel production cost (gallon equivalent of petrol, 1990)[1]

No		Production cost		Effective cost		Society cost
		Gaseous	Liquid	Gaseous	Liquid	
1	H_2 from electric power	1.42	1.78	1.05	1.31	
2	H_2 from direct/ indirect solar	1.91	2.38	1.41	1.75	1.37
3	Synthetic natural gas from coal	1.09	2.13	2.39	3.43	2.91

[1] Solar hydrogen, the power to save the earth, Macdonald Optima, 1991

4.4 Time scale's shorting

Based on experiences show that from the point at which a scientist publishes an idea to the point that at which the product is available in the shops takes about 75 years. And from the point at which an engineer takes the scientist's idea and build a model and test it to see if it works, to the point at which it is available in the shops takes 50 years But from the point at which a company takes a model and commercializes it to the point at which it is available in the shops only take about 15 years, maybe less.

However these timescales can change with the circumstances In war time, everything gets done many times faster An emergency spirit can unify nations like in the last war time At present, that the same emergency spirit to develop and produce clean fuels such as hydrogen, to convert the factories using clean energy And it need also same spirit to stop the war and allocate that fund to develop clean energy for human being

4.5 Economic consideration

Some informations from economic point of view have been analyzed and evaluated US federal Commission has calculated and evaluated the relative prices for delivered energy as shown in Table 12. It shows how, even when produced by electrolysis, hydrogen may be a cheaper synthetic fuel than electricity, at the point of consumption Table 13 shows the summary of thermal efficiency and hydrogen production cost from water by electrolysis and thermochemical cycle compare to fossil fuel as raw material Hydrogen production cost by thermochemical cycle is still higher than from natural gas

Table 12 Relative prices (US $ per GJ) for delivered energy (1970)[2)]
(US Federal Commission)

	Electricity	Natural gas	Electrolysis (H_2)
Production	2 53	0 16	2 84
Transmission	0.58	0 19	0 49
Distribution	1 53	0.26	0 32
Total	4 64	0 61	3 65

[2)] Energy -Present and Future Options, Vol.3, John Wiley & Son Ltd , 1984

Table 13 Some informations of thermochemical cycles and electrolysis

No	Information	Thermochemical	Electrolysis	Fossil (comparison)
1	Thermal efficiency[1]	Mark cycle 40-60% IS cycle >50% UT-3 cycle 42% Others cycle 41%	Elect Eff Conventional 57 - 72 % Advanced 80%	
2	Production cost[2]	UT-3 cycle 46 4 yen / Nm^3		Natural gas 32 6 Yen/Nm^3
3	Investment cost	Is cycle US $1000/Nm3	Conventional US$ 320/kg	

[1] Seminar on HTR technology and application II. 1995
[2] Toyo Engineering, 1980

5. CONCLUSION REMARKS

1 Hydrogen could be produced from water by introduced of nuclear heat (HTGRs) to electrolysis and thermochemical cycle

2 Hydrogen has a good prospect market in Indonesian industries such as petrochemical, fertilizer, steel and other chemicals industries

3 Hydrogen which its high abundant raw material, clean and good recycle system will be competitive as one of the candidate energy source for the future energy system

4 Hydrogen sound good, but it is more expensive then petroleum The cost of environmental damage should be added to the cost of production of fossil fuels

5 Possible to introduce HTGR to Indonesian industries processes to change the energy source from fossil to fissile, the way to reduce of using fossil fuel in the frame work of diversification and conservation energy program

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THERMAL ENHANCED OIL RECOVERY IN INDONESIA. PROSPECT OF HTGR APPLICATION

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Abstract

In the next future, Indonesia will face oil scarcity. The present reserves are estimated to be depleted in 20 years. However, after primary and secondary recovery processes, there are still more than 50 % of original oil in place remaining in the reservoir, and this could be recovered by using tertiary recovery method or which is known as enhanced oil recovery (EOR) processes.

Among the three major methods of EOR, steam flooding is a thermal recovery method into which High Temperature Reactor (HTR) module can be integrated for producing steam. However, the feasibility of application of HTR as an alternative to conventional oil-fired steam generator will depend strongly on the price of oil.

This paper discusses EOR screening for Indonesian oil fields to identify the appropriate oil reservoirs for steam flooding application as well as the possibility of steam supply by HTR module. Also reviewed is the previous study on HTR application for Duri Steam Flood Project.

1. INTRODUCTION

As considerable quantity of oil still remains in reservoirs after primary and secondary recovery, application of EOR is a very promising proposition. It also becomes more and more important due to limited new oil discovery in Indonesia.

Thermal enhanced oil recovery process, especially steam flooding, is a proven technology which can be applied for increasing oil recovery, particularly for reservoirs and crude oils having appropriate characteristics for this method.

HTR is a small high temperature reactor with low enriched uranium fuel. It is especially suited as a universal energy source for the cogeneration of steam and electricity, and process heat steam applications. The application of HTR in steam flooding project can substantially save crude oil burned for steam generation.

This paper discusses EOR screening for Indonesia's oil fields to identify the possible oil reservoirs for steam flood application, the technical possibility of steam supply by HTR module and briefly reviews the previous study on HTR application for Duri Steam Flood Project.

2. OIL RESOURCES IN INDONESIA[1,2]

Indonesia's oil fields are mainly found in the western and central parts of the country. Among the 60 tertiary basins in Indonesia, 38 basins have been explored and 14 basins are on production. The total oil reserves in Indonesia is about 9.5 billion barrels, consisting of 5.2 billion barrels of proven and 4.3 billion barrels of potential reserves (Table 1).

PERTAMINA and its operating contractors are currently exploiting oil and gas in Indonesia with total production capacity 1,5 million barrels crude oil/day including condensate.

Table 1

Oil and Condensate Reserves In Indonesia, Status 1-1-1994 (MMSTB)

No.	Operating area	Proven	Potential	Total
1	North Sumatera	278.4	302.1	580.5
2	Central Sumatera	2,657.5	2,807.4	5,464.9
3	South Sumatera	359.4	185.9	545.3
4	Java	771.2	341.9	1,113.1
5	Kalimantan	801.1	492.0	1,293.1
6	South China Sea	194.2	171.2	365.4
7	South Sulawesi	10.2	0.0	10.2
8	Irian Jaya	95.0	6.4	101.4
Total		5,167.0	4,306.9	9,473.9

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The scarcity of oil resources makes it necessary to apply an appropriate enhanced oil recovery technique because there are still more than 50% oil left in the reservoir after primary and secondary recovery.

3. EOR[3,7]

The term EOR is used in a broad sense. It covers a wide range of technology for improving oil recovery, from water flooding to the more sophisticated techniques such as chemical flooding. EOR is a technology which continues to develop, expanding its potential to increase oil recovery from old and newly discovered fields.

In general terms, the processes in EOR are based on introducing several means such as energy source and other means to modify favorably the characteristics of the reservoir rocks and fluids. These include injection of gas, flooding with water, introducing surfactant, injection of water including polymer to increase viscosity, introducing steam, in situ combustion, miscible gas floods and stimulating with microbes.

3.1. Screening of Indonesian Oil fields For EOR[1,3]

Suitable EOR method for a given reservoir is determined through screening. Many of the screening criteria are related to the reservoir properties. The screening criteria of EOR processes are summarised in Table 2. The initial evaluation based on suggested screening criteria generally is followed by laboratory and field test.

The results of a study on EOR screening of Indonesian oil reservoir which has been conducted are presented in Tables 3 and 4. It was estimated that 24 billion barrels of oil could be produced through the application of EOR. The increase of recovery through steam flooding is estimated to be about 4.2 billion barrels and through in situ combustion about 6.5 billion barrels. These figures could be higher as recent technology development indicated that even lighter oil reservoirs can be treated with steam flooding.

The oil fields appropriate for steam flooding of heavy oil in Indonesia are mainly located in Riau, namely in PT. CPI area.

3.2. EOR by Steam Flooding[5,6,7,8]

Thermal processes aim to recover more oil by reducing viscosities by injecting or generating heat in a reservoir.

Table 2
Guide for Technical Screening Criteria

No.	Reservoir Parameter	Units	Thermal		Chemicals			Miscible			Microbial
			Steam flood	Insitu comb.	Poly-mer	Surfac-tant	Alka-line	HC gas	N2 gas	CO2 gas	
1	Rock type	-	sst	sst	sst/lm	sst*	sst*	sst/lm	sst/lm	sst/lm	sst/lm
2	Net thickness	ft	>20	>10	NC	>10	NC	thin	thin	thin	NC
3	Depth	ft	<5000	>500	<9000	<8000	<9000	>2000	>5000	>2000	<5500
4	Temperature	F	NC	>150	<200	<175	<200	NC	NC	NC	<200
5	Ave. permeability	md	>200	>100	>40	>60	>20	NC	NC	NC	>50 mD
6	Ave. porosity	%	20	20	20	20	20	NC	NC	NC	-
7	Ave. oil saturation	%	40-50	40-50	>40	40-50	Sor	>30	>30	>30	>25
8	Pressure	psi	1500	2000	NC	NC	NC	-	-	MMP	<20000
9	Oil gravity	Api	10-25	<25	>25	>25	13-35	>35	25-35	>25	>15
10	Oil viscosity	cp	>20	>1000	<200	<40	<90	<10	<10	15	-
11	Oil composition		NC	asphal	NC	Light	NC	Light	heavy	heavy	-
12	Salinity (TDS)	ppm	NC	NC	<50,000	<30,000	100,00	NC	NC	NC	-
13	Wettability		OW	WW/OW	WW	WW	OW	WW/OW	WW/OW	WW/OW	WW/OW
14	Transmissibility, Kh/u		5	5	NC	-	-	-	-	-	-
15	Minimum oil content at Start of Process ϕ. So	Fraction	>0.1	>0.08	NC	-	-	-	-	-	-
16	Inject. water salinity	ppm	-	-	<50,000	20,000	-	-	-	-	<190,000
17	Clay content	%	-	-	<10	<8	-	-	-	-	-
18	pH	-	-	-	-	-	-	-	-	-	4-9

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Note : NC - Not Critical
WW - Water Wet
OW - Oil Wet

sst - sandstone
lm - limestone (carbonate rock)
sst* - sandstone is preferable

Ref. 3

Table 3
EOR Screening of Indonesian Oil Fields

No.	Flooding Method	Number of Reservoirs	Estimation of Recovery Increase MMSTB
1	Water	929	1,640
2	Polymer	886	2,797
3	Surfactant	796	2,533
4	Alkaline	215	3,438
5	Miscible CO_2	270	2,910
6	Steam	106	4,203
7	In Situ Combustion	274	6,458
Total		3,476	23,979

Table 4
Reservoirs Potentials
To Perform Steam Flooding
(Criteria : heavy-medium heavy oil)

No.	AREA	NUMBER OF RESERVOIR ASSESSED	NUMBER OF RESERVOIR PASSED THE SCREENING	NUMBER OF POTENTIAL RESERVOIRS FOR STEAM FLOODING	ESTIMATION OF PRODUCTION INCREASE, MMSTB
1	WEST JAVA	550	218	13	268.4
2	RIAU	1,394	502	52	3,893.9
3	EAST KALIMANTAN	1,284	659	38	36.7
4	SOUTH SUMATERA	100	34	3	4.4

The recovery potential through thermal treatments such as steam flooding and in situ combustion are most suited to heavy, low API gravity crudes which will tend of not flow at all in the reservoir under natural conditions.

In steam drive process, because of its relatively low density and viscosity, steam tends to bypass oil along the reservoir (Figure 1). The steam may also cause the oil to vaporise by increasing its temperature. In suitable reservoirs, recoveries of up to 60 per

Table 5
Economic Evaluation (1987)
Application of HTR To Duri Steam Flood Project

No.	Net Cash Flow	HTR	Conventional
1	Pay out time (years)	7	4
2	Total Government take from the year 2001-2010, billion US $	23.7	16.2
3	PT. CPI profit share, billion US $	3,3	2,2
4	Oil substituted by nuclear fuel, million bbl/y	17	-

Data/assumptions :

- Oil price in 1987, $ 18/barrel
- Prediction of oil price escalation, 6% p.a. ($ 26/bbl in 1994, $ 40/bbl in 2000).
- Project life time : 40 years

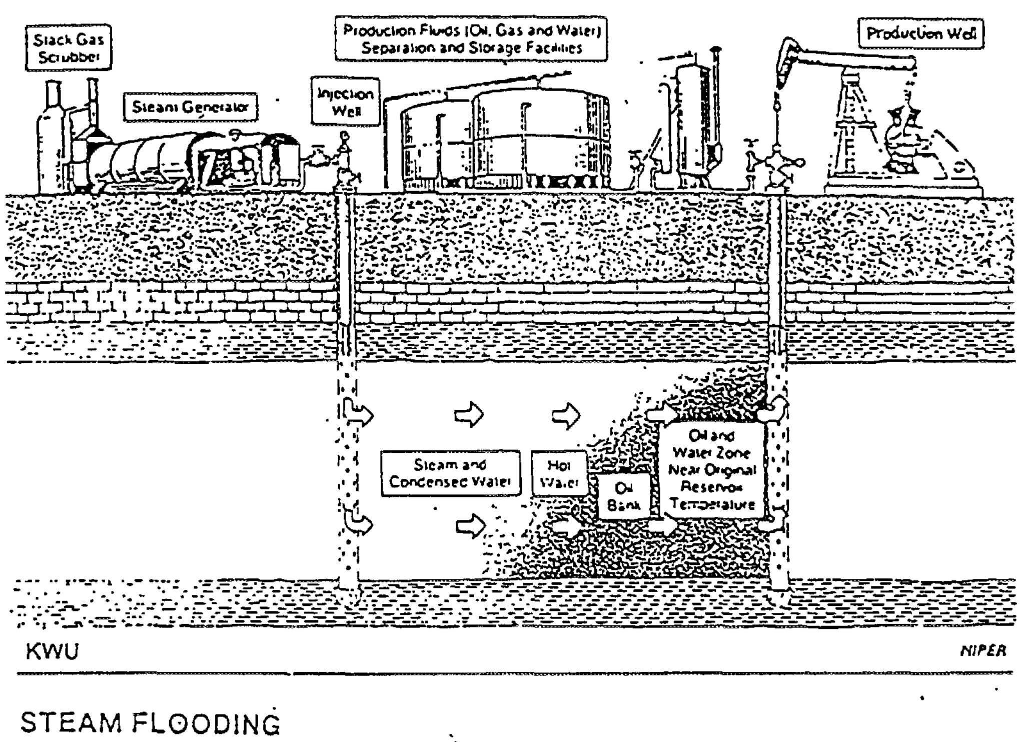

FIG. 1. Steam flooding.

cent of oil in place may be expected, with oil to steam ratio of 1.2 to 4.0 barrels per ton of steam. This compares very favorably with primary recoveries from shallow heavy oil reservoirs of 1 to 10 per cent of oil originally in place.

There is potential application of steam drive in the enhanced recovery of residual light oil. The oil evaporates when exposed to steam, and the resulting vapor of light components is transported (along with the steam) to cooler parts of the reservoir. The trapped oil is stripped by steam until a non-volatile residue is left. An oil bank forms ahead of the steam condensation front and is driven to the producing wells. The energy balance of this method is critical and it is suitable when a cheap energy source is available.

4. HTR MODULE APPLICATION[5, 6]

Because the temperature of HTR is higher than that of the current nuclear power plants, this plant could be used to produce steam and electricity (cogeneration). The flow scheme of this plant is presented in Figure 2. The high pressure steam will flow first into the high pressure turbine, and then flows into the medium and low pressure turbine. A part of the steam is sent to the steam injector.

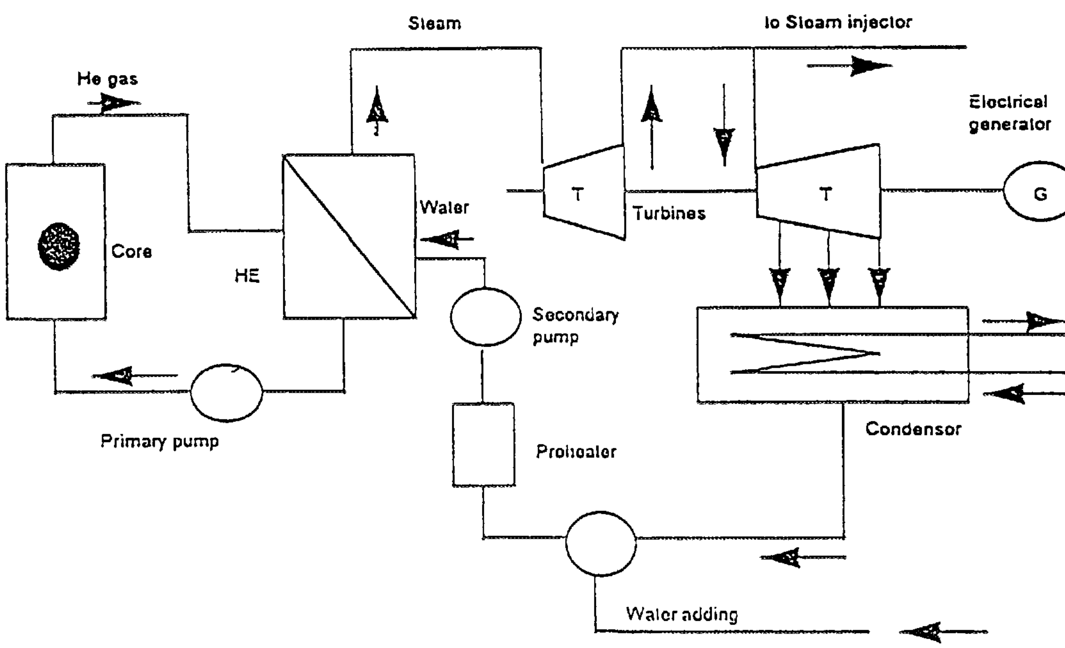

FIG. 2. Flow scheme of HTR cogeneration plant.

The steam pressure and temperature of 200 MW_{th} HTR as output of the heat exchanger (HE) are about 150 bar and 530°C. If 75% of steam (75 bar, 300°C) is sent to the steam injector, the electrical generator could produce about 25-30 MW electric power. This electric power is required to fulfill the electrical demand, i.e. for injector pumps, production pumps, water treatment, office, etc.

5. REVIEW ON STUDY OF HTR APPLICATION FOR DURI STEAM FLOOD PROJECT[5]

A study was conducted in 1987 to investigate the feasibility of the application of HTR-Module plants for injection steam and electricity in Duri steam flood project.

5.1. Project Description[5]

Duri field was discovered in 1941 and was commercially put on production in 1958. Duri crude is of medium heavy type (21°API), high wax content and rather viscous. The original oil in place is estimated at 7.1 billion STB.

Field trial of steam flood was performed for 10 years beginning 1975 and showed promising results. The steam injection in the project development area was subsequently started in March 1985.

The Duri Steam Flood (DSF) project was subdivided into 19 development areas covering 9000 ha of productive area (Figure 3). This project is recognized as the biggest steam flood project in the world. The typical area plot plant of the production facilities is presented in Figure 4. Surface facilities plan is based on decentralized system, so each quadrant of a development area has its independent system.

Peak production capacity of 300.000 bbl/d was achieved in Octobre 1994. It was predicted that the project could be operated up to year 2039 and could be on high production rate until 2033 (Figure 5). Figure 5 also presents the fuel requirement for generating steam. The total steam requirements averages between 4,000 and 5,000 tons/h in the peak time which means that about 20% of oil produced is needed for generating steam.

The steam is generated by oil fired steam generators. The steam pressure and quality at surface lines system from steam generator injection wells is presented in Figure 6.

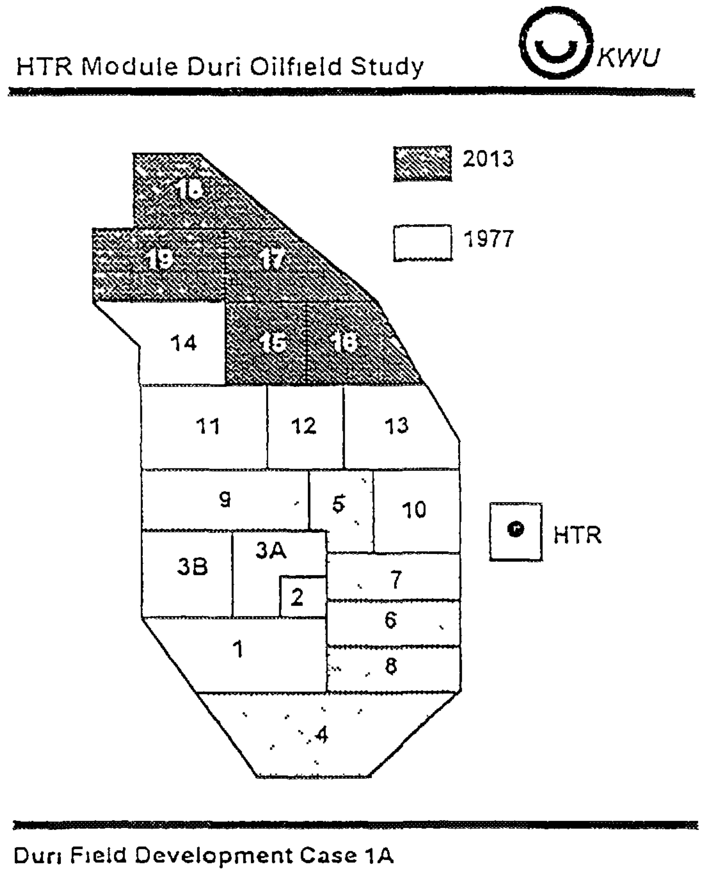

FIG. 3. Duri field development Case 1A.

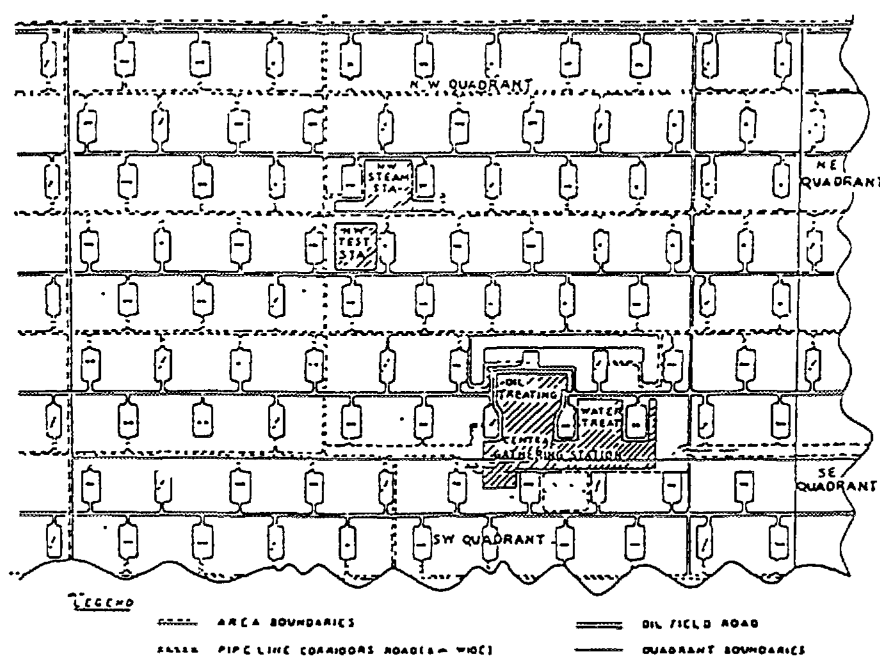

FIG. 4. Duri field typical area plot plant.

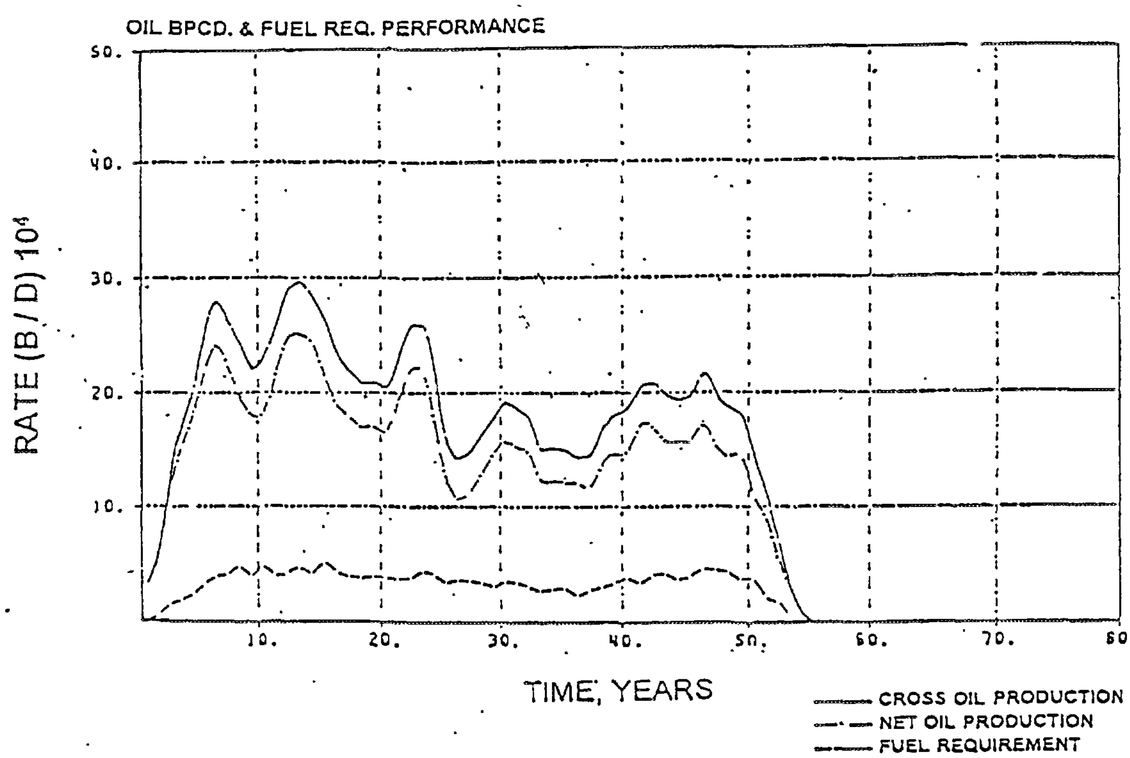

Fig. 5. Duri field predicted steamflood performance Case 1A.

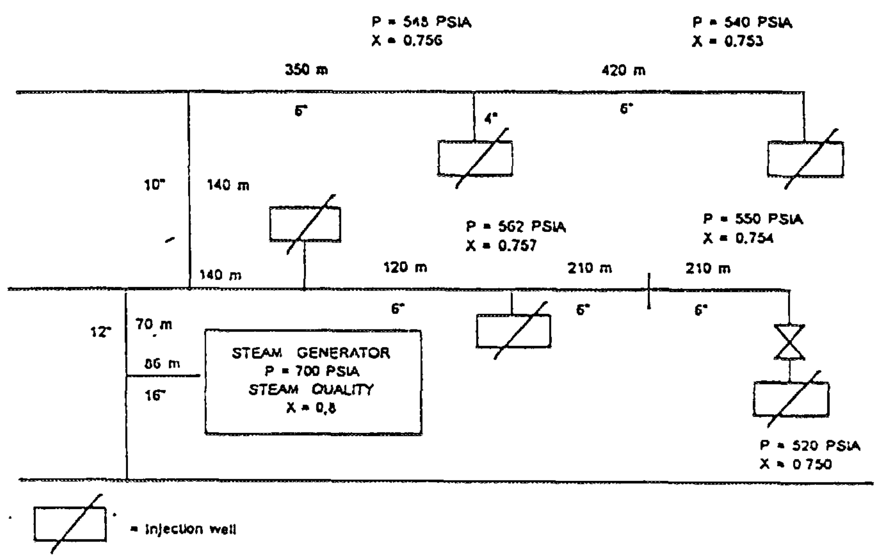

FIG. 6. Duri field steam pressure and quality at surface lines system from steam generator injection wells (typical calculation results).

5.2. Steam Supply by HTR

The total steam requirement (averages between 4,000 and 5,000 ton/h in the peak) gives a potential for installing at least 4 units HTR-4 Module Plants, each with 1,000 ton/h injection steam production capacity and 76 MW net electricity generating capacity (Figure 5).

In contrary to the development plan with oil fired steam generators, the development plan with HTR-Modules is based on centralized system supplying each Development Area with steam and electricity from the HTR-Module location to the delivery point in the supplied Development Areas.

5.3. Economic Evaluation

The feasibility and the profitability study of this project was performed based on the forecast of the oil price development.

The calculation were carried out on the basis of crude oil price of US $ 18/bbl in 1987, with the assumption of 4% inflation rate (investment price escalation) and 1,2, and 3% p.a above inflation escalation rates for oil price, giving 5,6, and 7% oil price increase rate.

The study showed promising results for HTR compared to conventional alternative from net cash flow, discounted net cash flow, pay out time, total Government take, Caltex profit share points of view (Table 4). However, the fact that transpired from 1987-now (1995) showed that the forecasted of oil price development did not match the real one because actually the oil price is still at the level of $ 18/barrel. The uncertainty of oil price development has made the economic study very difficult.

6. CONCLUSION AND RECOMMENDATIONS

1. Indonesia oil reserve is limited, enhanced oil recovery is therefore a very important method to increase oil recovery.
2. According to the available screening study (1991), only oil fields located in Central Sumatra are appropriate for the application of steam flooding. However, there would be a strong possibility to widen the application of this method to light oil.
3. Application of HTR is possible for steam flooding method, however the economic feasibility of using HTR as fuel alternative will strongly depend on oil price escalation, which is very difficult to predict.
4. Considering the development of steam flood method and criteria it will be worthwhile to update the screening study of Indonesian oil fields in order to reidentify the potential reservoir for steamflooding.

5. Beside the oil price, other alternatives of application scheme of HTR could improve the economic feasibility such as integration of crude oil refining processing plant. Further study on this could also be useful.

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NOTES ON HTR APPLICATIONS IN METHANOL PRODUCTION

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Abstract

Notes on the study of HTR applications are presented. The study in particular should be directed toward the most feasible applications of HTR for process heat generation. A prospective study is the conversion of CO_2 gas from Natuna to methanol or formic acid. Further studies needs to be deepened under the auspices of IAEA and countries that have similar interest.

Introductions

The role of HTR technology as an alternative technology in energy supply for sustainable development has been attracted many decision makers recently. This is in anticipation of the decline in oil and gas reserves. Oil and gas as fluid fuels have many advantages in the field because of its practical use and easy transportation. Reserved oil in Indonesia is estimated around 48.4 billions barrels, in which 10.9 billions is proven. With the current production the reserve may well continue to supply for around 15 years more. The domestic demands will be higher than the amount that have been allocated for, so that after the year 2000, Indonesia becomes net importer of oil. On the other hand gas reserves found to be around 216.8 TCF with 104.25 TCF proven, equivalent to 15 billion barrels of oil (equivalent to 3000^0 GWy). Assuming 10% of the production is used for generating domestic electrical energy, it can supply 10,000 MW for 21 years With the current production, the gas reserve last for more than 30 years Exploitation of Natuna gas reserve, is in preparation with 35 TSCF of CH_4, higher alcanes and some nitrogenes The amount needs to be separated from a mixtures of CO_2 amounting to 89 TSCF. Natuna will have enough energy gas supply at the anticipated production for more than 30 years.

Problems with Natuna gas are that it composes more than 71 % CO_2. Other composition are methane (CH_4), higher alcanes and some nitrogenes. Separation technology is first required to extract the fuel gas from CO_2. The next problem is how to handle the big amount of CO_2 so that will not disturb the environment. One possible solution is by reinjection of CO_2 gas into deep ground. For this technology the cost of exploitation and production may require an estimated investment of around US$ 40 billion. Other possible solution is to heat process the CO_2 into various products. Two attractive processes that convert CO_2 into valuable clean products are :

a. NA + heat + electricity + 16 $H_2O \longrightarrow$ 12 CH_3OH + 12 O_2

b. NA + heat + 6$H_2O \longrightarrow$ 12 CH_2O_2

It is assumed that NA (Natuna gas) is simplified into the natural composites of 3 CH_4 and 9 CO_2. The products are in a). methanol and oxygen, and in b). formic acid. Reaction b). is mentioned here because it needs just heat (no eleectricity). Conversion of Natuna gas into methanol is therefore of prime interest.

Rough Estimation

What really needs to be calculated is the minimum production cost and hence to get the highest benefit from the selling price of the Natuna gas. It is necessary to make comparative study on the following scenarios.

1.a. separation of the Natuna gas to obtain CH_4 and their alcanes and nitrogenes (required a separator installation)

b. inject the 71% CO_2 into deep ground (required a system of injector and underground gas reservoir)

2. a. separation of the Natuna gas

b. heat process of CO_2 into methanol

3. direct reforming of Natuna gas and synthesis of methanol.

Estimation of scenario 1 is around 20 billion US\$. In such a case in order that the scenario 2 is to be competitive, the cost of methanol production installation should be less than US\$ 20 billion and the selling price of the methanol should over cover its operation cost and production cost. If all CO_2 can be converted into methanol, one would gains 89 TSCF ($\approx$ 69 trillion liter liquid) methanol. Assuming the selling price of methanol is 0.02 US\$/l, then the total selling price of the whole methanol production would be US\$ 1.4 trillion. In scenario 3 no separation of the main components CH_4 and CO_2 is required.

Methods of producing methanol

Methanol is a clean synthetic fuel and chemical stock that can be made from a wide variety of materials and energy sources and applied to an equally wide variety of uses. The world production has increased tremendously and is now estimated over 10^{10} kg/year. Methods of production have several lines, two of interests are

a. natural methods where extraction (destillation natural products e.g. from wood), and fermentation could be applicable.
b. synthetic methods have several lines namely : hydrogen and carbon oxide synthesis, oxidation of hydrocarbons, electro or radiation synthesis of CO_2 etc. One of our interest is on the gas synthesis of hydrogen and carbon oxides. Most methanol commercially manufactured today is made by passing a synthesic gas containing hydrogen and carbon monoxide or carbon dioxsides over a catalyst chromium and zinc or copper oxide under pressure from 50 - 350 atm and elevated temperatures up to 400^0 C, according to the reactions

   $$2\,H_2 + CO \longrightarrow CH_3\,OH + \Delta\,G\,(T)$$

   where ΔG (T) is the energy formation satisfying an empirical formula

   $$\Delta G^0\,(T) = -105.0 + 0.238\,T$$

   $$3\,H_2 + CO_2 \longrightarrow CH_3\,OH + H_2O + \Delta\,G\,(T)$$

   where $\Delta\,G\,(T) = -64.9 + 0.200\,T$

Other interesting

In scenario 3 no separation of the main components CH_4 and CO_2 is required the Natuna gas is reformed directly, according to a process which is in simplified form discribed by the reaction, ref.3, p.7 :

$$NA + 9\,H_2O + HTR\text{ heat} = 6\,H_2 + 6\,CO + 6\,CO_2 + 9\,H_2O$$

Other interesting scenario is scenario 3. Respective experiments have been performed successfully in the helium-heated steam reformer semi-technical scale plant EVA-I at KFA Jülich in 1985. With additional H_2 (from electrolysis of water) finally methanol is produced.

In the case of scenario 2, the cost of producing CO_2 is already counted in the separation so that in the production of methanol alone one could save $69\ 10^{12}$ x 0.0015 US\$ = 103 billion US\$, apart from saving the cost of injection system. We have assumed that the cost of producing CO_2 in the production of 1 litre methanol is US \$ 0.0015.

The role of HTR is double purposes. It is favourable in generating high temperature for reforming CH_4 or Natuna gas into gas for the synthesis of methanol at once generating electricity for electrolysis, splitting hydrogen from water. Further economic detail calculation needs to be proceeded. Information on methanol synthesis from CO_2-rich natural gas using HTR is given in appendix.

Conclusion :

a. Conversion of the CO_2 gas from Natuna into methanol is a good option to consider to get the added value of the methanol and to avoid the reinjection of the CO_2 gas back to underground.
b. HTR application could be recommended for the exploitation of Natuna gas in its favourable function as heat and electrical generators in the conversion process.
c. A more detailed feasibility study needs to be proceeded with the help of IAEA technical assistance in cooperation with the countries having interest to share the same project.

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APPENDIX

I. Methanol Synthesis from Natural gas (mix CO_2), Conventional Background and Future Prospectives Using Nuclear Energy

The objectives of of this appendix is .

1 To inform on the conventional background

$CH_4 + H_2O = CH_3OH + H_2$

2 to demonstrate the increasement of production yield by application of high temperature heat from the HTR with the addition of CO_2

$CH_4 + 1/3\ CO_2 + 2/3\ H_2O = 4/3\ CH_3OH$, and

3 to indicate that with nuclear electricity via electrolysis a further increasement of the production yield is possible for very CO_2 rich natural gas; e.g. :

$CH_4 + 3\ CO_2 + 16/3\ H_2O = 4\ CH_3OH + 4\ O_2$

II. Methanol Synthesis from Natural gas (mix CO_2), Conventional Background and Future Prospectives Using Nuclear Energy

1 In summary · The application of nuclear energy, e.g. from the High Temperature Reactor, HTR, in the utilization, conversion and refinement of indigenous resources can contribute to the main objective to make best uses of the resources in the development. This is also true in production of methanol from natural gas, being mixed with carbondioxide CO_2. The improvement of the product yield has a factor of about 1 4, and even can be higher

2 In detail on the improvement of the production yield

2 1 The conventional process (e.g. low pressure process from LURGI), Lit CORNELIUS-1979, has a product yield y (y = energy content of the feed natural gas) of about y = 75% (70 to 80%), fig. 1. Methanol can be produced from natural gas, natural gas plus CO_2, naphta, heavy oil and coal, fig. 1. The process of methanol synthesis is well established, lit. ASINGER-1984.

	FEED				
SYTHESIS GAS	NAT. GAS	NAT. GAS + CO_2	C/H = 6	HEAVY OIL	COAL
H_2 Vol %	73.52	69.36	67.22	68.05	62.98
H_2 Vol %	16.42	15 48	20.37	28.24	21.77
H_2 Vol %	6.98	12.25	8.43	3.22	4.70
H_2 Vol %	3.08	2.91	3.98	0.49	9.06
H_2 Vol %	-	-	-	-	1.49
H_2/ CO	2.84	2.06	2.04	2.06	2.20
CONSUMPTION Nm^3 /t CH_3OH	3120	2680	2590	2300	2920
* include. 151 Nm^3 CO					

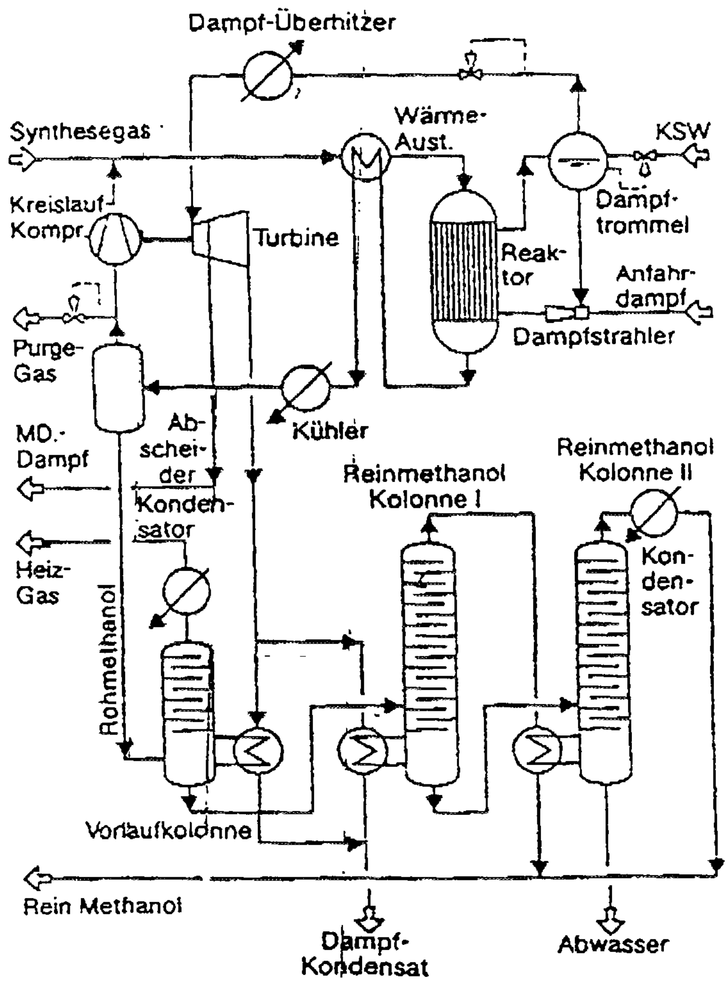
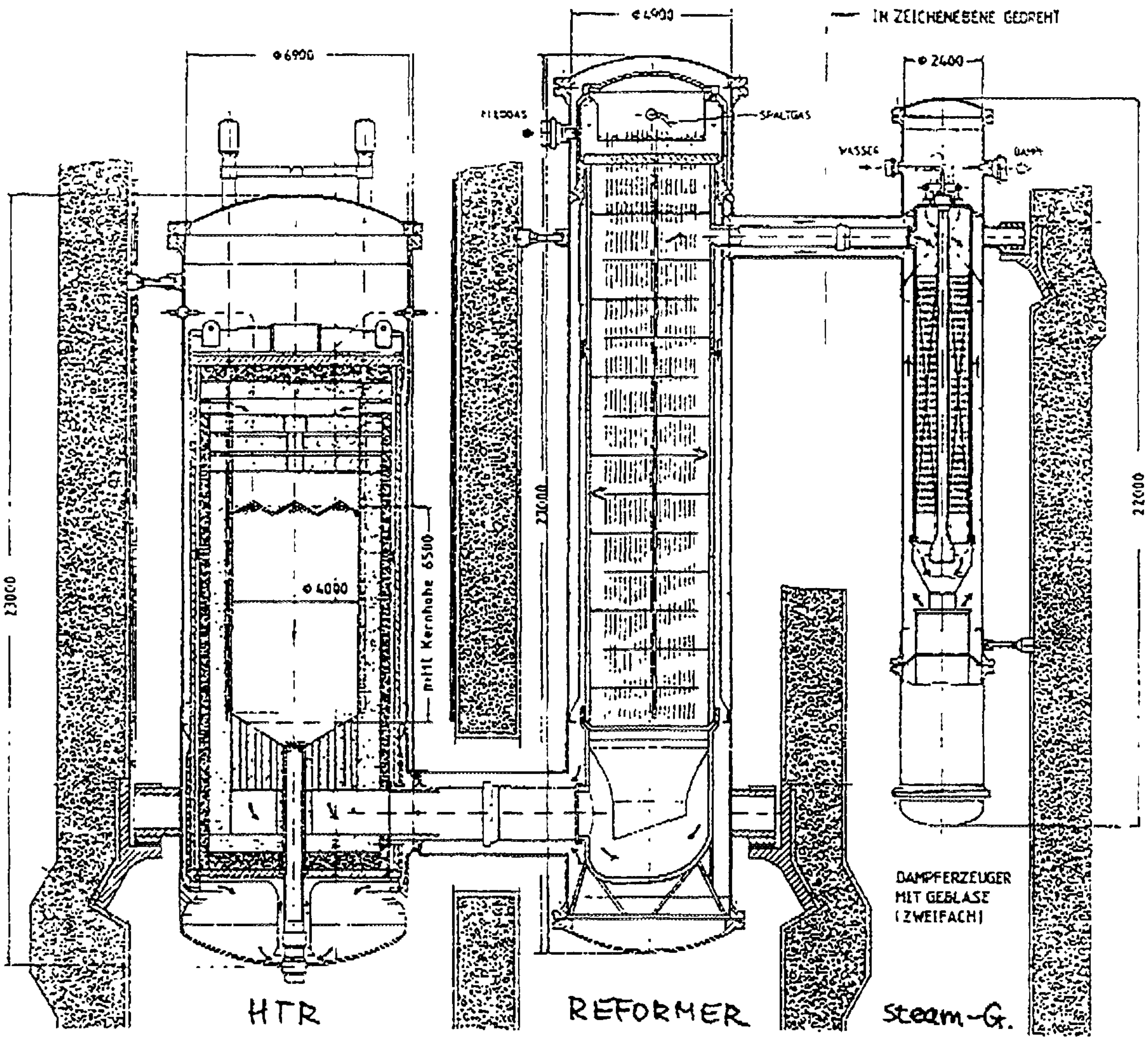


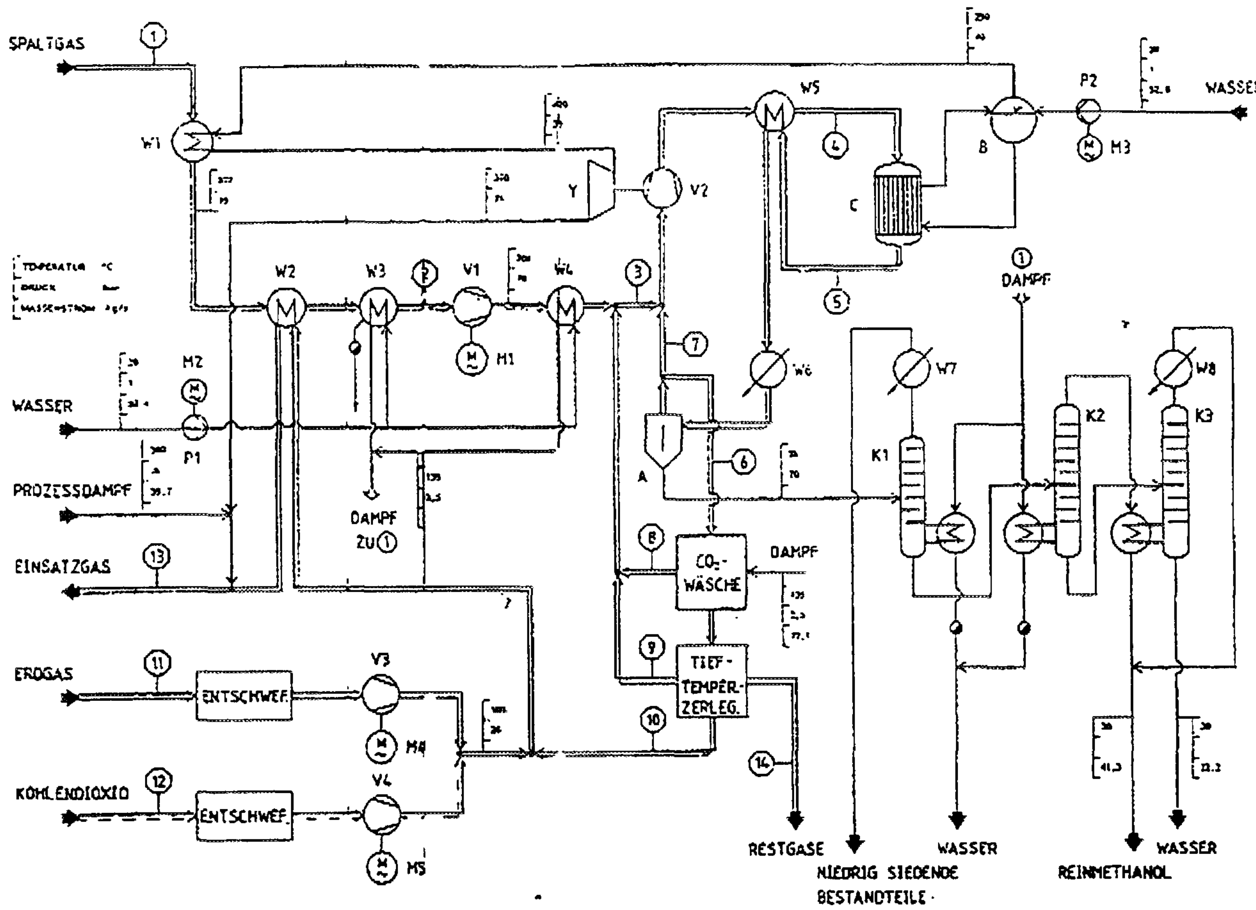
FIG. 1. Methanol-synthesis conventional

2.2. The HTR process for the production of methanol from natural gas plus carbondioxide, fig.2 and 3, lit. BOUSACK-1984, has a product yield y of y = 106% (933 MW(CH_3OH,B)/882 MW(CH_4,B)/B = high heating value HHV) with



MAIN DATA			
	DIM	3 X MRP-200	
			MW (B)
Thermal Power HTR	MW	3 x 200	
Natrium Gas	Nm^3/h	71820	882
CO_2	Nm^3/h	21790	0
H_2O net	t/h	140	0
		79.7	
Production :			
Methanol	t/h	148.7	933
Electricity	MW	52.6	

FIG. 2. Methanol from Nat. Gas + CO_2 with HTR
HTR-200 + Reformer + steam G, Main Data



	1		2		3		4		5		6		7	
	kmol/s	Vol %	kmol/s	Vol %	kmol/s	Vol %	kmol/s	Vol %	kmol/s	Vol %	kmol/s	Vol %	kmol/s	Vol %
H_2	3.276	39.58	3.276	68.00	3.704	68.99	16.058	57.01	12.799	50.03	0.447	54.28	12.352	54.38
CO	0.612	7.40	0.612	12.70	0.615	11.45	0.786	2.79	0.177	0.69	0.006	0.73	0.171	0.73
CO_2	0.681	8.23	0.681	14.13	0.801	14.92	4.143	14.71	3.462	13.53	0.120	14.60	3.342	14.60
CH_4	0.244	2.95	0.244	5.07	0.244	4.55	7.034	24.98	7.034	27.49	0.244	29.68	6.790	29.68
C_+	-	-	-	-	-	-	-	-	-	-	-	-	-	-
N_2	0.005	0.06	0.005	0.10	0.005	0.09	0.144	0.51	0.144	0.56	0.005	0.61	0.139	0.61
H_2O	3.458	41.78	-	-	-	-	-	-	0.681	2.66	-	-	-	-
CH_3OH	-	-	-	-	-	-	-	-	1.289	5.04	-	-	-	-
Σ	8.276	100	4.816	100	5.369	100	28.165	100	25.586	100	0.822	100	22.794	100
t [°C]	460		35		35		230		255		35		35	
p [bar]	19.4		18		70		75		-		70		70	

	8		9		10		11		12		13		14	
	kmol/s	Vol %	kmol/s	Vol %	kmol/s	Vol %	kmol/s	Vol %	kmol/s	Vol %	kmol/s	Vol %	kmol/s	Vol %
H_2	-	-	0.429	99.31	-	-	-	-	-	-	-	-	0.018	46.16
CO	-	-	0.002	0.69	0.003	1.28	-	-	-	-	0.003	0.05	0.003	7.69
CO_2	0.120	100	-	-	-	-	0.014	1.61	0.270	100	0.284	4.57	-	-
CH_4	-	-	-	-	0.231	98.72	0.766	86.08	-	-	0.997	16.06	0.013	33.33
C_+	-	-	-	-	-	-	0.105	11.97	-	-	0.105	1.69	-	-
N_2	-	-	-	-	-	-	0.005	0.52	-	-	0.005	0.08	0.005	12.82
H_2O	-	-	-	-	-	-	-	-	-	-	4.814	77.55	-	-
CH_3OH	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Σ	0.120	100	0.432	100	0.234	100	0.890	100	0.270	100	6.208	100	0.039	100
t [°C]	-		-		-		20		20		330		-	
p [bar]	70		70		26		18		10		26		50	

FIG. 3. Methanol from Nat. Gas + CO2 with HTR Flowsheet Methanol-Synthesis Balance.

an efficiency of 66% (985/1483) In comparison to the conventional process the improvement factor I of the product yield is

ı =106/75 = 1,41

2 3 If the side-product electricity of the HTR process, fig 2 and 3, is - in addition - used for the methanol production (together with additional carbondioxide CO_2) the product yield y can be increased to about y = 109%, which means an increasement of the improvement factor i

i = 109/75 = 1,45

2 4 With additional electricity, which-of course-best can be produced from nuclear energy, the improvement factor i can still be futher increased up to about i = 4 for very CO_2 - rich natural gas, e.g from the NATUNA gas field in Indonesia, but this increases the production costs equivalently

3 In detail on the energy balance of the example of an HTR process, fig 2 and 3

3 1 The HTR process, fig.2, has the following main data Natural gas of 71820 Nm^3/h, that is equivalent to 882 MW(B), is with the assisstance of nuclear energy of 3 x 200 Mwt = 600 Mwt, -under application of 21790 Nm_3/h of CO_2-, converted into 148,7 t/h methanol, equivqlent to about 1 mio t/y (7000 h/y), equivalent 933 MW (B), with the side product of 52,6 Mwe electricity

3.2. Remark The calculation of the mol-balance, fig.3, is made for ECOFISK-natural gas, with about 12% oh higher alkanes, fig.3, lower part, column 11

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POTENTIALS FOR ADVANCED NUCLEAR TECHNIQUE (REACTOR) DEMONSTRATION IN EASTERN PART OF INDONESIA

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Abstract

Because the differentiation of the ground water, the mining resources, the climate, the people density and the distance between one and another island so the national industry development becomes unique and complex. The main requirement for the national industry development is the supply of adequate energy, especially for developing of eastern part of Indonesia. The advanced nuclear reactor should be an energy source which can be universally used for the electric power and non electric application. It means, that using of this technology could the development of eastern part of Indonesia be done.

INTRODUCTION

There are more than 13,000 islands in Indonesia and only 5 islands, i.e. Kalimantan, Sumatera, Irian Jaya, Sulawesi and Jawa, are categorized as the big islands. The distance between west and east is about 1/8th of equator length. The total area of Indonesia is about 7 million sq.km., which is more than 70% sea. Because the differentiation of the ground water, the mining resources, the climate, the people density and the distance between one and another island so the national industry development becomes unique and complex.

The energy in industry, which is the motor of the industry development centers, has several effects, i.e.: to propagate and develop the economic spread, to fulfill the local and nation vital necessity and to increase the local and national capabilities in field of software and hardware. Because about 65% of the energy production in the end of year 1993 was produced by oil and because the oil reserves are finite so the energy diversification policy are needed and done by the government to reduce the domestic oil consumption and promote the other energy sources, i.e. hydro, coal, geothermal, solar, wind, sea and biomass inclusive nuclear energy.

THE POTENTIALS OF EASTERN PART OF INDONESIA

Indonesian has divided into 3 times zone, i.e. the western, middle and eastern time zone. This zone dividing is similar with the western, middle and eastern part of Indonesia. The difference between one and another adjacent time zone is one hour.

The island conditions are not the same. Some islands have coal resources and or oil, geothermal, gas etc, but the other islands do not have any energy resources. Some islands have enough ground water resources, but the others have a lot of sea water intrusion. Other condition is the heterogeneous density of the people in each islands. For example the people density in Irian Jaya is about 3 person per sq.km, in Maluku is between 3 - 15 person per sq.km. In general it is difficult to develop for an island, which doesn't have enough energy resources, but rich with costly natural resources.

The natural resources

It is divided into 2 kinds of resources, i.e. the mineral and agriculture resources.
In Seram islands there is an oil resources. Another places are in Tenggara, Sorong, Babo, Kamano and Biak. Coal resources is in Cenderawasih Peninsula. Copper and iron sand are in Irian Jaya. Nickel, which is used for stainlessteel fabrication, is in Gag island. Asbest resources are in Seram and Halmahera islands.
Seram islands is well-knowned with 'sugar trees' and Maluku islands is famoused with a lot of kind of fishes.

Base Indutrial zones in Indonesia

There are 29 base industrial zones in Indonesia (see Fig. 1). Seven base industrial zones are located in Sumatera, 12 in Jawa, 5 in Kalimantan, 3 in Sulawesi, 1 in Kupang and another one base industrial zone is in Seram. It means that there are 2 base industrial zones there.

ADVANCED NUCLEAR TECHNIQUE (REACTOR)

The advanced nuclear technique (reactor) should be an energy source which can be universally used for electric and non electric application. It should be operated in long cycle time and has a better passive safety system. The current state of technology, i.e. in the application of High Temperature Reactor (HTR), is still being developed. The long term objective of this advanced reactor development is to use this reactor type for extracting nuclear heat at temperatures up to 950°C. Chemical industry such as synthesis gas factory, natural gas subsitution and hydrogen production could be served by using HTR with temperature of more than 800°C. For long term period it will be understood that synthesis gas, which is a mixture between H_2 and CO, can be used as reduction gas for steel industries, and H_2 gas can be used

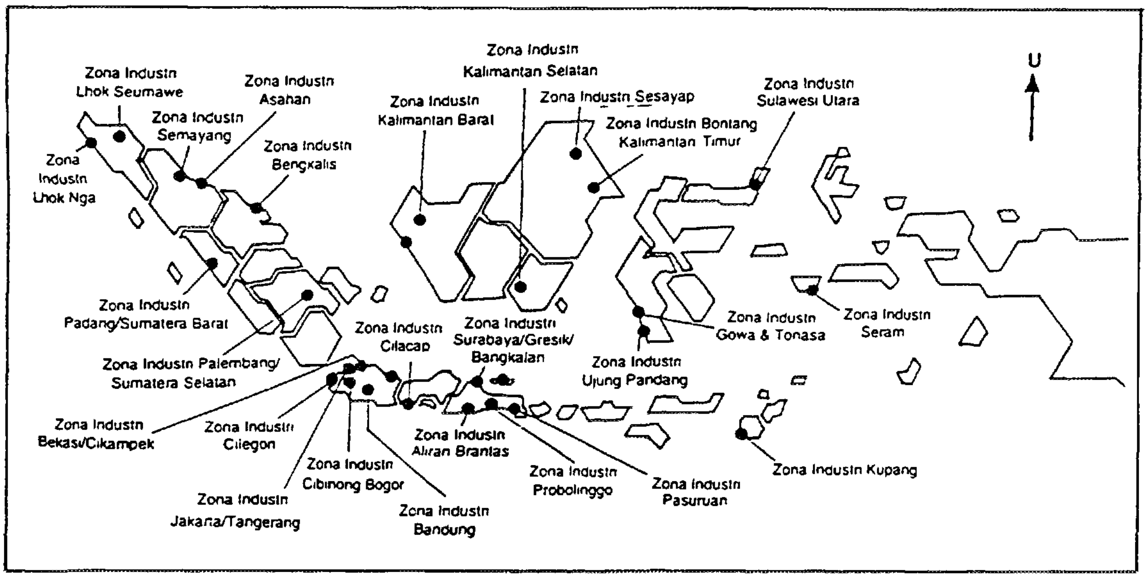

Fig. 1. Base industrial zones in Indonesia.

by petrochemical industry, for example to change the heavy oil to become short chain of hydrocarbon. In the field of oil industry the HTR is used to produce steam for tertiary oil recovery. Table 1 shows the heat application of some industries.

TABLE 1. PROCESS HEAT APPLICATION

Temperature level	Application
1. Low temperature 80° - 250°C	Water heater (household), boiling, evaporation, distillation, organic and petrochemistry, hot forming of plastic, food chemistry, etc.
2. Medium temperature 250° - 550°C	Distillation and purification of petrochemical, catalytic methane reforming, hydrogenating petrochemistry, reforming processes of organic chemistry, steam power process, etc.
3. High temperature 550° - 950°C	thermal reforming of petrochemistry, warm forming of metal, metal annealing processes, coal gasification, steam gasification, etc.

There are 2 base industrial zones in eastern part of Indonesia, i.e. in Kupang and Seram. Because Seram is in the middle of eastern part of Indonesia and also because some natural resources are there. so the demonstration plant of advanced nuclear reactor for eastern part of Indonesia has some advantages if be build here. Therefore this energy supply could give some positive effects, i.e. to propagate and develop the economic spread, to fulfill the local and nation vital necessity and to increase the local and national capabilities in field of software and hardware.

CONCLUSION

One of the national policy is the developing of eastern part of Indonesia. Two places are chosed here as the base industrial zone, i.e. Kupang and Seram. Because Seram has some natural resources and the location of Seram is in the middle of eastern part of Indonesia, so the building of advanced nuclear reactor demonstration in this place has some advantages, i.e. to use it for electric generation and heat application. It means that using of this advanced nuclear reactor demonstration could accelerate the local and national key industries in eastern part of Indonesia.

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TECHNOLOGY STATUS AND ECONOMIC ASSESSMENTS OF NON-ELECTRIC APPLICATIONS OF NUCLEAR ENERGY

ROLE OF IAEA IN NON-ELECTRIC APPLICATIONS OF NUCLEAR ENERGY

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Abstract

Worldwide, approximately 30% of total primary energy is used to produce electricity. Most of the remaining 70% is either used for transportation or is converted into hot water, steam and heat. The International Atomic Energy Agency (IAEA) is a specialized agency within the United Nations family whose role includes the development and practical application of atomic energy for peaceful uses throughout the world. The focus of this paper is on those applications associated with district heating and process heat production for industrial use.

The temperature requirements for these applications vary greatly from low temperature heat for district heating and desalination up to high temperature process heat for coal gasification and hydrogen production. Processes requiring temperatures of up to 300°C can be supplied by water cooled reactors while breeders may be applied to processes requiring up to 540°C. The high temperature gas cooled reactor can provide process heat temperatures of 950°C. Thus, nuclear energy has the potential to provide not only electricity, but also heat for many of the world's industrial heat application processes.

Currently, only a small number of countries have nuclear plants for the production of hot water and steam. However, the interest in non-electric applications of nuclear energy is growing, primarily in those countries having negligible fossil fuel resources or countries experiencing or expecting serious shortages in potable water. Nuclear seawater desalination has been a renewed topic of considerable emphasis within the IAEA since 1989. National and regional water shortages, especially in some Arab States, prompted an assessment of the technical and economic potential of nuclear reactors for seawater desalination. The initial phase of this assessment included a status report of the experiences gained in various countries throughout the past decade. A study was then undertaken to determine the economic viability of nuclear seawater desalination in comparison to the use of fossil fuels. An Options Identification Programme has now been initiated through the IAEA to determine the most feasible combinations of nuclear reactors and desalination processes for practical demonstration projects.

Other IAEA supported activities for non-electric application of nuclear energy includes use of the high temperature gas cooled reactor for heat processes such as steam reforming of methane and hydrogen production. Some Member States, through an IAEA Coordinated Research Programme, are investigating these high temperature processes for further development and actual demonstration in a test reactor currently under construction in Japan.

1. Introduction

The International Atomic Energy Agency (IAEA) is a specialized agency within the United Nations family and its charter includes to "foster the exchange of scientific and technical information", and "encourage and assist research on, and development and practical application of, atomic energy for peaceful uses throughout the world". This also concerns the promotion of the utilization of nuclear energy for electricity generation as well as for district heating and process heat production for various industrial applications.

As the World Energy Council has noted during its meeting in October 1995 in Japan, energy supplies will have to increase in years ahead, especially in the electricity sector, to meet the needs of the world's growing population At the same time, environmental problems, including the greenhouse effect, linked to emissions of carbon dioxide and other gases from the burning of fossil fuels, pose serious challenges in the view of the Intergovernmental panel on Climate Change and other bodies

Nuclear energy has the potential to contribute to solutions of such problems It already has become a valuable energy source with important environmental benefits Its share of the world's electricity production is now about 17%.

Yet only part of its potential is being realized The technology can play an even greater role in assuring adequate energy supplies by producing both electricity and heat for residential, industrial and other purposes

2. Characteristics of energy use

Worldwide, about 30% of total primary energy is used to produce electricity Most of the remaining 70% is either used for transportation or converted into hot water, steam and heat This shows that the non-electrical market, in particular that for hot water and steam, is rather large [1]

Nuclear energy is now being used to produce electricity in 29 countries [2] Some 432 nuclear plants, with a total capacity of about 340 gigawatts-electric (GWe) are in operation Only a few of these plants are being used to supply hot water and steam. The total capacity of these plants is about 5 GW thermal (th), and they are operating in just a few countries, mostly in Canada, China, Kazakhstan, Russian Federation and Ukraine

There are many reasons for the disparity in electricity and heat production from nuclear energy They include a fragmented co-generation market, electrical grid sizes, low costs of alternate energy sources for heat production, and high costs of transportation and distribution.

For heat applications, specific temperature requirements vary greatly (Fig. 1). They range from low temperatures, just about room temperature, for applications such as hot water and steam for agro-industry, district heating, and seawater desalination, to up to 1000° Celsius for process steam and heat for the chemical industry and high-pressure injection steam for enhanced oil recovery, oil shale and oil sand processing, oil refinery processes and olefine production, and refinement of coal and lignite [3] The process of water splitting for the production of hydrogen is at the upper end Up to about 550° Celsius, the heat can be supplied by steam, above that, requirements must be served directly by process heat, since steam pressures become much higher than 550° The upper limit of 1000° for nuclear-supplied process heat is set on the basis of the long-term strength capabilities of metallic reactor materials [4]

Of course, there are industrial processes with temperature requirements above 1000°, for example, steel production Such processes can utilize nuclear energy only via secondary energy carriers, such as electricity, hydrogen and synthesis gas

3. Capabilities of reactors

At all nuclear plants, the primary process in the reactor core is the conversion of nuclear energy into heat Therefore, in principle, all nuclear reactors could be used to produce process heat However, in practice, two criteria are decisive the temperature of the produced heat (of primary coolant), and the pressure of produced steam (in some cases)

Regarding the first factor, water-cooled reactors offer heat up to 300° Celsius These types of reactors include pressurized-water reactors (PWRs), boiling-water reactors (BWRs), pressurized heavy-water reactors (PHWRs) and light-water-cooled, graphite-moderated reactors (LWGRs) Organic-cooled, heavy-water-moderated reactors (OCHWRs) reach temperatures of about 400°, while liquid-metal fast breeder reactors (LMFBRs) produce heat up to 540°. Gas-cooled reactors reach even higher temperatures,

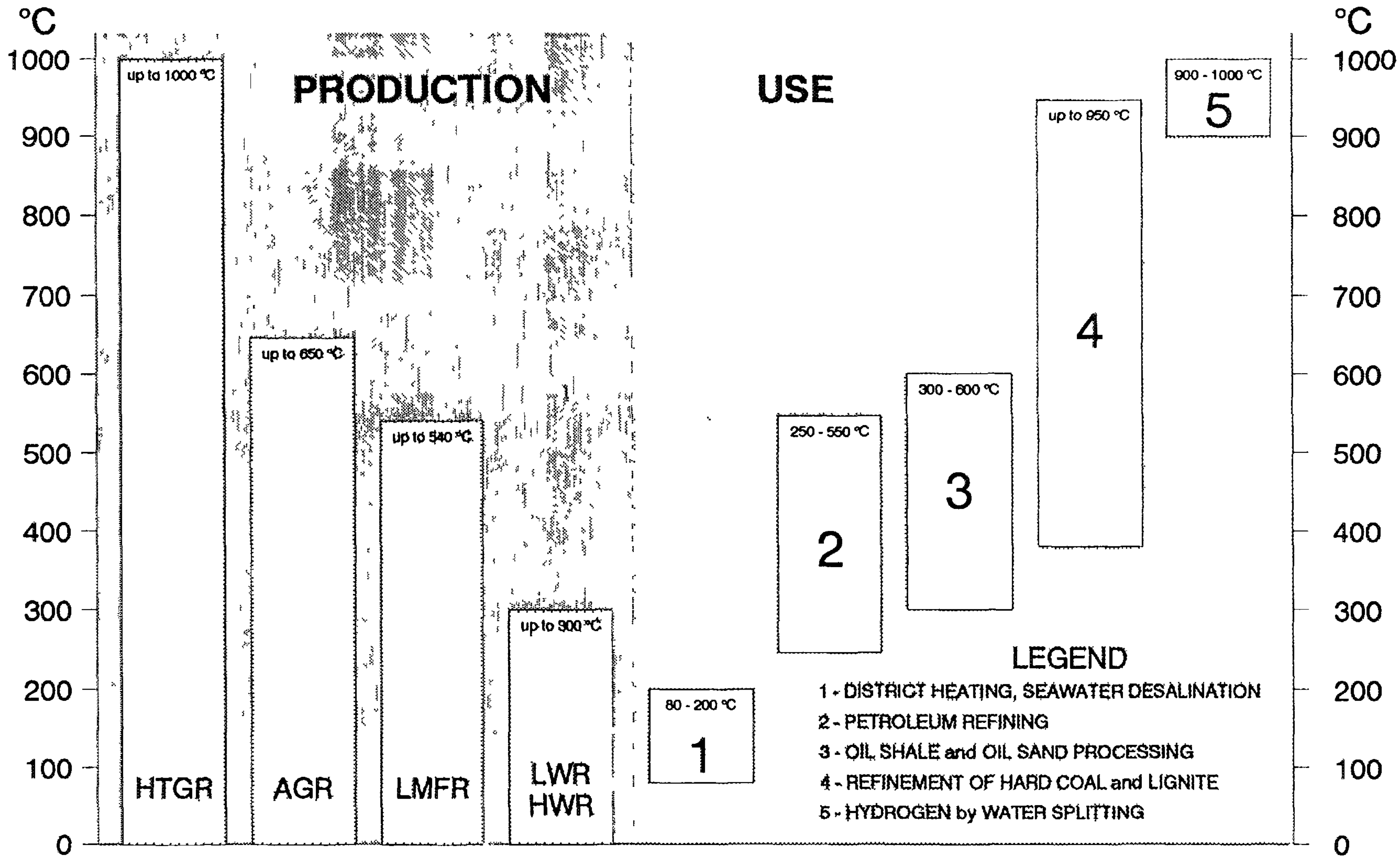


Fig 1 Temperature ranges in production and use of nuclear energy

about 650° for the advanced gas-cooled, graphite-moderated reactor (AGR), and 950° for the high-temperature gas-cooled, graphite-moderated reactor (HTGR)

In addition to the maximum temperature of the primary coolant, another important consideration is the temperature difference between coolant inlet and outlet. The pressure of the produced steam is important when it comes to applications in the field of enhanced oil recovery: The deeper the oil resource, the higher the injection steam's pressure must be Here, reactor types that have primary coolants other than water - the OCHWR, LMFBR, AGR and HTGR - have advantages They can easily produce injection steam with a higher pressure (for example, 10 Mpa), for an oil field depth of about 500 meters. For water-cooled reactors, attainment of such pressures would require the additional step of steam compression

4. Thermodynamics of electricity and heat generation

As noted before, the primary conversion process in a nuclear reactor is the conversion of nuclear energy into heat This heat can be used in a "dedicated" mode of operation for direct heating purposes In this case, no electricity is produced.

The other mode is co-generation of heat and electricity. Parallel co-generation is achieved by the extraction of some of the steam from the secondary side of the steam generator, before the entrance to the turbine. Series co-generation is achieved by the extraction of some or all of the steam at some time during steam expansion in the turbine, when it has the right temperature for the intended application. During this cycle, the extracted steam also has been used for electricity production. Series co-generation is ideally suited to industrial processes related to district heating, desalination and agriculture.

5. Examples of existing applications

Currently, a number of countries have nuclear plants that are being used for the production of hot water and steam The total capacity amounts to about 5 GWth

Significant experience in the co-generation of electricity and heat has been gained in these countries, notably in Canada, China, Kazakhstan, Russian Federation and Ukraine. This experience encompasses reactors at Beloyarsky, Kursk, Novovoronezh, Rovno and Kolskaya in Russia, Tsinghua University in China, Bruce Nuclear Power Development in Canada, Bohunice in the Slovak Republic and Goesgen and Beznau in Switzerland.

A brief technical overview of some of these applications follows

Heat reactor in China. At the Institute of Nuclear Energy Technology (INET), Tsinghua University, Beijing, a nuclear heat reactor with the capacity of 5MWth started operations during the Winter of 1989-90. Used to supply heat to the INET centre, the reactor's operating experience has been very good Its design principles follow that of a PWR The design pressure of the primary circuit is 1 5 Mpa (about ten times smaller that in a usual PWR) and temperature conditions in the primary loop are 186/146 degrees Celsius Temperatures in the intermediate loop are 160/110° at 1 7 MPa, and in the heat grid, 90/60°

Parallel co-generation of process steam and heat in Canada. One of the largest uses of process steam occurs at the Bruce Nuclear Power Development Facility in Ontario, Canada The Candu PHWRs at this site are capable of producing over 6000 MWe of electricity, as well as process steam and heat for use by Ontario Hydro and an adjacent industrial energy park The Bruce-A nuclear station consists of four 825-MWe units that are generating electricity Additionally, the plants supply steam to a steam transformer plant This plant generates 720 MWth of process heat and steam for heavy water production plants, 70MWth for the Bruce energy centre, and 3 MWth for side services The cycle is typical for parallel co-generation Nuclear heat generated in the reactor is transferred to the steam generator, in parallel with the steam supply to the turbine and then fed directly to the steam transformer plant The extracted steam is not used to produce electricity

Series co-generation of hot water for district heat in the Slovak Republic. The Bohunice nuclear power station consists of two Russian-designed VVER-440/230 units, and two VVER-400/213 units All units are in service Each one cosists of the reactor with a thermal power of 1375 MWth, six horizontal steam generators, and two condensation turbines The plants co-generate electricity and low-temperature heat for heating, industrial and agricultural purposes in the area near Trnava

In the series co-generation cycle, water is heated to temperatures of 70° and 150° Celsius, the turbines are capbale of supplying 60 MWth of heat

Series co-generation for seawater desalination in Kazakhstan. Exploiting natural resources in the arid regions of Kazakhstan became possible once water and electricity supply problems were solved An important contributor to this effort has been Aktau complex. It includes a fast reactor, type BN-350, three thermal power stations, and a desalination plant with thermal distillation equipment The complex constitutes the world's first plant where a nuclear reactor is used in seawater desalination

In the process, the BN-350's steam generators and a boiler unit supply steam to several different turbines. Steam from the BN-350 unit at 4.5 MPa and 450° Celsius is directed to the back-pressure turbines and to the condensing turbine. Steam from the back-pressure turbines is directed towards the desalination units and the industrial enterprises of the town

6. Integration of nuclear and fossil energy

More than 80% of the world's energy use is based on fossil energy sources, namely coal, oil and gas Burning these fuels is known to cause serious environmental problems from emissions of sulphur oxides, nitrogen oxides and carbon dioxide

To help solve such problems, one approach that has been proposed is the integration of energy systems A typical example for one future integration is the application of nuclear heat for the reforming of natural gas Synthesis gas, methanol, hydrogen, heat and electricity would be produced from natural gas and uranium, using what is known as the HTGR-reforming process In the process, natural gas is decomposed into mainly hydrogen and carbon monoxide The main products are methanol, a liquid carbohydron, and hydrogen Side products are heat and electricity.

A separate IAEA paper by Mr L Brey will provide you with a review of IAEA activities on gas-cooled reactors and their applications.

Another example of this integrated approach is seen in the oil industry. Several studies have been done on the use of nuclear power as a heat source for heavy oil exploitation They have shown that under favourable oil market conditions, the nuclear option presents economical and environmental benefits, as compared to conventional methods

A third example is the integration of coal and nuclear energy in the steel industry From the technological point of view, this is the most ambitious integration It involves gasification of hard coal heated by hot helium from an HTGR. The intermediate products are synthesis gas and coke, which is used for iron ore reduction The final products are methanol and pig iron

Experience with HTGRs for electricity generation is available in the USA and in Germany Small HTGRs, for high temperature process heat applications, are under construction in Japan and China.

7. Potential role of nuclear energy in seawater desalination

7.1. Need for Water

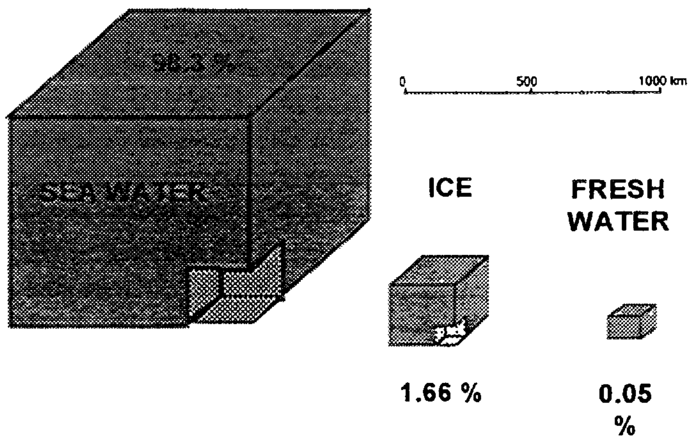
Worldwide availability of fresh water resources substantially exceeds the amounts of water being used. However, water resources are not evenly distributed and about three quarters of the world's population lack safe drinking water

Population growth, increased pollution and reduction of ground and surface water resources are expected to increase water supply problems, in particular in arid regions. Water is also required by households to ensure an adequate quality of life, by industry and by agriculture, where irrigation may be needed to complement rainfall.

Fresh water resources, however, are not a global resource like most natural resources. In many regions the amount of the available fresh water resources is decreasing and often the quality is deteriorating Acute water shortages exist in many water-scarce countries. Mainly due to the population increase during the next 30 years the availability of fresh water per capita will decrease and the number of countries with water scarcity will increase steadily [5]. Therefore, the water scarcity is becoming a global issue

7.2 Fresh Water Supply through Seawater Desalination

Seawater is the largest existing water resource on earth (Fig. 2) Its availability is essentially unlimited in the foreseeable future and it is still relatively unpolluted



	Amount of water (cubic meter)	Share in % (1. level)	(2. level)	Share (absolute)
WATER	1.40E+18	100		1
SEAWATER	1.38E+18	98.3		
SWEETWATER	2.40E+16	1.7	100	1/60
ICE	2.33E+16	1.66	97.0	
FRESHWATER	7.10E+14	0.05	3.0	1/2000

Fig 2 Water resources on Earth

Worldwide there has been a rapid increase in the installed seawater desalination capacity (Fig. 3) during the last decade, but there is no inventory of requirements Nevertheless, the extent and distribution of seawater desalination capacity (by the end of 1994, 13.5 million m^3/d capacity had been contracted) indicates that there are regions and countries which have already exhausted other less expensive potable water supply options, and are expected to continue to expand their desalination capacities [6].

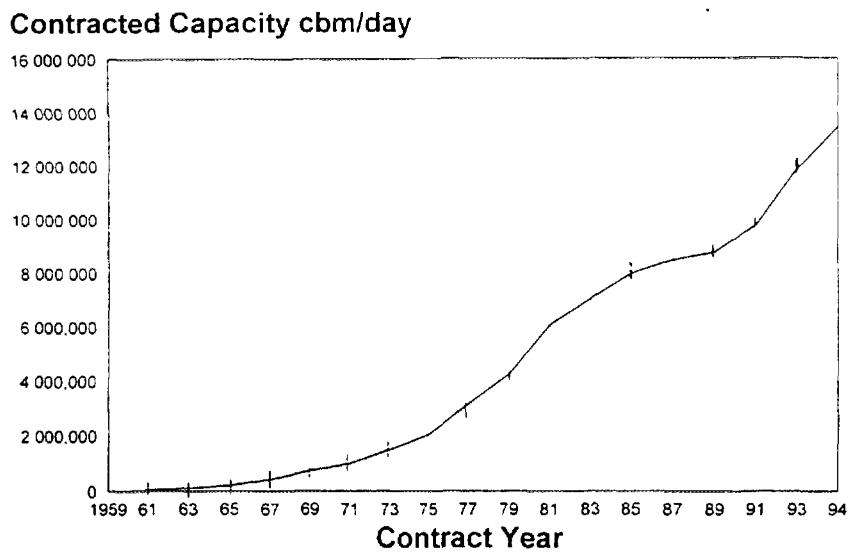


Fig 3. Worldwide cumulative seawater desalination capacity (daily capacity of all land based desalting plants contracted cumulatively (Source: Wangnick Consulting).

The most important users of seawater desalination are the Middle East (about 70% of the worldwide capacity), mainly Saudi Arabia, Kuwait, the United Arab Emirates, Qatar and Bahrain; following by Europe (9.9 %), America mainly California and Florida (7.4 %), Africa (6.3 %) and Asia (5.8 %). Assuming that the growth rate of the last decade will be maintained during the 1990s, there could be about 20 million m^3/d desalination capacity in operation worldwide by the year 2000. Medium and long term forecasts beyond the year 2000 predict a further increase of installed capacity each decade, assuming that current trends are maintained. Should there be major cost reductions, growth rates could be much higher.

7.3 The use of nuclear energy

All reasons which have led in the past to the development of nuclear power, and which prevail at present in those countries which have a nuclear power programme, are applicable to the choice of nuclear power as an energy source for seawater desalination plants. These reasons include the production of less expensive energy as compared to other options, overall energy supply diversification, conservation of limited fossil fuel resources, promotion of technological development and, lately, environmental protection through the reduction of emissions causing climate change and acid rain which originate from the burning of fossil fuels. The latter reason might be enforced due to proposed CO_2 taxes.

On the other hand, the reasons which have led countries to reject the nuclear option or to slow down their nuclear power programmes also apply to the use of nuclear energy for seawater desalination. Political or public opposition, concerns about nuclear safety, lack of financial resources and lack of necessary infrastructures are some of these factors.

Coupling of the heat source to the desalination plant is obtained via a heat transfer circuit. With a fossil fueled boiler, coupling is relatively simple but, for a nuclear reactor, the risk of possible radioactive contamination of the potable water produced must be avoided. Unless the reactor design excludes the possibility of radioactive contamination reaching the product water (i.e. via a pressure gradient), an additional intermediate heat exchange circuit is required. This can be done without undue complication, as demonstrated by the experience with several dual purpose nuclear plants in Bulgaria, Canada, the former Soviet Union, Czech Republic, Slovak Republic, Germany, Hungary and Switzerland. However, there are extra costs involved.

The decision regarding the use or rejection of nuclear power are country specific and views of countries may be different and may also change in time. International concerns and political considerations, including non-proliferation issues, also have an influence on the decisions of individual countries.

Similarly as it penetrated the electricity sector, nuclear energy could do the same in the potable water production sector through seawater desalination plants which require energy to produce potable water.

8. IAEA ACTIVITIES ON SEAWATER DESALINATION

The IAEA has been studying the feasibility of nuclear desalination since the 1960s and published a series of reports [7-11] as part of its programme on this technology. The programme was terminated in 1977. The reasons were mainly uncertainty in costs and mismatch between the size of nuclear power plants being available at that time and desalination plants.

During the annual IAEA General Conference in 1989, renewed interest in nuclear seawater desalination was indicated by some Member States. The interest was based on existing national and regional water shortages, especially in some Arab States due to their increasing need for potable water on one hand and their diminishing fresh water resources on the other hand. The General Conference requested that the Director General assess the technical and economic potential of nuclear reactors for seawater desalination in the light of experience gained during the past decade. This ushered in a new era of activities at the IAEA. These activities have been carried out in close co-operation and with significant input from many institutions in our Member States.

8.1 State-of-the-art Report

In order to address the activity of nuclear desalination thoroughly, it was decided to prepare a state-of-the-art report based on experience gained and studies conducted in various countries during the past decade. The report was published in 1990 and a review of the studies mentioned in the previous section was included. Many desalination technologies have been developed based on different principles of separation. Some of them have been successfully deployed, and these are discussed in detail in [12]. For the near term application, the most promising technologies are distillation and membrane processes.

8.2 Economic Assessment

Following the status report, a study was undertaken including an assessment of the need for desalination and gathering of information on the most promising desalination processes and energy sources, as well as on nuclear reactor systems proposed by potential suppliers worldwide. The main part of the study was devoted to evaluating the economic viability of seawater desalination by using nuclear energy, in comparison with fossil fuels. The evaluation encompasses a broad range of both nuclear and fossil plant sizes and technologies, and combinations with desalination processes. The results were published in 1992 [13].

Among the various existing desalination processes described in [12], the following have been used in [13] as the most interesting for large scale water production: reverse osmosis (RO), multi effect distillation with vapor compression (MED/VC), multi effect distillation (MED), and multistage flash distillation (MSF). All are proven by experience and all are commercially available from a variety of suppliers.

A broad spectrum of nuclear reactors have been proposed by vendors for desalination, comprising current as well as new designs. Most of the new designs under development are intended to meet even stricter performance and safety requirements: passive removal of decay heat, simplification of systems, reduction of radioactive release even under severe hypothetical conditions, etc. In principle, all nuclear power reactors are capable of providing energy for desalination processes.

Depending on the availability and size of an electric grid, nuclear power plants can be integrated into the grid to supply the electricity market, in addition to meeting the energy requirements of the desalination plant. The size of the power plant will depend mainly on the grid capacity. To capture the economies of scale, a grid connection is essential and the relative scale of a nuclear power plant and of desalination processes must be taken into account when considering a combination of these two technologies.

In areas without the possibility of any suitable grid connection, the reactors would have to be dedicated exclusively to supplying energy to the desalination plant, leading to small nuclear units. Such small reactors could be installed on shore as land-based units supplying adjacent desalination plants, or as barge-mounted self-sufficient floating plants. The use of small reactors can only be analyzed on a case by case basis. According to studies, floating MED plants could supply water in the range of about 20 000 m^3/d up to 120 000 m^3/d. Floating RO plants may reach even 250 000 m^3/d. Floating desalination plants could be especially attractive for supplying temporary demands of potable water.

For any desalination process, specific water production costs would be lower with larger desalination units (economics of scale). Site related factors also have a substantial influence on production costs, in particular seawater composition and temperature, and water intake and outlet structures. Costs for RO desalination plants are strongly influenced by the required quality of the water produced. None of the processes selected in the study show a clear general economic advantage with respect to the others, though recent contracting experience indicates preference for the RO process.

The method considered appropriate for deriving average water costs for seawater desalination is the constant money levelized cost method. In the assessment, the costs of water storage, transport and distribution were not considered. This cost component is fundamentally site dependant and can only be analyzed on a case-by -case basis. The cost of electricity, which depends on the energy source chosen, will effect the water transport and distribution costs (pumping), but this will be relatively minor. A more important effect on the cost of transport may come from siting constraints, if the energy source and the desalination plant have to be located adjacent to each other, as compared to independent siting conditions applicable to the processes which require electricity only. The desalination cost component (excluding energy input) has been evaluated using cost information available from the desalination market. It has been found that desalination plants (excluding the energy sources) are in general capital intensive, investment requirements being on the order of $1000 to $2000 per m^3 of production per day, for large units. Plants using the RO process are at the lower end of capital investment, but they have higher operation and maintenance costs.

The choice of the energy source has little influence on the two production cost components of the desalination plants which are capital charges and operation and maintenance costs. The influence of the choice of the energy source on the water cost is practically limited to the energy cost component.

Among fossil fueled plants, it has been found that low speed diesel engines are the most economical choice for small electricity generation capacities, up to about 50 MW(e); gas turbines for up to about 100 MW(e); combined cycle gas and steam turbines or fuel oil or gas fired plants for the largest sizes available for these options (500 MW(e)); and coal plants for sizes above 500 MW(e). All fossil fueled plants are less capital intensive than the equivalent nuclear options, but have a larger fuel cost component.

The economic assessment of the nuclear option has been based on cost information available in general, and in particular on information provided to the IAEA in response to the questionnaire. To cover a wide range, representative sizes of 50, 300, 600 and 900 MW(e) were selected for single purpose electricity or dual purpose (cogeneration of electricity and heat) plants, and of 50, 100, 200, and 500 MW(th) for single purpose heat only units. The economics of units in the very small size range have not been analyzed in detail. For single purpose electricity and dual purpose nuclear plants (electricity being the main product), the estimated specific construction costs were between $1600 and $2800 per kW(e). Heat only single purpose plants were estimated to cost between $650 and $1700 per kW(th).

The study shows that specific water costs range from 0.70 to 2.00 US$/$m^3$ and concludes that, the use of nuclear energy as an alternative option to the use of fossil fueled plants for supplying energy for seawater desalination is technically feasible, and in general economically competitive for medium to large size units integrated into the electric grid system. Large electricity generating nuclear power plants, which are integrated into the electricity supply grid system and which supply electricity to separately located desalination plants using reverse osmosis, offer the most cost advantageous option.

8.3 Example: North Africa

The adequate supply of potable water is one of the major problems of the North African Region Therefore, in view of the limited regional water resources and the possible role of nuclear energy in seawater desalination, the five North African countries Algeria, Egypt, Libyan Arab Jamahiriya, Morocco and Tunisia submitted a request to the IAEA for technical assistance in carrying out a feasibility study on the use of nuclear energy for seawater desalination at some selected sites in order to cover their potable water needs economically

Data on the demand and supply of potable water and electricity had been collected in all the participating countries Data had also been collected on available energy and water resources, experience with seawater desalination and on possible sites Five sites had been suggested for further study [14]

To estimate the cost of power and water for these five selected sites, the same methodology was used as in the generic study described in 7 2 (IAEA-TECDOC-666) The reactors were selected on the basis of power outputs compatible with grid requirements and the availability of economic data supplied by the vendors The water plant size had to match the site water demand independent of the power plant size Numerous improvements and performance options were added to the calculation methods to adjust to the regional conditions

The cost estimates of the various nuclear/desalination coupling schemes for the five reference sites were made in constant value January 1994 US dollars and compared on a consistent basis with fossil fueled plants (steam power plants, gas turbines, combined cycles, diesel engines, and boilers) as well as solar ponds Adjustments were made to the nuclear plant costs to reflect the additional costs anticipated for construction in the NACs For the base case an 8 % annual discount rate and an oil price of US$ 15 per barrel (+ 0 5 US$ per barrel for transportation) with 2 % per year real escalation was used Both oil price and nuclear fuel cost reflect current and projected market conditions

The most economic combination of nuclear/desalination and fossil/desalination for each site are shown in Table 1 It is clear from the Table that the levelized water costs of fossil and nuclear options are in similar range for the base case The average costs of produced water in the various sites by the nuclear and fossil options are also shown in the table below Water production costs with single purpose heat only plants were found to be substantially higher than with dual purpose (electricity and heat), or single purpose electricity only power plants

Plant Size $10^3 m^3/d$	Location	Economic Couplings (1)				Average $/m³
		Nuclear	Water Cost $/m³	Fossil	Water Cost $/m³	
720	Tripoli	GT-MHR/RO C(2)	0 73	GT/Hybrid	0 70	0 715
240	El-Dabaa	CANDU-6/RO-C	0 80	CC/RO-C	0 78	0 790
120	Oran	GT-MHR/RO-C(2)	0 79	CC/RO-C (3)	0 83	0 810
60	Zarzis	CAREM-25/RO-C(2)	0 87	CC/RO-C	0 89	0 880
24	Laayoune	(4)		Diesel/RO-C	1 04	-

(1) Base case 8% interest rate, 2% oil price escalation and US$15 5/bbl oil price including cost of transportation
(2) Preheat is used
(3) GT/MED will give slightly lower costs of US$ 0 82/m³ However this combinaiton was chosen to facilitate comparison with other combinations in the Table
(4) All selected reactors for this site were heat only reactors

Table 1 Most economic cases of nuclear and fossil couplings

Under the assumptions made in the economic assessments, the use of nuclear energy for seawater desalination is competitive with fossil energy A preliminary conclusion on the competitiveness and viability of nuclear desalination can be reached at the feasibility study stage The final decision on the investment could only be reached on the basis of responses to an invitation to tender

8.4 Example: Saudi Arabia

In Saudi Arabia, the demand of potable water is almost entirely met through seawater desalination. The enormous power and heat requirements are met by fossil energy resources.

Because fossil energy resources eventually will be depleted and their costs are expected to escalate, also Saudi Arabia is interested in carrying out a feasibility study on prospects for nuclear desalination. It requested the IAEA to assist under its regular programme of Technical Co-operation to perform such a study. The study has recently been started.

8.5 Example: Morocco

As a follow-up of the North-African Feasibility Study Morocco has requested in 1995, technical assistance from the Agency for a pre-project study, to be performed by Morocco and China on a bi-lateral basis. The study includes the review of the possible introduction of a nuclear desalination plant (about 7000 m3/day) around the year 2000. The reactor will be a nuclear heating reactor (about 10 MWth) from INET, China, which will be coupled to an MED desalination process.

8.6 Current Activities - Options Identification Programme

Besides the finalization of the report on the North African feasibility study, the continuation of the Saudi Arabian feasibility study and reviews of generic technology areas, such as the technical status at and experience with floating nuclear energy plants for desalination, the Agency is currently conducting with experts from interested Member States the Options Identification Programme as requested at the General Conference in 1994.

8.6.1 Objective

The purpose of the Options Identification Programme is to narrow down the very broad range of possible combinations of nuclear reactors with desalination processes to a much more limited set of practical demonstrations projects. This limited set of options would be ones which would be well defined, in which all the aspects necessary to ensure success would be fully investigated, which had an applicability much broader than the specific country and site at which they were carried out, and which could practically be developed on a time scale commensurate with the needs of that specific option being identified. Any demonstration options identified would be based on reactor and desalination technologies which were themselves readily available without further development being required at the time of the demonstration.

8.6.2 Approach

The study of the Option Identification Programme is carried out in the framework of a small standing working group which uses consultant meetings and workshops for further input and advise.

The Programme will be carried out over a period of approximately two years. It has just started early 1995. The phase 1 of the study was completed in 1995 and phase 2 will be finalized in 1996, with a final report and recommendations going to the General Conference in September 1996.

8.6.3 Current Status

In the framework of this study the number of possible nuclear reactors has been considerably reduced by the application of a set of screening criteria based on design status and licensing status as go/no go criteria. These criteria were applied to all reactors, which were assumed to be commercially available within the next ten years.Three combinations of reactors with desalination processes have been selected as the most promising candidates for demonstration.

The assessment of the world market projection for seawater desalination was carried out in March 1995. The assessment results into a demand for additional desalination capacity of large magnitude by the years 2015 (35,000,000 m^3/d in 2015 municipal use). Furthermore, it was concluded that several countries will need large desalination production plants producing in the order of 200,000 to 500,000 m^3/d at one site.

At the present time, the Agency is preparing the progress report for the 1996 General Conference.

9. Conclusions

Energy demand will continue to grow worldwide, with a faster growth in developing countries, and generation capacity will have to be expanded accordingly. Therefore, a wide range of options needs to be maintained for energy production in order to achieve environmental and economic objectives. While fossil fuels will remain a major component of energy production mixes in most countries, alternatives have to be developed in order to diversify energy sources, enhance the security of supply, and to preserve natural resources, including our environment. Renewable sources are not likely to play a significant role in the short and medium term for energy production.

Nuclear power, which has reached the stage of commercial deployment and has demonstrated excellent technical and economic performance in many countries, could play an important role in energy policies aiming towards sustainability. Nuclear power plants contribute to mitigate the risk of global climate change and to alleviate many other environmental burdens. While nuclear power alone will not suffice to reconcile adequate service supply and environmental protection aiming towards worldwide enhancement of quality of life, it is indeed one of the elements of sustainable development.

Resources, technologies and industrial capabilities for reactors and fuel cycle services supply are available to support a broader deployment of nuclear power. Technological progress is likely to further enhance its competitiveness and safety.

The attractiveness of using nuclear energy for non-electric applications, compared to fossil energy is the long-term stability of nuclear fuel prices in contrast to the rising prices of fossil fuels, increase of energy independence, decrease of the environmental impact and contribution to national technology development and to highly qualified manpower.

The interest in non-electric applications by using nuclear energy is growing in many countries, mainly in those countries having only negligible own fossil fuel resources, or countries experiencing or expecting serious shortages in potable water. Feasibility studies are on desalination are being performed for North Africa, Saudi Arabia and Morocco, and follow-up studies could lead to the initiation of a nuclear desalination demonstration facility and hence constitute to solving the potable water problems in many arid areas in the world. However, international co-operation and political willingness is required for implementing any project on non-electric applications of nuclear energy. The IAEA as the only global organization dealing with nuclear power could provide an appropriate international forum for promoting international information exchange and cooperation in non-electric applications of nuclear energy.

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THE APPLICATION OF NUCLEAR ENERGY FOR SEAWATER DESALINATION. THE CANDESAL NUCLEAR DESALINATION SYSTEM

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Abstract

As the global consumption of water increases with growing population and rising levels of industrialization, major new sources of potable water production must be developed. Desalination of seawater is an energy intensive process which brings with it a demand for additional energy generation capacity. The Candesal nuclear desalination/cogeneration system has been developed to address both requirements, providing improved water production efficiency and lower costs. To meet large scale water production requirements the Candesal system integrates a nuclear energy source, such as the candu reactor, with a reverse osmosis (ro) desalination facility, capturing the waste heat from the electrical generation process to improve the efficiency of the ro process. By also using advanced feed water pre-treatment and sophisticated system design integration and optimization techniques, the net result is a substantial improvement in energy efficiency, economics, and environmental impact. The design is also applicable to a variety of conventional energy sources, and applies over the full range of desalination plant sizes. Since potable water production is based on membrane technology, brackish water and tertiary effluent from waste water treatment can also be used as feed streams to the system.

Also considered to be a fundamental component of the Candesal philosophy is a technology transfer program aimed at establishing a complete local capability for the design, fabrication, operation and maintenance of these facilities. Through a well defined and logical technology transfer program, the necessary technologies are integrated into a nation's industrial capability and infrastructure, thus preparing local industry for the long term goal of manufacturing large scale, economical and environmentally benign desalination facilities.

Introduction

In many regions of the world the supply of renewable water resources is inadequate to meet current needs, and that from non-renewable sources is being rapidly depleted. Since the world-wide demand for potable water is steadily growing, the result is water shortages which are already reaching serious proportions in many regions, with the threat of global water starvation continuing to grow. To mitigate the stress being placed on water resources, additional fresh water production capability must be developed. For many regions seawater desalination is the best alternative. The main drawback of desalination, however, is that it is an energy intensive process. Therefore, the increasing global demand for desalted water creates a tremendous collateral demand for new sources of electrical power. Since water is an undeniable life sustaining resource, improvements in the efficiency of energy utilization must be considered a significant benefit to both the environment and the consumer. Candesal Inc., is a Canadian company working internationally to improve the energy efficiency and economics of fresh water production and to deliver that technology to markets where such facilities are most required.

The Candesal Nuclear Desalination/cogeneration System
Development of the Candesal Design

Because of the pressing need for additional large scale water production capability, the focus of Candesal's early design concept development work [1,2] was placed first on the use of theCANDU nuclear reactor as an energy source for desalination. Two approaches were considered in preliminary studies: the use of electrical energy for reverse osmosis (ro) and the use of process steam from the nuclear steam supply system to provide the energy for a multi-effect distillation system. This latter approach, however, was found to require changes to the balance of plant design that were both expensive to implement and led to reduced electrical generating efficiency to such a degree that the total water and electrical production capacity was not as great as that which could be achieved using RO.

Having selected the RO process, it was then recognized that improvements in the efficiency of energy utilization could be achieved by taking advantage of waste heat normally discharged from the reactor through the condenser cooling system. Use of the condenser cooling water as preheated feedwater to the ro system improves the efficiency of the ro process, and therefore the economics of water production. As the development work progressed, it was also found that further improvements could be achieved by taking a systems approach to optimizing the design. Hence a strong emphasis has been placed on the integration of the energy and water production systems into a single, optimized design for the cogeneration of both water and electricity.

This approach to the integration of seawater desalination systems with nuclear reactors has the advantage of maximizing the benefits of system integration while at the same time minimizing the impact of physical interaction between the two systems. In essence, the reactor operates without "knowing" that there is a desalination plant associated with it. Transients in the desalination plant do not have a feedback effect on reactor operation. This is extremely important, since there must be a high degree of assurance that unanticipated operating transients in the desalination unit do not have an adverse impact on either reactor safety or operational reliability. Conversely, it would also be undesirable to have reactor shutdowns, whether unanticipated or for planned maintenance, that would require shutdown of the water production plant.

Hence as the Candesal nuclear desalination/cogeneration system design has developed, it has evolved in a direction which allows standardized off-the-shelf reactor systems to be used without modification, while at the same time accruing significant benefits from the systems integration due to improved performance characteristics and energy utilization.

Benefits of cogeneration

In addition to allowing the use of the standardized candu reactor design, the beneficial use of waste heat from the nuclear power generation process and the ability to optimize the overall system design, there are several other benefits that result from an innovative cogeneration systems design. These can be generally expressed in terms of their impact on the plant design and its key performance parameters, ease of operation and maintenance, and plant reliability. Although not the only important factor, the benefits are frequently quantified as reductions in plant capital cost and the cost of potable water production.

A fully integrated cogeneration design based on co-located nuclear energy and desalination systems allows for shared land acquisitions and commonality of many on-site facilities including water intake and outfall structures, maintenance facilities and staff, and administrative facilities and staff. These all have clear economic benefits. Fresh water and electrical transportation costs may also be reduced through the use of common rights-of-way to bring these two resources to their markets. By designing the power plant and desalination facility to operate independently of each other even though they are thermally coupled, the Candesal system allows the flexibility of phased increases in the size of the desalination plant with no collateral requirement to modify the power plant.

Additionally, coupling the reactor with the desalination system in this manner provides the flexibility of varying water production without adversely impacting the operation of the power plant. The nuclear power plant can be operated at maximum electrical production efficiency, while the desalination plant is operated so that fresh water production meets or exceeds requirements under various operating conditions, including annual variations in site specific feed water conditions and daily variations in demand. During periods where the power plant is off-line and the preheat is therefore unavailable to the desalination plant, the desalination process can still continue, although at a reduced efficiency.

Through this combination of design and performance optimization, along with the unique electrical and thermal coupling of the energy source and desalination system, significant improvements in water production efficiency and reductions in desalination plant capital cost are realized. The result is, of course, a reduction in levelized water production costs. Although the costs for any given facility are highly specific to the site, seawater conditions, and other design requirements, detailed cost assessment models nevertheless indicate that savings on the order of 20-40% in plant capital cost and 10-15% in water production costs are achievable. These savings are generally independent of plant size.

Key features of the Candesal design

Certain features of the Candesal design are considered to be integral to the concept. Already mentioned is the use of reactor plant condenser cooling water as a preheated feed stream for the desalination plant. Substantial gains in fresh water production efficiency can be achieved, resulting in reduced plant capital cost as well as reduced energy consumption per unit of water produced.

Ultrafiltration (uf) pre-treatment is used to provide high quality feed water to the RO process. This serves to protect the RO membranes and enhance their performance, thereby reducing the total number of RO membranes required and increasing their lifetime. The result is reduced plant capital cost and a reduced requirement for membrane maintenance and replacement.

Sophisticated analysis techniques drawn from reactor design experience are used in the Candesal desalination/cogeneration system design. Drawing on the combined expertise of desalination system and nuclear power plant designers, the design is numerically modeled to allow design optimization and integrated system performance analyses. This comprehensive design optimization allows further performance enhancements and reduced costs.

Maximum use is made of energy recovery techniques. Much of the electrical energy consumed in RO desalination is used to pressurize the RO feed stream to the high operating pressures required for optimum performance. Since there is relatively little pressure drop through the RO membranes, a significant portion of this energy can be recovered, thereby reducing energy consumption and hence energy costs and water production costs.

System design integration and optimization studies

As previously noted, the engineering development of the Candesal design has been based on taking a systems view of the design and its operation. This formed the basis of the design approach which lead to an optimization of design features, performance characteristics and costs, all based upon individual site specific operating parameters. The results of this design approach centered around an optimization code for plant design and operation which provides for significant impRovements in the efficiency of the desalination pRocess, with a corresponding reduction in plant capital cost and potable water costs.

This optimization code permits the plant to be designed and operated at peak efficiency by taking into account realistic operating parameters and annual variations in site specific feedwater conditions. The code is pRoprietary, but is based on an iterative optimization algorithm which examines the plant operating characteristics and optimizes the design and/or operation for a selected set of parameters and operating limits on those parameters.

The RO process depends on a set of complex relationships between a variety of operating parameters including the preheated feedwater temperature, feedwater analysis, RO system operating pressure, membrane feed flow rate, recovery, permeate quality and flow rate, and brine concentration and flow rate. Design optimization thus involves carrying out a large number of parametric analyses to assess the impact of variations in one or more of these parameters on system performance. The objective is to obtain the best balance of performance characteristics which will achieve specified requirements. This is done by the design optimization code based on user selected evaluation criteria.

Achieving an optimum design with enhanced performance characteristics and improved economics introduces the possibility of approaching design limits in one or more areas. Of particular concern with respect to RO membrane lifetime is the potential for precipitation and scale formation due to excessive brine concentrations. Parametric studies have been carried out to evaluate the discharge brine concentrations as a function of RO system recovery and RO feedwater temperature for various operating conditions. Typical results of such an analysis are shown in figure 1 for a 1000 psi operating pressure and seawater at 38,500 and 42,000 ppm total dissolved solids. Data from such analyses have then been used to determine maximum allowed discharge brine concentration under various operating conditions. A typical result is plotted in figure 2, representing an upper operating limit on the allowed brine discharge concentration for the seawater and RO system conditions shown in figure 1.

The upper limits of acceptable operation are defined, for the specific conditions of this analysis, by the limit lines shown in figure 2. Not only does the efficiency of water production increase with feedwater preheat, but the likelihood of precipitation and scaling problems decreases as the

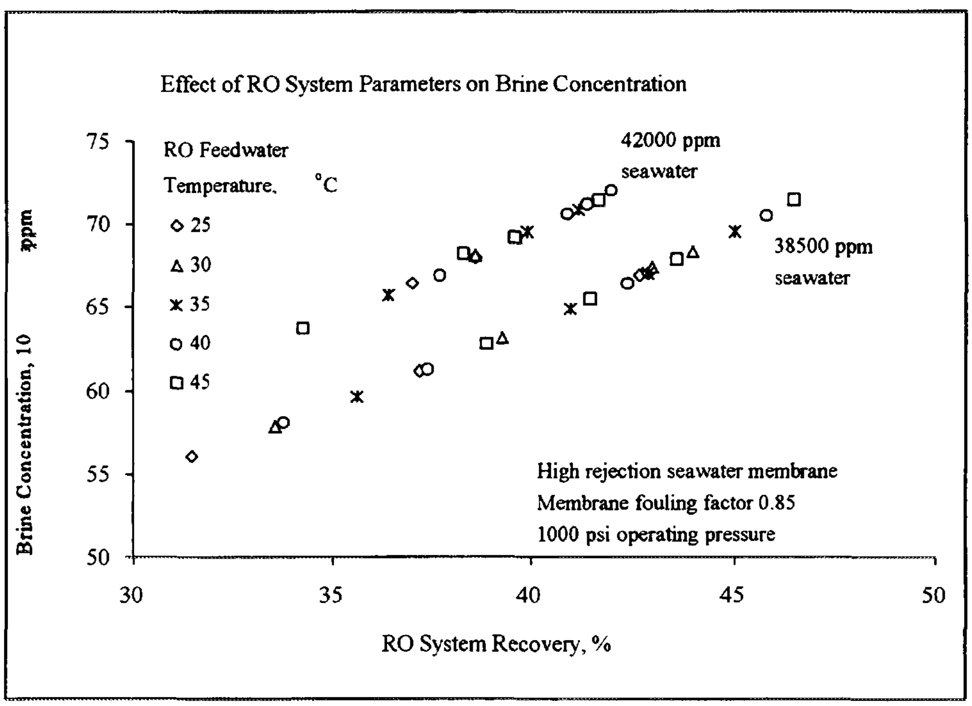

FIG. 1. Effect of RO system parameters on brine concentration

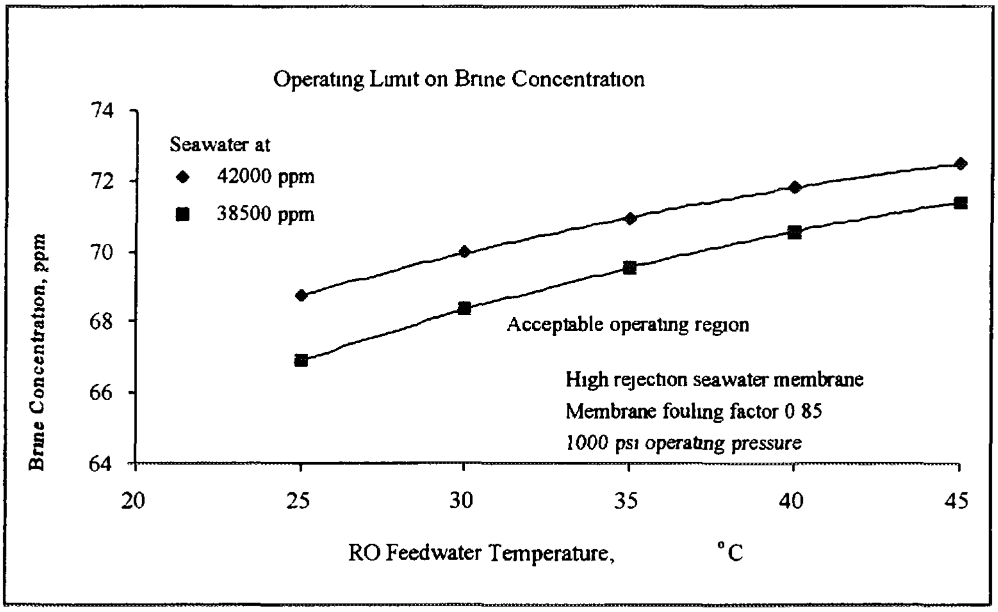

FIG 2 Operatıng lımıt on brıne concentratıon

feedwater reaches temperatures in the range of 35-45°C (45°C is the current operating temperature limit defined by the manufacturer for the membrane used in this analysis) operation with RO system parameters which fall to the right of these limit lines will ensure satisfactory performance Operation with RO system parameters which fall to the left of these limit lines exceeds membrane performance limitations and is likely to result in system performance degradation and possibly premature membrane failure This is of particular interest in the regions of north africa and the middle east, where relatively high ambient seawater temperatures prevail, as it illustrates that the economic benefits of feedwater preheat can stıll be realızed even where average ambient seawater temperatures reach 25-30°C

The Egypt applications study

An applications study [3] encompassing a technical and economic evaluation has been carried out for a Candesal nuclear desalination/cogeneration system located at the el dabaa site in egypt This site was selected for the applications study because it has been qualified as a nuclear site and is under consideration as a potential site for a CANDU 6 reactor Two cases were evaluated in order to consider a range of water production capabilities one in which the full reactor condenser cooling flow was used as input to the RO system, and one in which only about a quarter of the flow was used The system design was carried out in accordance with the approach described above The design analyses used a 9Cc preheat, as that ıs representative of the condenser cooling water δt for the CANDU 6 under consideration for El Dabaa The economic evaluation was carried out in accordance with the assumptions and methods used by the international atomic energy agency (IAEA) in their evaluation of the technical and economic viability of nuclear desalination [4,5]

The results of the study indicated that for a design capacity of 240,000 m^3/d the levelized cost of potable water is about $0 70US/$m^3$ For a potable water production capacity of 1,100,000 m^3/d, corresponding to the full condenser cooling water flow, the cost is essentially the same, dropping slightly to $0 69US/$m^3$ These figures represent a cost reduction of approximately 13% relative to the cost of water produced by a reference plant without preheat or design optimization The similarity in water price over the wide production range is expected, since in both cases the full benefit of preheat and desıgn optimization is realized

The Egypt applications study concluded that the Candesal system "provides a readily available and economically attractive solution which meets both of these needs (water and electricity) without contributing to the ever-increasing global pollution problem. It offers a safe, reliable, proven source of electricity coupled with a well established desalination technology. This combination provides a cogeneration system capable of producing both water and electricity in proportions which can be optimized to satisfy client requirements."

Application to other energy sources

As previously noted, the initial Candesal development work was carried out for large scale water production systems using the CANDU reactor as an energy source. However, it became apparent as the development work progressed that the principles of design optimization and waste heat utilization being applied to large scale nuclear desalination/cogeneration systems are equally applicable to large fossil fueled power stations and to smaller scale systems based on small reactors or conventional energy sources. Engineering studies have demonstrated that this is the case, and that the improvements in water production efficiency, energy utilization, fuel consumption and water production costs with small scale systems can be expected to be on the same order of magnitude as those for the very large nuclear desalination systems.

Diesel generators as an energy source

For smaller scale systems using a diesel generator as the energy source, the process flow is essentially the same as for larger systems. The primary difference is that instead of using condenser cooling water, the waste heat is utilized through the diesel's jacket cooling water and exhaust gas heat recovery systems. With these small scale systems, as with the much larger systems, the optimum performance improvements are found to occur with cooling water flow rates which give about 10-15°C temperature rise, and with use of the full preheated cooling water flow stream as feedwater to the desalination system.

Operating in a cogeneration mode, these small systems using diesel generators require about one quarter to one third of their electrical supply for water production. The rest is available for sale to the grid, or to offset the cost of purchased power for other uses. A study has been done for a 435 m^3/d plant in which the savings in the cost of water production due to feedwater preheat was evaluated as a function of the difference in the cost at which electricity could be purchased from the grid and the cost at which it could be generated. Even when the cost of generated electricity was the same as that of purchased electricity, the savings in water production costs due to the availability of waste heat from the diesel generator to provide preheated feedwater exceeded 10% where purchased power exceeded the cost of generated electricity by only $0.01/Kw-hr a cost savings of over 15% was realized in the production of potable water. These results, which are quite consistent with those obtained from much larger energy sources, are shown in figure 3.

Gas turbines as an energy source

Another interesting application has recently been developed in which the energy source for desalination is derived solely from the exhaust gas discharged from a gas turbine. Recognizing the importance of cogeneration as described above, the system uses an exhaust gas heat recovery boiler to produce steam. The steam is used in a steam turbine to generate electricity, and the condenser cooling water flow for the steam cycle is used as feedwater for the RO system. As an example, preliminary analyses were carried out for a 20,000 shaft horsepower gas turbine assumed to be used as a pumping engine. The thermal energy recovered from the exhaust gases of this turbine was sufficient to allow the production of about 2000 m^3/d of potable water using an optimized RO system drawing electricity from the turbo-generator. In addition, approximately 2 MWe of electrical energy

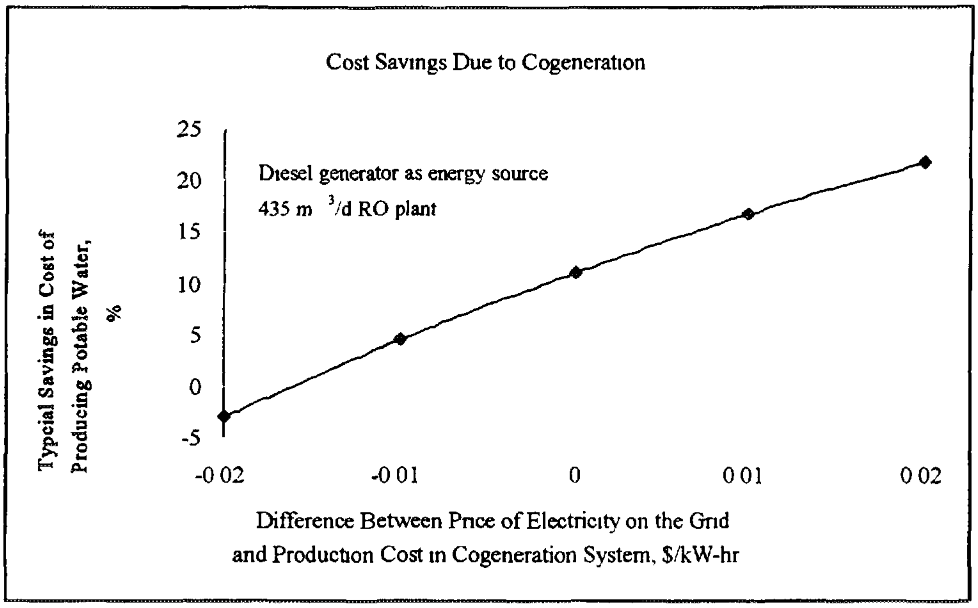

FIG. 3. Cost savings due to cogeneration

was available for distribution to the electrical supply grid. Because the energy to operate the desalination system and provide the preheat necessary for optimized performance is obtained as a free resource, this design results in extremely attractive water production costs [6].

Small nuclear reactor as an energy source

In remote regions or small communities which do not require the large scale water and electrical production capacities provided by a CANDU based system, but where nuclear energy still offers attractive advantages as an energy source, the Candesal design RO design process can be applied to small reactors. As an example, a preliminary design study has been carried out [7] in which the RO design techniques described above have been applied to a cogeneration system based on the russian federation's KLT-40 reactor design. As a base case, an RO system design was established which did not take advantage of preheat or design optimization. This base case system produced 80,000 m^3/d of potable water and about 50 Mw of electricity. Three design cases were then analyzed. one in which the only change was the use preheated RO feedwater, and two in which various degrees of design optimization were applied. In all cases the feedwater flow rate remained constant, as did the pumping power required and hence the amount of electricity delivered to the grid Water production rates at this constant feed flow rate showed the expected increases due to feedwater preheat and design optimization Potable water production rates of 88,400 m^3/d, 90,400 m^3/d and 92,900 m^3/d were achieved for the cases of preheat, preheat plus moderate design optimization and preheat plus a more highly optimized design These correspond to increases in water production rate, and hence decreases in unit water production cost, of about 10%, 13% and 16%, respectively.

Regional benefits as a basis for industrial growth

In addition to helping meet the basic humanitarian need for an adequate supply of fresh water, a fundamental component of the Candesal philosophy is a technology transfer program aimed at establishing a complete local capability for the design, fabrication, operation and maintenance of cogeneration facilities. Through a well defined and logical technology transfer program, the necessary technologies are integrated into a nation's industrial capability and infrastructure, thus preparing local industry for the long term goal of manufacturing large scale, economical and environmentally benign desalination facilities. This positive contribution to national and regional development results from a program of industrial growth benefits, technology transfer, job creation, and export development. In addition, the Candesal system can effectively serve to stabilize international relations in regions which are experiencing critical shortages of potable water This could be particularly true in the middle east, where water shortages are already quite severe and are a source of tension amongst a number of countries.

The design's application to smaller systems permits the early introduction of the technology into a developing industrial base through the implementation of a series of small scale plants, gradually increasing in capacity and design sophistication. The longer-term goals of a comprehensive development program include demonstrating that nuclear desalination can be successfully incorporated as one element of a national and international cooperative program to develop energy sources, water resources, and foster industrial growth, while meeting established safety, reliability and environmental objectives.

With specific regard to the Candesal nuclear system, the CANDU reactor has been designed to enhance the ease of technology transfer to the purchaser. It was designed specifically to facilitate installation in modestly industrialized regions where technology transfer programs can be effectively implemented in order to enhance the local industrial infrastructure. CANDU does not require the advanced technology necessary for enrichment, nor does it require the heavy industry associated with large pressure vessel fabrication.

The Candesal desalination/cogeneration system allows for the associated technologies to be easily acquired and applied in developing regions [8]. since a large part of the design and construction work can be done locally, the technology transfer program and the high degree of regional involvement in all aspects of a project result in the development of technological capabilities over a wide variety of disciplines. These include the many aspects of plant design and engineering, normal and emergency operating procedures, test and maintenance procedures, operations and maintenance skills, and experience.

The industrial benefits arising from the installation Candesal systems span the full range of economic sectors and will assist the development of a regional industrial infrastructure as well as promote international export markets in the technology The design, construction and operation of a desalination plant will create a large number of jobs, in a variety of sectors from high technology fields through to support services. Additionally, the benefit of having increased availability of both electrical power and fresh water, at lower costs, cannot be underestimated in its impact on the further development of the industrial base. By making these two key industrial resources readily available to the market, a true stimulus for growth and development is achieved.

Environmental impact

Desalination is an energy intensive process, and any technological advances which improve the efficiency of water production result directly in a reduction in the energy consumption per unit of water produced. Such reductions have the dual benefit of improved resource utilization and improved economics. For large scale systems using nuclear reactors the economic and environmental benefits are clear. For smaller scale systems using other energy sources the improvement in resource use reflects itself in terms of reduced fuel consumption for a given water production capacity. With respect to the environment, it means reductions in both resource depletion and production of environmental emissions.

The design and performance optimization analysis tools provide additional confidence in the long term development of large scale nuclear and conventional desalination systems. The environmental impact of the transition from conventional to nuclear power systems as the energy source for water production is very large and positive In many regions of the world, the demand for potable water production is expected to triple over the next two decades Even at current production rates (12-15 million m^3/d), the global production of potable water by conventional desalination results in environmental emissions of about 30 million t/yr of CO_2, 300,000 t/yr of SO_2 and 90,000 t/yr of NO_x Such emissions will not be present with a nuclear energy source Hence, in addition to the economic benefit, an immense environmental benefit accrues in the long term

Conclusion

The use of nuclear power as a source of energy for potable water production is both technically viable and economically competitive Candesal's system integration and design optimization techniques provide significant improvements in the efficiency of energy use and the economics of water production These features will allow nuclear desalination to play an important role in the solution to the growing global demand for water and electricity

The Candesal desalination/cogeneration system provides a readily available and economically attractive solution which meets the increasing global demand for both water and electricity It offers a safe, reliable, and proven source of electrical energy coupled with a well established desalination technology The system is designed for the cogeneration of electricity and fresh water, using the waste heat from the electrical generation process, in proportions which can be optimized to satisfy local or regional requirements

In addition to the economic advantages, the benefits accruing from the installation and operation of a Candesal desalination/cogeneration system are many They arise because the system provides a contemporary, unique approach to solving the increasingly severe problem of water and energy shortages In helping to meet the basic humanitarian need for an adequate supply of potable water, the Candesal system is environmentally benign and serves to mitigate the impact of power production on the ever-increasing global pollution problem In addition, the system contributes positively to a national or regional economy through cogeneration of electricity, job creation, industrial benefits, technology transfer, and the potential export of both technology and products through the continued operation and development of the system.

These results are extremely positive Through a combination of design integration and optimization, significant improvements in water production efficiency and reductions in desalination plant capital costs have been realized The result is a reduction in levelized water production costs The costs for a facility of this type are highly site specific, depending on seawater conditions, design requirements, and operating and maintenance strategies Nevertheless, the results of this work demonstrate the benefits of design integration and optimization, and suggest that substantial cost savings are achievable

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HTR PROCESS HEAT APPLICATIONS, STATUS OF TECHNOLOGY AND ECONOMICAL POTENTIAL

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Abstract

The technical and industrial feasibility of the production of high temperature heat from nuclear fuel is presented. The technical feasibility of high temperature heat consuming processes is reviewed and assessed. The conclusion is drawn that the next technological step for pilot plant scale demonstration is the nuclear heated steam reforming process. The economical potential of HTR process heat applications is reviewed: It is directly coupled to the economical competitiveness of HTR electricity production. Recently made statements and pre-conditions on the economic competitiveness in comparison to world market coal are reported.

Keywords:
High Temperature Reactor, Process Heat Applications, Co-generation, Heat Loops, Nuclear Long Distance Energy, Coal Refinement, Economical Potential, Economical Competitiveness in Comparison to World Market Price Coal.

HTR Process Heat Applications, Status of Technology and Economical Potential

1. HTR for High Temperature Heat Production

1.1. In summary: The technical and industrial feasibility of the production of high temperature heat has been proven by the experimental HTR plant AVR in Jülich and the demonstration plant THTR-300 in Hamm/Schmehausen, Federal Republic of Germany, as well as with the plants Dragon, Peach Bottom and Fort St. Vrain in Great Britain and in the United States. The AVR in Jülich operated for more than 10 years with a mean helium outlet temperature of 950 °C.

1.2. In detail on the temperature niveau, on reactor types and projects:

1.2.1. The High Temperature Reactor, HTR, belongs to the family of the gas-cooled reactors. Its development and demonstration was originally oriented towards electricity production. The big advantage in comparison to water-cooled reactors with the possibility to produce lifesteam of conventional conditions for conventional steam turbine processes. For these purposes a mean helium outlet temperature of 700 to 750 °C is sufficient; therefore the demonstration plants THTR-300 and Fort St. Vrain were operated at that point.

1.2.2. The HTR experimental plant AVR in Jülich (AVR = Arbeitsgemeinschaft Versuchsreaktor, Joint Working Group Experimental Reactor) is an HTR with pebble bed core, fig. 1. It operated in total for 21 years, and for more than 10 years at a mean helium outlet temperature of 950 °C very successfully. The heat is used in the steam generator for the production of lifesteam with 515 °C; the heat is transferred via the "shortest hot gas duct of the

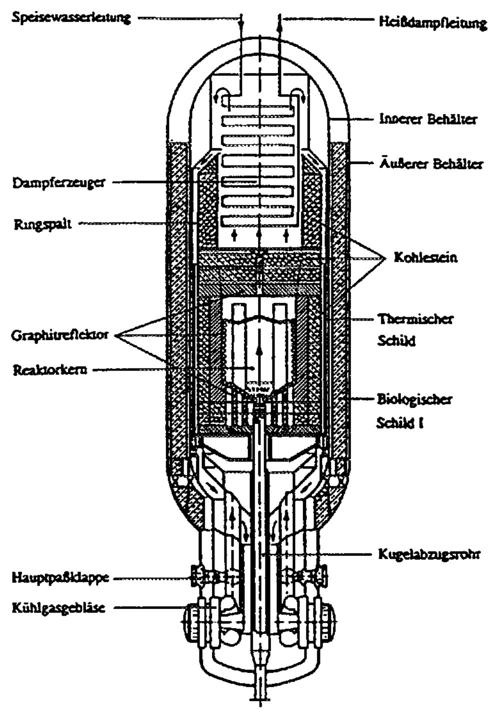


FIG. 1. AVR Jülich Pebble Bed HTR
Mean outlet temperature 950°C

world". The operation of the AVR was terminated at 31. December 1988, as planned a few years before, when the THTR-300 had started operation. Right now (October 1995) the discharge of the fuel pebbles from the core is in function.

1.2.3. The demonstration plant THTR-300 in Schmehausen/Hamm (THTR = Thorium HTR pebble bed core, 300 MWe) was in operation for about 3 years, and the project was terminated in summer 1989 after some technical difficulties mainly for political reasons. Valuable experiences were gained with respect to the in-core-shutdown rods, the hot gas ducts and the discharge systems. Right now (October 1995) the discharge of the fuel pebbles from the core has been finished.

1.3. In extension to co-generation:
1.3.1. Nuclear process heat applications at lower temperature levels have been realized in a number of plants mostly in the form of co-generation. Examples are agro-industrial applications in Canada and district heat systems in Russia, lit. BARNERT-KRETT-KUPITZ-1991.

1.3.2. The HTR plants mentioned above were operated for pure electricity production, and not in co-generation.

2. High Temperature Heat Consuming Processes

2.1. In summary: The technical feasibility of high temperature heat consuming apparatus and components, in particular the helium-heated steam reformer, the helium-heated gas-generator for the process of "steam coal gasification, SCG", and the intermediate heat loop has been proven by experimental facilities up to the pilot plant scale. In addition the technical feasibility of the process of "Hydrogen Coal Gasification, HCG" has been proven by experimental facilities in the pilot plant scale. This was done in the HTR process heat application projects in the Federal Republic of Germany.

2.2. In detail on the various processes, the apparatus and components:

2.2.1. From a scientific point of view there is a clear ranking in the following high temperature heat consuming processes and apparatures; the ranking is, fig. 2:

1) The helium-heated steam generator (as a part of a steam turbine cycle),

2) the helium-heated steam reformer (also called methan-reformer), and

3) the helium-heated steam coal gasification, SCG, gas-generator.

Step 1) is the base, step 2) is more complicated because of the gaseous catalytic chemical reaction (and step 3) is even more difficult because of a (non-catalytic or catalytic) chemical reaction between steam and pulverized coal, a solid.

2.2.2. The helium-heated steam reformer has successfully been tested in semi-technical scale in the EVA plant in Jülich (EVA = Einzelrohr-Versuchs-Anlage = Single Tube Experimental Plant) and in pilot plant scale in the large scale experimental plant "EVA/ADAM-II" in Jülich in two different designs the "baffle orifice-bundle", lit. NFE-1985 and in the "counter current bundle", lit.: PNP-1992, and appendix 1, as well as lit. BARNERT-1995-1. In the large scale

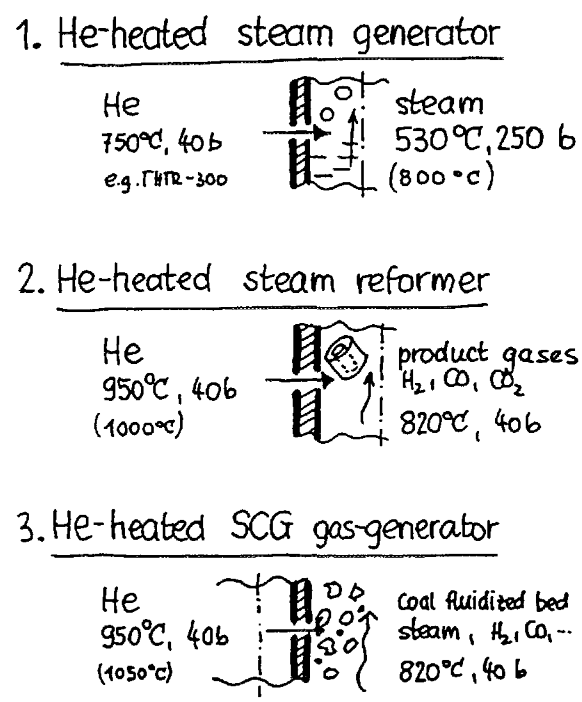


FIG. 2. High T Heat Processes
Ranking with resp. to complexity

experimental facility "EVA/ADAM-II" the 950 °C helium was provided by electric heating. In the project work the helium-heated steam reformer was foreseen to be heatd by primary helium (not by secondary helium from the intermediate heat loop).

2.2.3. The helium-heated steam coal gasification, SCG, gas-generator for the process of "steam coal gasification, SCG" has been tested in the semi-technical plant with a throughput of 200 kg/h bituminous coal successfully. The heat was provided to the fluidized bed of the steam gas generator by emerged heat tranfer bundles, being heated by 950 °C from an electrical source, see appendix 1 and lit. BARNERT-1995-1. Originally the helium-heated steam gas-generator was foreseen to be heated by secondary helium (with an intermediate loop); recent studies indicate that it should be possible also to heat it by primary helium, because it is expected, that coal slurries can cross the wall of the confinement.

2.2.4. The intermediate heat loop with the intermediate heat exchanger and other components, e.g. valves, has been tested in the large experimental facility "KVK" in Bensberg (KVK = Komponenten-Versuchs-Kreislauf, Component Experimental Loop) in the pilot plant scale (10 MW) for two variants of the intermediate heat exchanger - the HELIX-variant and the U-TUBE-variant very successfully. Also in this experimental plant the 950 °C helium was provided by electrical heating. Originally the intermediate heat loop was thought to be useful for a better separation of the primary circuit of the nuclear plant and the circuits of the coal gasification plant, but later, it has been shown that an intermediate heat loop does also have disadvantages and that it might not be necessary. The tested valve has the task of an isolation valve in case of a rupture in the intermediate loop.

2.2.5. The process of "Hydrogen Coal Gasification, HCG" in its hydrogenating chemical reaction is an exotherm process, has been tested in the semi-technical and the pilot-plant scale very successfully, lit. BARNERT-1995-1. The necessary hydrogen is produced in a steam reformer step, and this is the way of the coupling of the required HTR-high temperature heat. In total, the overall process is a two-stop process, this may be an economical disadvantage.

2.2.6. The before mentioned R & D and demonstration work was performed of the two projects "Nukleare Fernenergie, NFE, (Nuclear Long Distance Energy)", lit. NFE-1985 and "Prototypanlage Nukleare Prozeßwärme, PNP, (Prototype Plant Nuclear Process Heat)", lit. PNP-1992. The NFE-project cost about 300 million Deutschmark, the PNP-project finally summed up to about 1.7 billion Deutschmark: So the overall efforts were 2 billion Deutschmark, being equivalent to about 1.4 billion US $. Both projects were done in strong cooperation between nuclear industry, coal industry and the Research Centre Jülich, KFA.

2.2.7. A large number of processes for high temperature heat applications with the HTR has been proposed and assess from co-generation for electricity and district heat to water splitting, lit. BARNERT-SINGH-1994.

2.3. In extension on water splitting:

2.3.1. In cooperation with the European research centre ISPRA and with funding from the European Community a research programme was performed on the splitting of water with thermochemical cycles, in particular the Westingshouse-Sulfuric Acid Cycle. In the sulfuric acid process the heat consuming step is the splitting of sulfuric acid.

2.3.2. For the splitting of sulfuric acid bench scale experiments were performed with 950 °C heat (from a furnace) and at 40 bars pressure in pressurized quarts-apparaturs successfully at KFA Jülich.

3. The Coupling of the High Temperature Heat Source and the Consumer

3.1. In summary: For the demonstration of the coupling of a nuclear high temperature heat source and a consuming process two projects - the projects - "AVR-II" and "AVR-reconstruction" - were performed, but not realized in the Federal Republic of Germany. According to the plans the first nuclear demonstration of the coupling is foreseen to be realized in the projects "High Temperature Engineering Test Reactor, HTTR" at JAERI, Oarai, Japan, and "HTR-Test Reactor, HTR-10" at INET, Beijing, China.

3.2. In detail on the coupling projects in FRG:

3.2.1. The 1st project for coupling as the project "AVR-II" with a modular type HTR of 50 MWt and with the process of steam reforming in the primary circuit. It was proposed to select KFA Jülich as the side. The project was not realized, mainly due to the lack of funds.

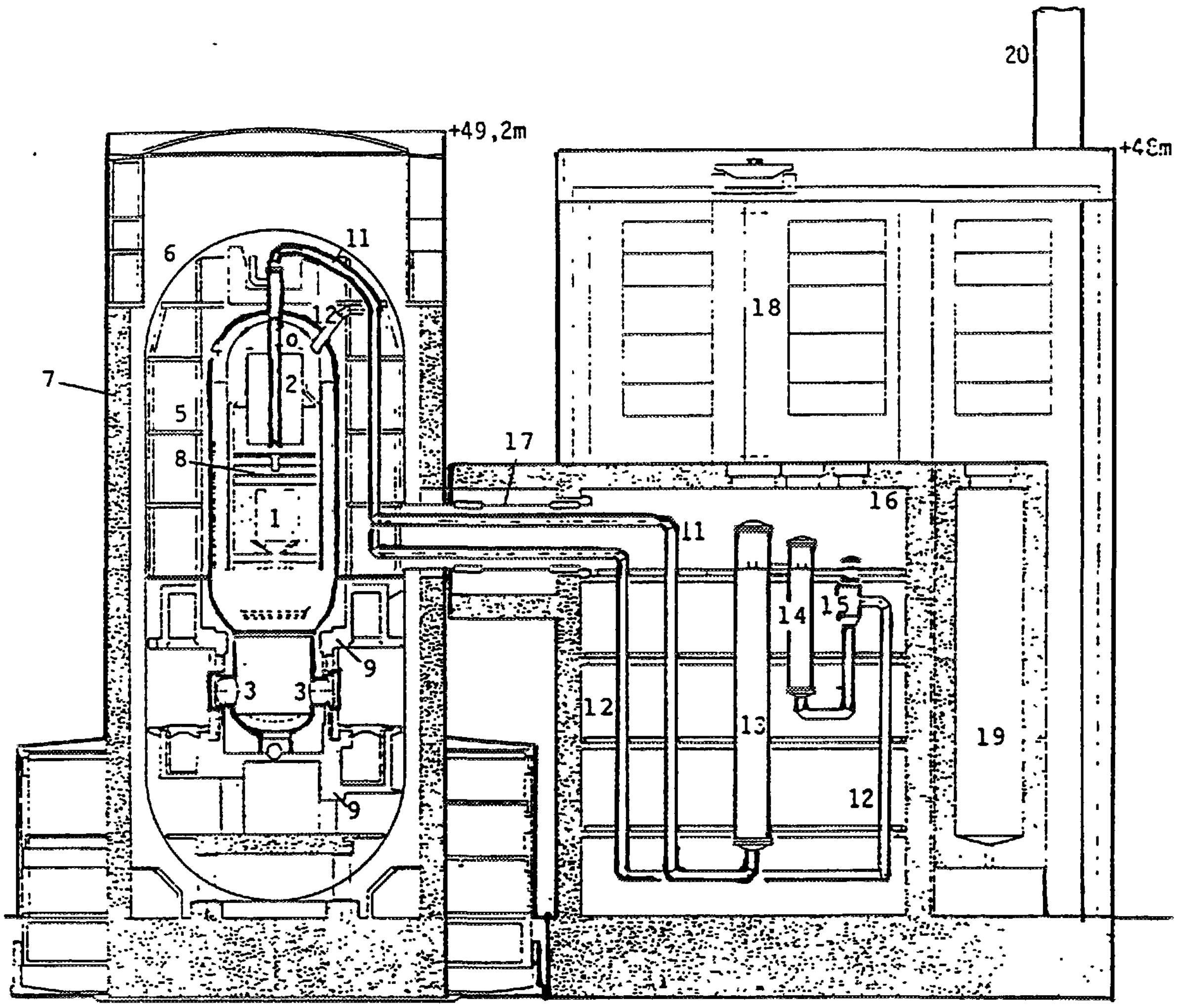
3.2.2. For this reason the project "AVR-reconstruction" was performed afterwards, making use of the existing AVR and reconstructing it from an electricity producing plant into a process heat demonstration plant with a thermal loop power of 10 MW, operating in co-generation of heat and electricity, at AVR-side, close to KFA, Jülich, fig. 3. But also this project was not realized, to some extend already because of political difficulties.

3.2.3. The German HTR process heat projects have been terminated without the demonstration of the nuclear coupling after the end of the oil price crises.

3.2.4. According to the respective R & D and demonstration programs the coupling of a nuclear high temperature heat source and an appropiate consumer will first in the world be demonstrated in the projects "High Temperature Engineering Test Reactor, HTTR" at JAERI in Oarai, Japan and "High Temperature Test Reactor, HTR-10" at INET in Beijing, China.

3.3. In recognition of the experiences on the coupling in the PNP-project:

3.3.1. The R+D+D-work on HTR process heat applications was done in parallel to the bigger efforts for demonstration and market penetration of HTR electricity producing plants. Two



AVR		HOCHTEMPERATUR-PROZESSWÄRMEKREISLAUF	
1	Core	10	Heißgasdurchführung
2	AVR-Dampferzeuger	11	Heißgasleitung
3	2 Gebläse	12	Kaltgasleitung
4	Reaktordruckbehälter	13	Röhrenspaltofen
5	Bühnen	14	Prozeßdampferzeuger
6	AVR-Schutzbehälter	15	Prozeßwärmekreislaufgebläse
7	Reaktorgebäude	16	Prozeßwärmekreislaufschutzgebäude
8	Deckenreflektor	17	Schutzbehälterverbindung
9	ringförmige Betontragstruktur	18	Halle mit Kran
		19	Heiße Zelle
		20	Kamin

FIG. 3. AVR Process Heat Reactor
Project FRG 1983, not realized

vendors have it developed and therefore two types of concepts existed: The HTR-monolith, HTR-1250 (1250 MWt for 500 MWe) and the HTR-Modul (200 MWt for 80 MWe per modul). For both concepts process heat-versions were developed with the mean helium outlet temperature of 950 °C. Both versions had to be adjusted to the two coal gasification processes the steam coal gasification and the hydrogen coal gasification process. Usually there is a surplus of lower temperature heat, that was converted into electricity as a side product. The main product changed due to the market conditions in the various evaluations and assessment, including substitute natural gas SNG (= CH_4), hydrogen H_2, town gas H_2 + CH_4, and methanol CH_3OH.

3.3.2. Conclusion from the experiences in the PNP projects are:

a) Co-generation e.g. the production of the side product electricity, is energetically meaningful , but may be of disadvantage if the price for the electricity is to low.

b) The unit size of the nuclear heat source should not be to large because the unit size of the heat consuming operators, e.g. helium heated steam reformer, is smaller than unit sizes known from nuclear electricity, as steam generators and in particular steam turbines.

c) A proper adjustment between the heat source and the heat consuming apparatus, including steam generators for electricity production, are decisive for the economical result, recycling of mass streams and recuperation of heat must be adjusted to minimum costs, lit. POTENTIAL-1987.

d) For the process of steam reforming as well as steam coal gasification it is meaningful to increase the temperature niveau of the heat vector for 50 or 100 K to a mean outlet temperature of helium to 1 000 °C to 1050 °C.

e) The application of an intermediate heat loop brings only a few advantages, but costs much.

f) The main products are substances, gases or/and liquids, which can carry radioactivity - in contrary to the main product electricity in nuclear electricity production - the so-called production limit needs to be fulfilled (Herstellungsfreigrenze, e.g. 200 pCi/g or tritium).

3.3.3. Within the R & D work to improving and confirm the design and economics and to prepare the market introduction of "nuclear coal gasification techniques", lit. PNP-1992 and PNP-ANHANG-1992 a study on a process heat HTR, called AHTR-500 (AHTR = Advanced HTR, 500 MWt), has been performed for the process of steam coal gasification at KFA Jülich, fig. 4 to 6. The design features are: Increased helium gas outlet temperature of 1 000 °C, increased helium-inlet temperature of 350 °C (to avoid side-product electricity), adjusted thermal output of 500 MWt for two streets of gasification plants, each 250 MWt helium loop power, lower primary pressure to 25 bar (which is preferable for the chemical reactions in the gas generator), primary helium heated gas generator of vertical design in counter current heat transfer arrangement. For the process of steam reforming a similar design of the process heat plant (as in fig. 6) is feasible.

3.3.4. The process heat reactor AHTR-500, fig. 4, can fulfill the modern requirements of catastrophe-free nuclear energy technology because of the low power density of 2.5 MWt/m^3, in minimizing the reactivity response in the case of water ingress, and provided that pebbles and other graphite and carbon structures are coated with silicon carbide to improve corrosion resistance in case of air ingress. The design base incident "heat up" has maximum temperatures of about only 1 400 °C, fig. 5, that means less than design limit 1 600 °C.

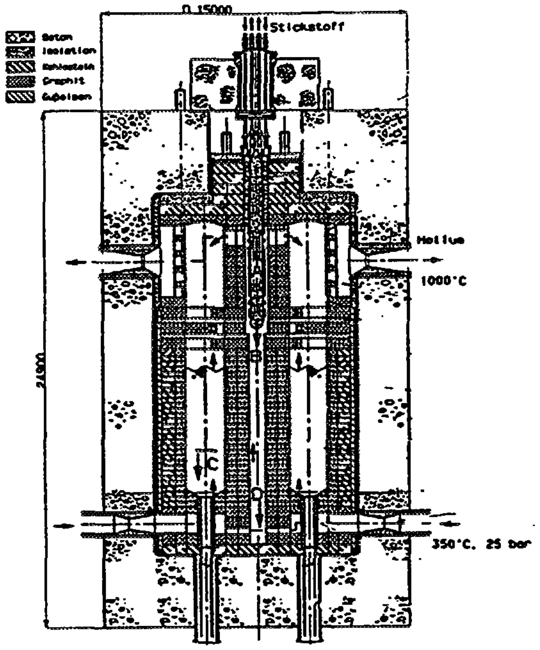


FIG. 4. AHTR 500 Process Heat Reactor General Design T = 350 - 1000 °C

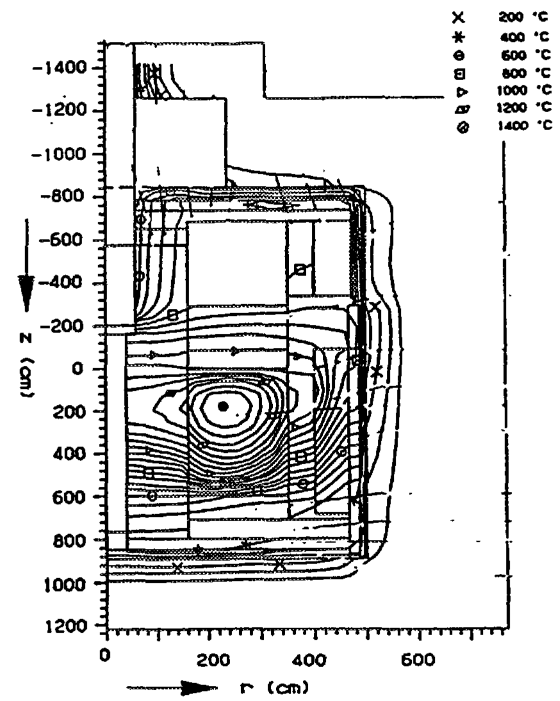
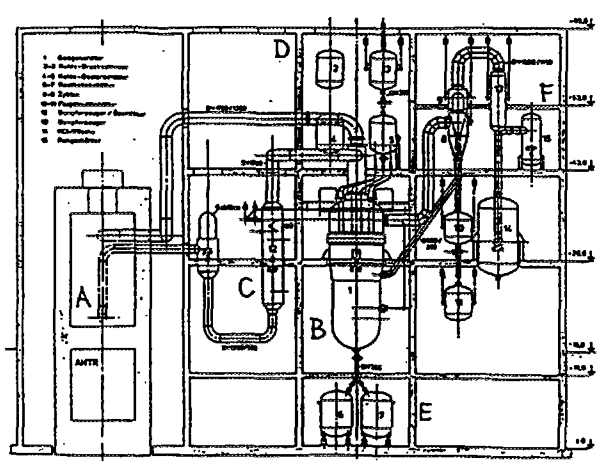


FIG. 5. AHTR 500 Process Heat Reactor Design Basis Incident: Heat Up



A Process Heat Reactor AHTR 500
B Gas-Generator Steam Coal Gasification SCG
C Steam Generator and Super Heater
D Coal Feed System
E Fine Coke or Ash
F Product Gas H_2 CH_4 CO CO_2

FIG. 6. HTR Process Heat Plant Steam Coal Gasification SCG

4. On the Economical Potential of HTR Process Heat Applications

4.1. In summary: Nuclear process heat applications are economically attractive if nuclear electricity production is economically competitive. This applies also to the HTR. A technical answer to the historical cost increases could be: catastrophe-free nuclear energy technology and simplification. Relevant theoretical evaluations have shown that HTR modul power plants could be economically competitive in comparison to world market coal under the assumption of a construction in series of about 800 MWe per year.

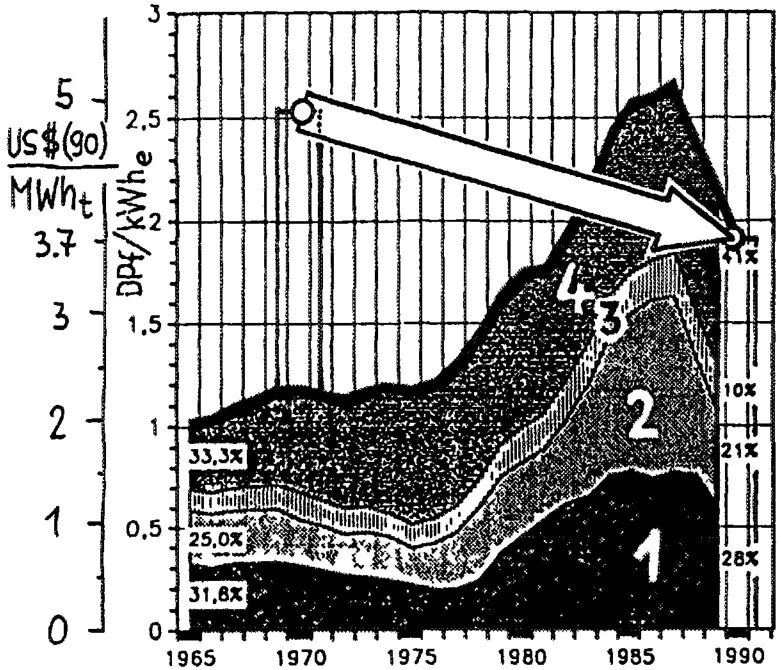
4.2. In detail on experiences from LWR on HTR-modul and conclusions for HTR process heat applications:

4.2.1. In many countries of the world nuclear electricity production has been - and is up to now - a commercial success. To some extend this success was pushed also by the oil price crisis. Question marks have to be put for the future, mainly because of the historical experience of increases of capital costs. Will nuclear electricity be competitive in comparison to world market coal?

4.2.2. The main driving force for economical attractiveness of nuclear energy is the fact that nuclear fuel is by a factor of 3 to 4 cheaper than fossil alternatives. The price of nuclear fuel in FRG is about 3.7 US \$ (90)/MWh_t, equivalent to 1.9 DPf (90)/kWh_e, lit. HANSEN-1993, S. 223, calculated with an efficiency of 31 % for LWR-fuel. The over all trend of the development of the nuclear fuel prices in FRG is a reduction of 25 %, fig. 7. This is an encouraging positive fact for nuclear energy from the historical development.

4.2.3. The price for nuclear fuel of about 3.7 US \$ (90)MWh_t has to be compared to e.g. energy prices to consumers in the European Community in 1990 (average) for industry of steam coal of 13, heavy fuel oil (3.5 %) of 13, and natural gas of (also) 13 US \$ (90)/MWh_t, lit. BARNERT-1995-7, p. 19. For those prices the advantage factor of nuclear fuel compared to fossil fuel is 3.5 (13/3.7). The maximum value of the oil price during the oil price crisis of 40 US \$ (87)/barrel is equivalent to 23,5 US \$ (87)/MWh_t, corrected by the US consumer price index CPI (1990: 130,7; 1987: 113,6; lit.: ALMANC-1992, p. 150) to 27 US \$ (90)/MWh_t. Compared to this maximum value of the oil price the advantage factor of nuclear fuel is even 7.7 (27/3.5).

4.2.4. The negative cost stories, putting a question mark to the economic viability of nuclear energy in comparison to e.g. cheap coal, were produced by the historical development of the capital costs. In FRG, for 20 PWRs and BWRs, the capital cost increased by a factor of about 4 from 600 to 2 500 US \$(90)/kWe in two decades of market penetration with much competition between vendors, fig. 8. This factor of 4 is a real factor (excluding inflation), because the actual figures have been adjusted by the consumer price index CPI of FRG (1990:



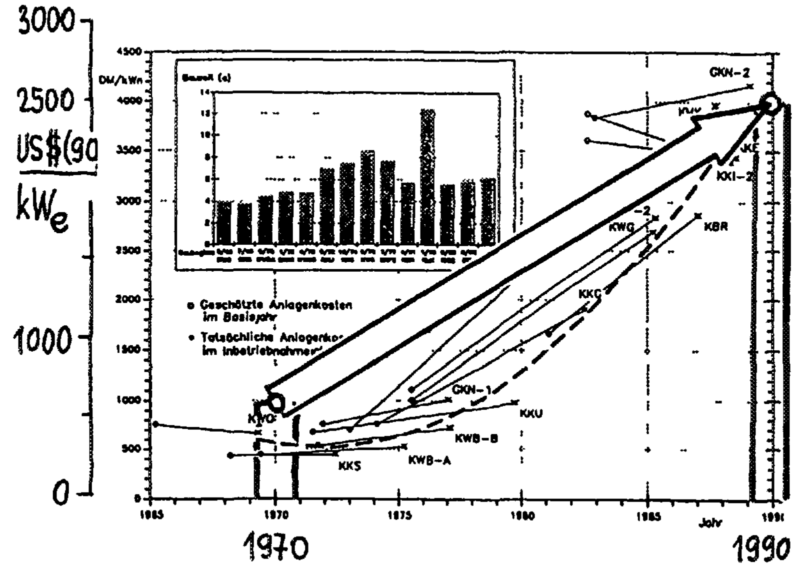
Actual Values:

1 Uranium, incl. Conversion
2 Separation Work
3 Fuel Fabrication
4 Disposal

Real Values:

○ Adjusted with CPI, FRG
1990: 100 ; 1970: 47

FIG. 7. Nuclear Fuel Price, FRG
Hist. Dev · Reduction by 25 %



Actual Values:

◇ Estimated Plant Costs in year of order
✳ Real Costs in year of start of operation

Real Values:

○ Adjusted with CPI, FRG
1990: 100 ; 1970: 47

FIG. 8. Nuclear Capital Costs, FRG
Hist. Dev. Increase by factor 4

100, 1970: 47; lit. AKTUELL-1995, S. 250; -1988, S. 143; -1987, S. 148) to the value of money of 1990 in fig. 8; in actual money the factor of the increasement of capital cost is about 8.

4.2.5. For the reason of the increase of the capital cost the utilities in the US and in Europe have formulated goals (limits) for the capital costs of future nuclear plants. The European Utility Requirements, being in the state of preparation this year, formulated the goal for the capital cost C = 1 100 ECU/kW_e (ECU = European Currency Unit), lit.: BRÖCKER-ESSMANN-1995, S. 83, equivalent to 1447 US $ (95)/kW_e (1,8681 DM/1 ECU x 1 US $/1,42 DM, Oct. 1995).

4.2.6. The question is: what are the reasons for this immense increases of capital costs, recognizing that no technical progress in the temperature niveau of the produced heat and in the efficiency to produce electricity has been achieved? Obviously the reasons are the nuclear controversy, the reduced acceptance of large scale risks in the public and in the utilities, the build-up of a big bureaucracy, the fact that nuclear energy became a political issue after Chernobyl. In summary: the reason is the lack of safety.

4.2.7. Discussions of these question in the Federal Republic of Germany finally led to the 7th amendment of the Atomic Energy Act, lit. ATOMIC-ENERGY-ACT-1994, see appendix 2, with the requirement "no impact outside of fence".

4.2.8. A technical answer to this situation could be: Catastrophe-free nuclear energy technology and thereby simplification by omittance of costly safety devices, which are not needed anymore.

4.3. Recent cost statements on the HTR-modul:

4.3.1. In a hearing of the inquiry emission "protection of the atmosphere of the earth" of the German Parliament, lit. LIPPOLT-1993, the question "which production cost of electricity can be expected with the HTR?" has been answered by Mr. A. Hüttl, president of the board of directors, Energy Production KWU and member of the board of directors of Siemens AG with the following statements:

4.3.1.1. "Relevant theoretical evaluations have shown that HTR-modul power plants could be economically competitive in comparison to import coal (that is cheap world market coal) under the assumption of a construtcion in series of about 800 MWe per year, this is equivalent to 4 power stations with each a twin modul". And it was added:

4.3.1.2. "The pre-condition for the market penetration of the HTR-modul of in total some billion Deutschmarks for a demonstration plant, for a large scale supply of fuel elements, as well as for the production facilities for the series production, should be earned by the construction and operation of a number of larger HTR module power plants. This requires first of all the establishment of the necessary security of investment". The last sentence was, of course, ment for FRG.

4.3.2. In contrary to these positive statements it must be reported from FRG that right now (October 1995) the HTR modul is still in "hibernation", political efforts to reach a consensus on the "security of investment" failed.

4.4. In detail on the economical potential of process heat applications:

4.4.1. The primary product of the conversion of nuclear fuel in all types of nuclear reactors is heat. For electricity production this heat is converted into electricity via a thermodynamical cycle in the same way as in non-nuclear thermal powerstations. Therefore the statement can be made: Nuclear process heat applications are economically attractive if nuclear electricity production is economically competitive.

4.4.2. This also applies to the HTR, because high temperature heat is attractive for electricity production, e.g. in combi-cycles, lit. BARNERT-KUGELER-1995, as well as for process heat applications.

4.4.3. The main driving force for studies, R+D programs and the large experimental demonstrations for HTR process heat applications in FRG has been the large market of non-electrical secondary carriers, the oil price crises and the huge resources of bituminous coal (which has been the base for the industrialization) and of lignite. But it turned out that it is difficult to reach competitiveness against the established non-electrical secondary energy carriers steam coal, heating oil, motor fuel, fuel gases and others more.

4.4.4. In the final assessments on the competitiveness of process heat application for coal gasification in "R+D Work to Improve and Confirm the Design and Economics and to Prepare the Market Introduction of Nuclear Coal Gasification Technology", lit.: PNP-1992 and PNP-ANHANG-1992, it was concluded that in the best lay-outs nuclear processes had an competitiveness advantage of 25 % compared to conventional processes, but that this was not competitive in comparison to conventional fuel.

4.4.5. The CO_2-climate change problem has up to now not gained enough public interest to become a driving force for more nuclear applications; but this may change in future. The reduction of the product specific emissions of carbondioxide CO_2 and methane CH_4 by HTR coal refinement is in the order of about 25 %; but not more. This is a drawback. Therefore it has been proposed to use biomass, and even garbage as a source for the carbon atom for the production of liquid secondary energy carriers, e.g. methanol, lit. BARNERT-1995, -7 and -4.

5 Summary and Conclusion

5.1. Total summary: The technical (and industrial) feasibility of the production of high temperature heat from the HTR and of a number of high temperature heat consuming processes and apparatus has been demonstrated. The demonstration of the coupling needs to be done. A technical answer to the historical cost increases of nuclear energy could be: catastrophe-free nuclear energy technology and simplification.

5.2. Detailed summary from the previous chapters:

5.2.1. The technical and industrial feasibility of the production of high temperature heat has been proven by the experimental HTR plant AVR in Jülich and the demonstration plant THTR-300 in Hamm/Schmehausen, Federal Republic of Germany, as well as with the plants Dragon, Peach Bottom and Fort St. Vrain in Great Britain and in the United States. The AVR in Jülich operated for more than 10 years with a mean helium outlet temperature of 950 °C.

5.2.2. The technical feasibility of high temperature heat consuming apparatus and components, in particular the helium-heated steam reformer, the helium-heated gas-generator for the process of "steam coal gasification, SCG", and the intermediate heat loop has been proven by experimental facilities up to the pilot plant scale. In addition the technical feasibility of the process of "Hydrogen Coal Gasification, HCG" has been proven by experimental facilities in the pilot plant scale. This was done in the HTR process heat application projects in the Federal Republic of Germany.

5.2.3. For the demonstration of the coupling of a nuclear high temperature heat source and a consuming process two projects - the projects - "AVR-II" and "AVR-reconstruction" - were performed, but not realized in the Federal Republic of Germany. According to the plans the first nuclear demonstration of the coupling is foreseen to be realized in the projects "High Temperature Engineering Test Reactor, HTTR" at JAERI, Oarai, Japan, and "HTR-Test Reactor, HTR-10" at INET, Beijing, China.

5.2.4. Nuclear process heat applications are economically attractive if nuclear electricity production is economically competitive. This applies also to the HTR. A technical answer to the historical cost increases could be: catastrophe-free nuclear energy technology and simplification. Relevant theoretical evaluations have shown that HTR modul power plants could be economically competitive in comparison to world market coal under the assumption of a construction in series of about 800 MWe per year.

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APPENDIX 1

Research Centre Jülich GmbH, KFA
Institute for Safety Research and Reactor Technology, ISR
Prof. Dr.-Ing. Heiko Barnert

Objectives and Results of the Project "Protoype Plant Nuclear Process Heat, PNP"

The PNP-Project was founded by the three partners Bergbau-Forschung, Rheinische Braunkohle and KFA Jülich in 1972. In 1976 the actual contract was made and two additional partners from reactor industry joint the co-operation. GHT Gesellschaft für Hochtemperaturreaktor-Technik GmbH of the Siemens Konzern and Hochtemperatureaktorbau GmbH, HRB, of the former BBC Konzern.
The PNP-Project was terminated 1992, June 30. Partners were

Forschungszentrum Jülich GmbH, KFA
former
Kernforschungsanlage Jülich GmbH (KFA)
Jülich

GHT Gesellschaft für Hochtemperatur-Technik mbH
Bergisch-Gladbach

Hochtemperatur-Reaktorbau GmbH
Mannheim

DMT Gesellschaft für Forschung und Prüfung mbH
former Bergbauforschung
Essen

Rheinische Braunkohlenwerke AG
Köln

1. To the Objectives

In the contract on the co-operation between Industrial Companies and the Research Centre Jülich GmbH, KFA in the frame of the project "Prototype Plant Nuclear Process Heat, PNP" the following has been fomulated on the objectives:

a) to develop a high temperature reactor for high values of the gas outlet temperature (950°C) for the application as a source for process heat to be applied in processes of coal refinement, including the components for heat transfer, being necessary for this purpose and

b) to develop and to demonstrate components and pilot plants for the process of steam gasification of coal and for the process of hydrogenating gasification of coal.

2. Results in Summary

A) The technical feasibility of a Nuclear Process Heat Plant for the Refinement of coal has been established. The main parts "High Temperature Reactor for Process Heat Production" and "Refinement Plant for Coal" have sufficiently been developed and demonstrated for the realization of a prototype plant. This means: the technical objectives of the project have been achieved. Nevertheless the costs of the plant are guessed to be much higher than originally been expected.

B) The economical competitiveness of a nuclear process heat plant for the refinement of coal is in comparison to the conventional alternatives of coal refinement in principle achievable, including the realizability of potentials of improvement. But the economical competitiveness of the refinement of coal in total does not exist any more under the market conditions since the end of the oil price crisis.

C) The process of the refinement of coal using nuclear energy contributes to the fundamental goals "security of energy supply", "diversification of the resources" and "environmental friendliness".

Remark:
Remaining work to be done in the future: Definition of reference concepts, R & D work for ensuring of the technical feasibility as well as planning, construction and operation of a pilot plant for process heat application for refinement of coal.

APPENDIX 1 (cont.)

Results in Detail

1. The development of the High Temperature Reactor for the production of high temperature heat with high values of the outlet temperature of the coolant (950 °C) for the application as source for process heat is conceptually accomplished to a very large extend: Several concepts of reactors have been established ready for construction

2. The fuel element being envisaged for application in the HTR for process heat production: "Pebble type fuel element, low enriched fuel, coated particle with TRISO coating", have been successfully qualified in mass tests in the AVR reactor in Jülich.

3. Components for the high temperature heat transfer are qualified: Examples are the successful tests for hot gas ducts including insulations and liners in the sacle 1:1 test facilities "Component Experimental Loop (Kühlversuchskreislauf KVK, SIEMENS, INTERATOM, IA Bergisch Gladbach and in the Experimental Plant ADI and the succesful tests on magnetic bearings for circulators, (HRB Jülich).

4. Verifications on the safety of a HTR for process heat have successfully been accomplished. Examples are the explosion tests with hydrogen (SIEMENS/INTERATOM; Bergisch Gladbach) and the tests on earthquakes for the core with pebble type fuel elements including support structures (earthquake test facility MAVIS; Jülich, former SAMSON, HRB Jülich), as well as experimental work on the retention of tritium (KFA Jülich and others more).

5. The realizability of the production of process heat in a nuclear reactor, in the form of high temperature-helium with 950 °C, has successfully been demonstrated by the operation of the HTR experimental reactor AVR in Jülich by its many years of operation with such a mean helium outlet temperature.This has been reconfirmed by the project "reconstruction of the AVR into a process heat plant" (it has not been reslized), also with respect to the licenseability.

6. The technical feasibility of components of HTR for process heat in the industrial scale has been supported by the operation of the HTR demonstration plant THTR-300 in Schmehausen with its valuable experiences. The operation of the THTR-300 was finished in 1989, also due to political difficulties.

7. The qualification of the metallic materials for high temperature applications is very advanced: For the materials of the reformers and of the intermediate heat exchangers the prognostic lifetimes of more than 100 000 hours have been achieved. The newly developed material for the helium-heated gas generator of the process of a steam gasification of coal withstand very hard corrosion conditions in the gasification of coal.

8. Methods for the design, including detailed design and production of documents for the licensing process for the components of high temperature heat transfer and high temperature heat consuming apparatus have been developed completely.

9. The development and demonstration of the process of reforming of methane with a helium-heated reformer has successfully been performed. Two variants of the reformer - baffle-variant and tube-variant - have been tested successfully in pilot-scale in the large scale experimental plant EVA/ADAM-II (KFA Jülich).

10. The development and demonstration of the helium intermediate loop for the transfer of high temperature heat has been performed successfully . Two variants of the intermediate heat exchanger - the Helix-variant and the U-tube-variant - have been tested successfully in the large scale experimental plant "Component Experimental Loop (Komponenten Versuchs-Kreislauf , KVK, SIEMENS/INTERATOM-Bergisch-Gladbach) together with hot gas tubes and fittings.

11. The development and demonstration of the process of the hydrogenating gasification of coal, HGC, in experimental facilities in the semi-technical scale and in the pilot-scale (Union Kraftstoff, Wesseling) have been performed successfully . The process has been developed in the main for lignite, the applicability for hard coal has also been tested successfully.

12. The development and demonstration of the process of steam gasification of coal, has been performed successfully in an experimental faciltiy in the semi-technical scale (Deutsche Montan Technologie, DMT, former Bergbauforschung Essen). The process has been developed in the main for hard coal.

13. Assessments of the technical feasibility and the economical competitiveness of the processesses for the refinement of coal using nuclear energy assessment have been performed in the year 1987 (ROeG study and RBW assessment). Both studies confirm the techncial feasibility. On the economical competitiveness the following is stated:

    For the process of the steam gasification of coal: The cost values of the processes using nuclear energy are higher than those of the conventional processes and there is a potential to decrease the costs "but without the possibility to be cheaper than the conventional alternatives. However, it had also be shown that it would be necessary to have an optimal coupling between the HTR and the heat consuming processes", and

    for the hydrogenating gasification of coal: "The product costs are remarkable higher than the market prices of today and also above the conventional alternatives, with the conclusion at an economical competitive may be achieved only in the long term".

APPENDIX 1 (cont.)

14. The R & D work for the improvement and the securing of the technical feasibility and the economical competitiveness and for the preparation of the market penetration of coal refinement using nuclear energy in phase I: "Development of concepts and assessment" (1989-1992) have identified potentials of improvement. With these improvements the economical competitiveness of nuclear process heat for the refinement of coal in comparison to conventional alternatives has been achieved: the best value is 75 % of the cost value of the conventional alternative. But the economical competitiveness of coal refinement as a whole is not achieved in comparison to the market conditions after the end of the oil price crisis for the moment (1992).

15. The licenseability of nuclear heat application for coal refinement has been evaluated in 1980 by the assessment committee of the Bundesminister des Innern (Federal Ministry of the Interior) and has received a positive votum: requirements can be fulfilled and proofs can be made. This votum has been revitalized by the evaluations in the frame of the project "Reconstruction of the AVR into a process heat plant" in 1984. The primary helium-heated reformer fulfills all requirements being important in a licensing process.

16. The environmental friendliness of nuclear coal gasification with respect to emissions from the coal refinement processes has been proven by the experimental plants: The products specific emissions of carbondioxide of the nuclear coal refinement is in comparison to the conventional alternative smaller by the factor of 1.5 to 1.8. With the nuclear coal refinement the "CO_2-disadvantage" of the coal in comparison to oil and gas can be diminished.

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PNP-1987
Prototypanlage Nukleare Prozeßwärme, PNP: Arbeiten zur Festlegung des Anlagenkonzepts, (HTR, HKV), Rheinische Braunkohlenwerke AG, Bereich Forschung und Entwicklung, (RBW-Bewertung, Juli 1987), (in English: Prototype Plant Nuclear Process Heat, PNP: Works for the Fixation of the Concept of the Plant High Temperature Reactor plus Hydrogenating Coal Gasification, here called RBW Assessment).

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Atomic Energy Act

Federal Republic of Germany

7th amendmend

effective 28.July '94

Translation „word by word", in parts
to improve technical understanding
5 pages (1 of 5)

Research Center Jülich GmbH, KFA
Institute for Safety Research and Reactor Technology ISR
H. Barnert
07.09.94

Atomic Energy Act, Germany (2 of 5)

Article 7. Licensing of Plants
Paragraph (2)

The licence may only be granted

if

Item 3:

the precautions

- against damages
- required
  according to the state of art

have been taken
- through
  the construction and
  operation of the plant.

Atomic Energy Act, Germany, 7th Amendment (3 of 5)

Article 7, Paragraph (2a) (that is the new)

With respect to plants
- for the fission of nuclear fuel
  = serving to produce electricity

paragraph (2), item 3
is legal with the restriction
that
- as a further precaution
  = against risk to the public

the licence may only be granted
if
- due to the nature and operation of the plant

even such events,
whose occurance is practically excluded
- by the precaution
  = to be taken against damages

would not necessitate
decisive measures
- for protection
  = against damaging effects
  of ionizing radiation

- beyond the enclosed boundary of the plant,...

Atomic Energy Act, Germany, 7th Amendment (4 of 5)
Explanation, 1st paragraph:

Over and above
- the existing concept
  = for the design of nuclear power plants
    ≡ against incidents and
  = for plant-internal emergency protection

  = within the scope of precautions
    ≡ against damages
    ≡ required
      according to the state of art
      (paragraph 2, item 3)

it appears appropriate
- in view of the advancing state of art
- for future reactors

to take precautionary measures

against any events,
such as

accidents with core melt,

- that may occur
- in spite of the precautions
  = against damages
- already practised.

Atomic Energy Act, Germany, 7th Amendment (5 of 5)
Explanation, 2nd paragraph:

The measures,
- e.g. for controlling
  = accidents with core melt,

must be such
- that the licensing authority is convinced

that no releases will occure

that would necessitate

any decisive measures,
such as evacuation,

- for protection
  = against damaging effects
    ≡ of ionizing radiation.

Bundesgesetzblatt

1617

Teil I Z 5702 A

1994 Ausgegeben zu Bonn am 28. Juli 1994 Nr. 46

Artikel 4

Siebentes Gesetz
zur Änderung des Atomgesetzes

Das Atomgesetz in der Fassung der Bekanntmachung vom 15. Juli 1985 (BGBl. I S. 1565), zuletzt geändert durch Artikel 6 Abs. 77 des Gesetzes vom 27. Dezember 1993 (BGBl. I S. 2378), wird wie folgt geändert:

1. In § 7 wird nach Absatz 2 folgender Absatz 2a eingefügt:

   „(2a) Bei Anlagen zur Spaltung von Kernbrennstoffen, die der Erzeugung von Elektrizität dienen, gilt Absatz 2 Nr. 3 *mit der Maßgabe, daß zur weiteren Vorsorge* gegen Risiken für die Allgemeinheit die Genehmigung nur erteilt werden darf, wenn auf Grund der Beschaffenheit und des Betriebs der Anlage auch Ereignisse, deren Eintritt durch die zu treffende Vorsorge gegen Schäden praktisch ausgeschlossen ist, einschneidende Maßnahmen zum Schutz vor der schädlichen Wirkung ionisierender Strahlen außerhalb des abgeschlossenen Geländes der Anlage nicht erforderlich machen würden; die bei der Auslegung der Anlage zugrunde zu legenden Ereignisse sind in Leitlinien näher zu bestimmen, die das für die kerntechnische Sicherheit und den Strahlenschutz zuständige Bundesministerium nach Anhörung der zuständigen obersten Landesbehörden im Bundesanzeiger veröffentlicht. *Satz 1 gilt nicht für die Errichtung und den Betrieb* von Anlagen, für die bis zum 31. Dezember 1993 eine Genehmigung oder Teilgenehmigung erteilt worden ist, sowie für wesentliche Veränderungen dieser Anlagen oder ihres Betriebes."

Deutscher Bundestag
12. Wahlperiode

Drucksache 12/6908
25. 02. 94
Sachgebiet 750

Gesetzentwurf
der Bundesregierung

C. Kernenergie

Einzelbegründung

Zu Artikel 4 (Siebentes Gesetz zur Änderung des Atomgesetzes)

Zu *Nummer 1* (§ 7 Abs. 2a)

Über das bisherige Konzept der Auslegung von Kernkraftwerken gegen Störfälle und der Maßnahmen des anlageninternen Notfallschutzes im Rahmen der nach dem Stand von Wissenschaft und Technik erforderlichen Vorsorge gegen Schäden (Absatz 2 Nr. 3) hinaus erscheint es bei künftigen Reaktoren angesichts des fortschreitenden Standes von Wissenschaft und Technik sachgerecht, Vorsorgemaßnahmen gegen etwaige, trotz der schon bislang praktizierten Schadensvorsorgemaßnahmen eintretende Ereignisse wie Unfälle mit Kernschmelze zu treffen. Die Beherrschung solcher schon nach dem bisherigen Konzept als extrem unwahrscheinlich anzusehenden Ereignisse wird durch den neuen Absatz 2a zum Schutz der Allgemeinheit vorgeschrieben (Satz 1). Der neue Absatz 2a fügt sich damit in die geltende Systematik der Schadensvorsorge ein, die sich unterteilt in den Bereich der — stets drittschützenden — Gefahrenabwehr sowie den der grundsätzlich allgemeinschützenden Risikovorsorge, indem Satz 1 einen Teil der allgemeinschützenden Risikovorsorge umschreibt.

Die Maßnahmen z. B. zur Beherrschung von Unfällen mit Kernschmelze müssen so beschaffen sein, daß es zur Überzeugung der Genehmigungsbehörde feststeht, daß es nicht zu Freisetzungen kommen wird, die einschneidende Maßnahmen zum Schutz vor der schädlichen Wirkung ionisierender Strahlen wie eine Evakuierung erforderlich machen. Maßgeblich hierfür ist, daß nach der Einschätzung der Genehmigungsbehörde die in der Publikation Nr. 63 der Internationalen Strahlenschutzkommission, ICRP 63, sowie die von der deutschen Strahlenschutzkommission empfohlenen unteren Eingreifrichtwerte für eine Evakuierung nicht überschritten werden

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REFORMING TECHNOLOGY FOR SYNGAS PRODUCTION

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Abstract

Methane forming reactions using either steam or CO_2 have been known to industry for a long time. These endothermic reactions require the investment of a relatively large amount of energy. German researchers, in the 1970's, conceived and developed the idea to use this reaction and the reverse methanation reaction in a closed loop for the transportation and distribution of nuclear heat. The idea was also adopted for use with solar energy as a heat source. Utilizing solar energy as the heat source, the Weismann Institute of Science has fabricated, installed and operated a complete loop capable of the conversion and transportation of over 400 kW of heat. This system can be operated with a wide range of $CO_2/H_2O/CH_4$ feed mixtures.

Steam reforming is the common reforming reaction in the "open loop" mode for the purpose of synthesis gas production. This is accomplished with a large excess of steam on a nickel catalyst. However, it has only recently been recognized that there is also a substantial market for CO_2 reforming. The CO_2/CH_4 mixture in various proportions exists in many places and has, so far, not been used efficiently. The sources for this mixture are biogas produced in anaerobic digestion processes and gas resources such as the NATUNA gas field in Indonesia, and many others. Therefore, the system of CO_2/CH_4 deserves more attention.

Commercial catalysts used for steam reforming based on nickel are not suitable for this system. Therefore, other catalysts based on Rhodium and Ruthenium have been developed and some performance data is presented in this paper. Also presented is a conceptual schematic layout of a CO_2 reforming plant and matching methanator. A computer code for a detailed design of the entire loop in a commercial size system has been prepared where optimized operational conditions as well as equipment parameters can be determined.

Background

The methane reforming reactions using either steam or CO_2 are known to the industry for a long time. These endothermic reactions require the investment of a relatively large amount of energy.

In the seventies, German researchers in KFA, Julich[1], conceived and developed the idea to use this reaction and the reverse methanation reaction in a closed loop for the transportation and distribution of nuclear heat. The idea was also adopted for use with solar energy as a heat source. Several researchers worked in this area in the US and Germany, but only at WIS, Rehovot, Israel, a complete loop capable of conversion and transportation of over 400 kW heat was fabricated, installed and operated for about two years[2]. The system at WIS can be operated with a wide range of $CO_2/H_2O/CH_4$ feed mixtures. If solar energy is to be used as the energy

[1] Schulten, R., K. Kugeler, and W. Frohling; Progress in Nuclear Energy, vl. 14, , pp. 227-268, 1984.
[2] Epstein, M., Spiewak, I; "Design and Operation of the Weizmann Institute 480 KW Solar Reformer in an Energy Storage Cycle", Proceedings of 7th Intl. Symposium on Solar Thermal Concentrating Technologies, vol. 4, p. 958, 1994, Moscow, Russia.

source the CO_2 reforming is advantageous, because this cycle is thermodynamically more efficient and it is easier to operate it under changing conditions as in solar energy.
The common reforming reaction in "open loop" mode, namely for the purpose of synthesis gas production is steam reforming. This is done with a large excess of steam on a nickel catalyst. However, it has only recently been recognized that there is also a substantial market for CO_2 reforming. The CO_2/CH_4 mixture in various proportions exists in many places and has so far not been used efficiently. The sources for this mixture are biogas produced in anaerobic digestion processes and gas wells such as the NATUNA gas field and many others. Therefore, the system of CO_2/CH_4 deserves more attention. One of the main problems of this system is carbon formation. The commercial catalysts used for steam reforming based on nickel are not suitable for this system. Therefore other catalysts based on Rhodium and Ruthenium have been developed and some performance data is presented in this paper.

<u>CO_2 Reforming Of Methane Using Solar Energy</u>

A closed loop system aimed at demonstrating the process of CO_2 reforming of methane and the reverse methanation reaction was developed, constructed and tested at the Weizmann Institute in Rehovot, Israel (see Figure 1). The Reformer is capable of providing 480 kW of heat into the reaction. The reformer comprises of an insulated enclosure, pentagon shaped, with an aperture of bout 60 cm diameter in its front side. Through this opening the concentrated solar radiation enters and heats 8 reactor tubes filled with 1% Ruthenium/Alumina catalyst. The tubes are 2 inches in diameter and about 6 meters long. They are made of INCONEL 617. There are two banks of tubes connected in parallel, one on each side of the aperture. The tubes are directly heated by solar radiation reflected from the walls of the enclosure. They are placed and spaced in such a way that the illumination will be circumferential as uniformly as possible. The feed of CO_2/CH_4 ratio of 1.2/1 enters at about 500°C, 16-18 bars and the exit temperature of the products is in the range of 800-830°C.

<u>Methanation of CO Rich Synthesis Gas</u>

The methanation of synthesis gas with CO/H_2 ratio of close to 1:1 requires carefully controlled feed chemistry and outlet temperature of the first stage of methanation. The methanator operated at the Weizmann Institute comprises of two adiabatic stages and one "cooled" stage as shown in Figure 1 (operated almost isothermally). The control of the methanation is achieved by adding steam to the feed to control the total mass balance of hydrogen in the system and also recycle of part of the methanation product stream and mixing it with the feed.

<u>Catalysts for CO_2 reforming of Methane</u>

The catalyst used for the CO_2 reforming of CH_4 is 1% Ruthenium on Alumina. This catalyst showed good activity and stability in operating temperature of 900°C for several thousands of testing hours. The feed composition used during the CO_2 reforming tests was 45 mol% CH_4 and 55 mole % CO_2. The same catalyst was also used for reforming experiments with a mixture of steam and CO_2. The kinetics of the reaction with 1% Ruthenium on Alumina can be expressed as follows[3]:

[3] Berman, A., Levitan, R., Epstein, M. Levy, M; Ruthenium Methanation and Reforming Catalysts for Solar Chemical Heat Pipe" ASME proceeding of Solar Engineering, editor J.H. Davidson, p. 61, 1996.

$$W_{H_2} = \frac{k_H P_{CH_4}^2}{(b_0 P_{CH_4} + b_1 P_{CO_2} + b_2 \frac{P_{CH_4}}{P_{CO_2}} + b_3 P_{CO_2}^2)^2}$$

where W_{H2} is the rate of hydrogen production in liters (STP) per hour per gram catalyst and the other coefficients are:

$k_H = 5.22 \bullet 10^3 \bullet EXP(-E/RT)$ L/g cat h atm^{-2}
E= 9027 cal/mole for 600<T<700°C
E= 9027 - (T-973) •22.6 cal/mole for 700<T<750°C
$b_o = 1$ atm^{-1}
$b_1 = 3.686 \bullet 10^6 \bullet EXP(-32900a/RT)$ atm^{-1}
$b_2 = 5.43 \bullet 10^3 \bullet EXP(7570/RT)$
$b_3 = 6.59 \bullet 10^6 \bullet EXP(-17668/RT)$ atm^{--2}
R = 1.98 cl/mole grad

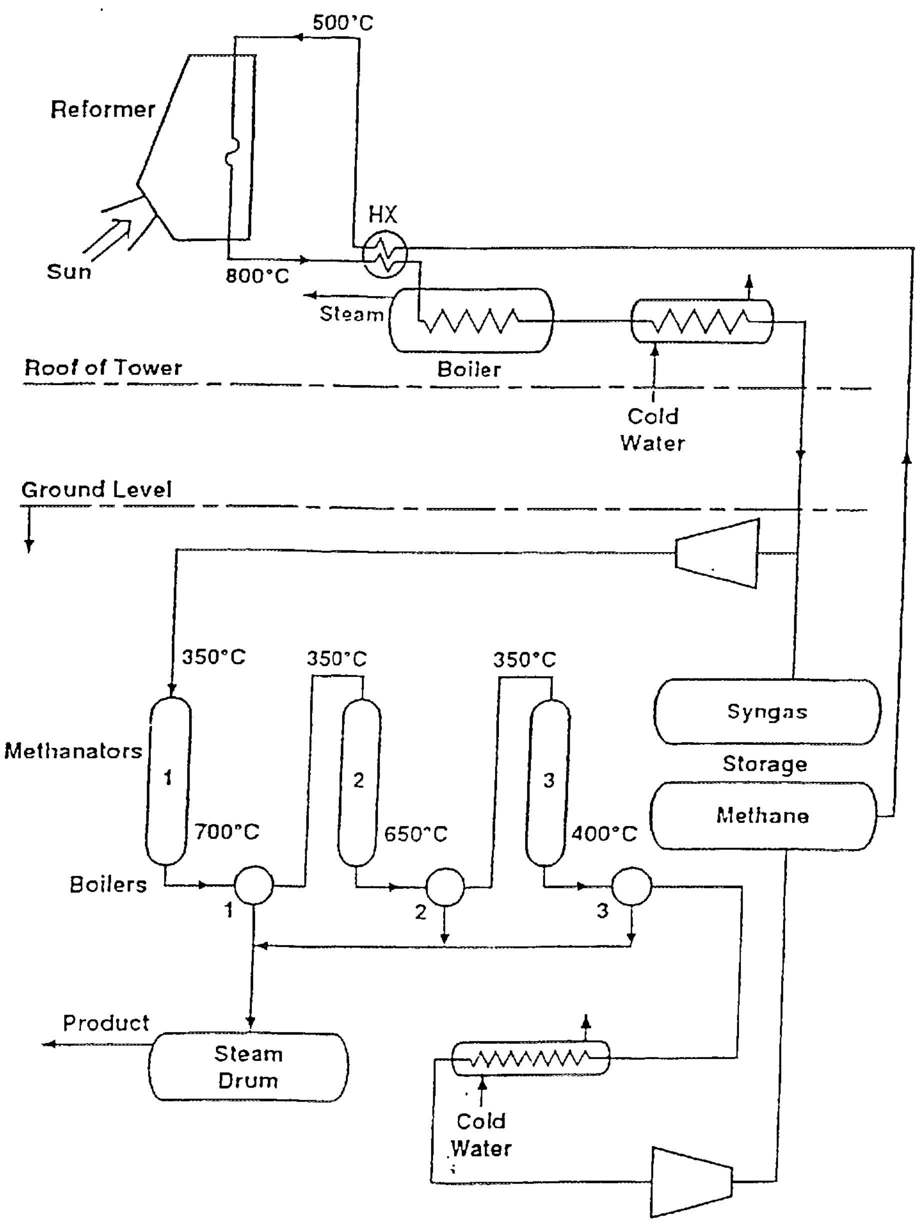

FIG. 1. The Weizman Institute solar chemical pilot plant.

The rate of the reverse water gas shift reaction (RWGSR) which happens as undesirable side reaction in the reformer, consumes hydrogen, produce CO and H_2O and therefore reduces the efficiency of the reformer and increase the danger of carbon deposition can be expressed as follows:

$$W_{H_2O} = \frac{k_w \cdot P_{CH_4} \cdot P_{CO_2}^2}{(c_0 P_{CH_4} + c_1 P_{CO_2})^2}$$

where W_{H2} is the rate of steam production and the other coefficients are:

$k_W = 2900 \bullet EXP\ (9200/RT)$ l/g cat h atm^{-3}
$c_1 = 0.06 \bullet EXP\ (5400/RT)$ l/g cat h atm^{-1}
$co = 1\ atm^{-1}$

This correlation shows that increasing the partial pressure of the CO_2 will favor the RWGSR and decrease the selectivity towards hydrogen production.

Catalyst for Methanation of CO-rich Synthesis Gas

Operating an efficient closed loop CO_2 reforming of CH_4 required the special development of catalyst for the methanator. The feed mixture containing high CO composition and therefore it is very exothermic and both the temperature and chemistry control of the methanator are difficult. This was achieved by injection of steam into the feed and by recycling part of the products.

An additional important requirement is that the catalyst should be active over a wide range of temperature from 240°C up to 750°C. Finally 4% and 2% Ruthenium Alumina were used in the first two adiabatic stages of the methanator and Ni on silica in the last stage(close to isothermal).

The following kinetic equations were obtained for 4% Ruthenium catalyst[3]:
For the temperature range of 240-320°C:

$$W_{CH4} = k \cdot P_{co} \cdot P_{H2} / (1 + aP_{co})^3$$

and for 400-650°C:

$$W_{CH4} = k_1 \cdot P_{co} \cdot P_{H2} / (b_o + b_1 P_{co} + b_2 P_{H2}^{0.5})^3$$

where W_{CH4} is the rate of CH_4 formation in liters/hour per gram catalyst and the other coefficients are:

$k = 1.63 \bullet 10^6 \bullet EXP\ (-10642/RT)$	l/gr.cat.atm^{-2}
$a = 0.09 \bullet EXP\ (5174/RT)$	atm^{-1}
$k_1 = 3.48 \bullet 10^9 \bullet EXP\ (18815/RT)$	l/gr.cat. atm^{-1}
$bo = 2.27 \bullet 10^2 \bullet EXP\ (-7163/RT)$	
$b_1 = 2.1 \bullet 10^3 \bullet EXP\ (-7615/RT)$	atm^{-1}
$b_2 = 1$	atm^{-1}
R = gas constant= 1.98 cl/mole K	

Results and conclusions

Typical results of several experiments with solar energy as a heat source are presented in Table 1. This table gives a summary of enthalpy balance for different

TABLE 1. TEST RESULTS OF WIS'S TUBULAR REFORMER

DATE	Time	T in °C	T out °C	ΔT °C	Solar Power in, kW (MIRVAL)	No. Helios	Power Absorb kW	Sens. Heat kW	Chem. Heat kW	moles CH4 in kgm/hr	moles CH4 out kgm/hr	% CH4 conv.
13/9/94	12 35	425	753 0	328	380	30	153	59	94	1 62	0 29	82 0
20/10/94	13 10	544	779 0	235	540	32	285	46	239	4 63	1 23	73 4
24/8/95	13 30	506	791.8	286	445	32	188	66	122	2 293	0 549	76 1
24/8/95	14.16	576	788 8	213	418	34	173	49	124	2 269	0 514	77 3
31/8/95	10:55	503	795.9	293	559	31	278	93	185	4.962	1 145	76 9
31/8/95	11 27	552	806 5	255	568	31	326	86	240	4 926	1 114	77 4
31/8/95	13.28	567	757 5	191	548	31	198	58	140	4.118	1 166	72 0
3/9/95	14 25	567	798 9	232	488	34	267	65	202	4.047	0 938	76 8
6/9/95	12 07	534	788 3	254	495	33	180	75	105	2 514	1 078	57 1
6/9/95	12 47	566	791 4	225	483	32	227	65	162	3 444	0 973	71 7
6/9/95	13 12	551	777 1	226	494	33	234	69	165	3 606	1 045	71 0
6/9/95	14 05	546	754.8	209	462	34	220	64	156	3 736	1 340	64.1
6/9/95	14 24	529	733 6	205	367	34	190	64	126	3 905	1 941	50 3
6/9/96	14 58	511	694 4	183	283	34	159	54	105	4.322	2 686	37 9

operation conditions. It distinguishes between the sensible heat and the reaction heat. One can see that the sensible heat in the product gases is a significant portion of the total enthalpy of the reaction and therefore it is important to exploit it usefully. It is, therefore, recommended that the commercial plant will be designed accordingly. In figures 2 and 3 schematic diagrams of a CO_2 reforming plant and a matching methanator are shown.

The methanator plant (figure 3) comprises of four reactors; the first three reactors accept the feed in parallel in any preset proportion and in addition the feed is

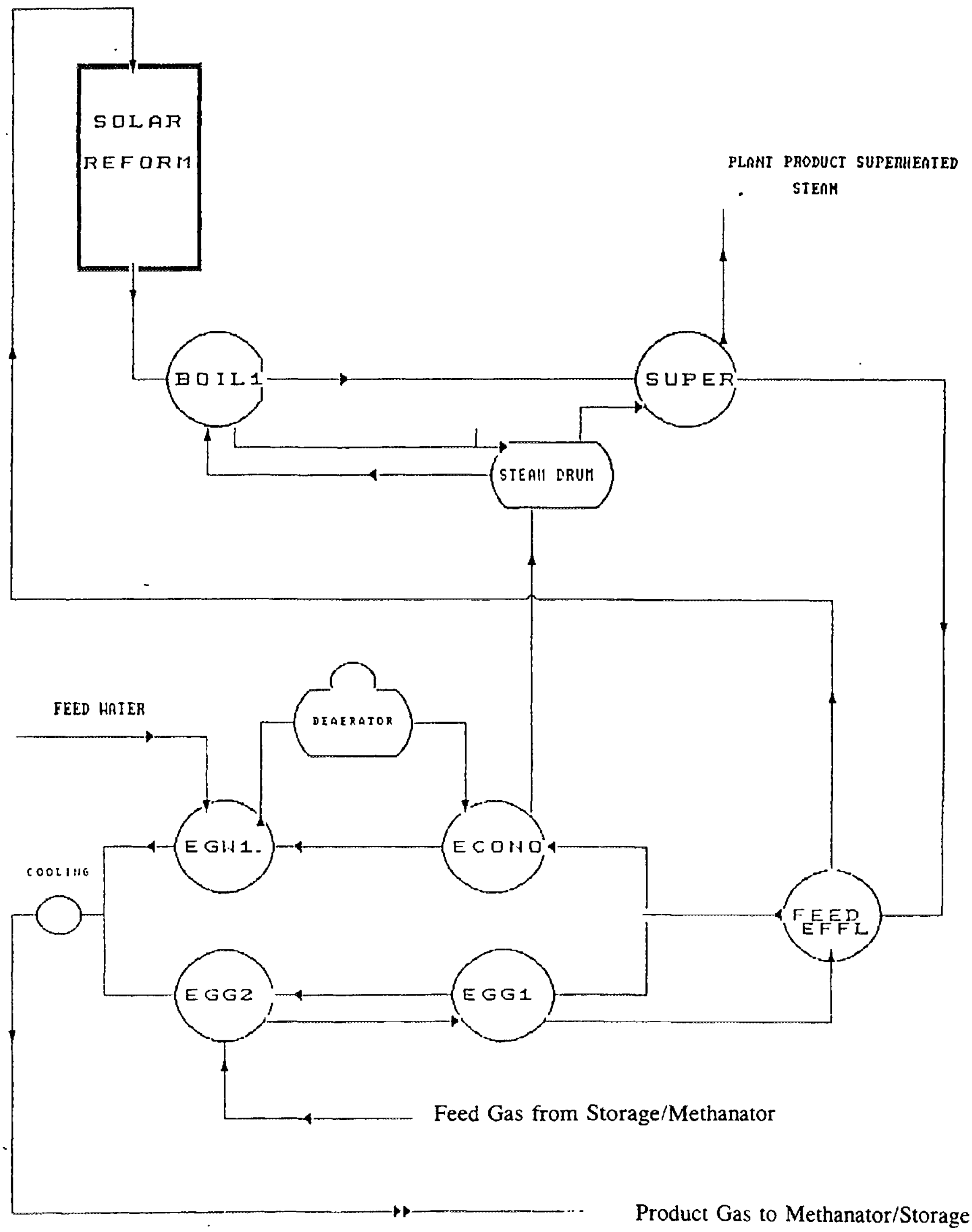

FIG. 2. Solar reforming plant
CO_2 reforming.

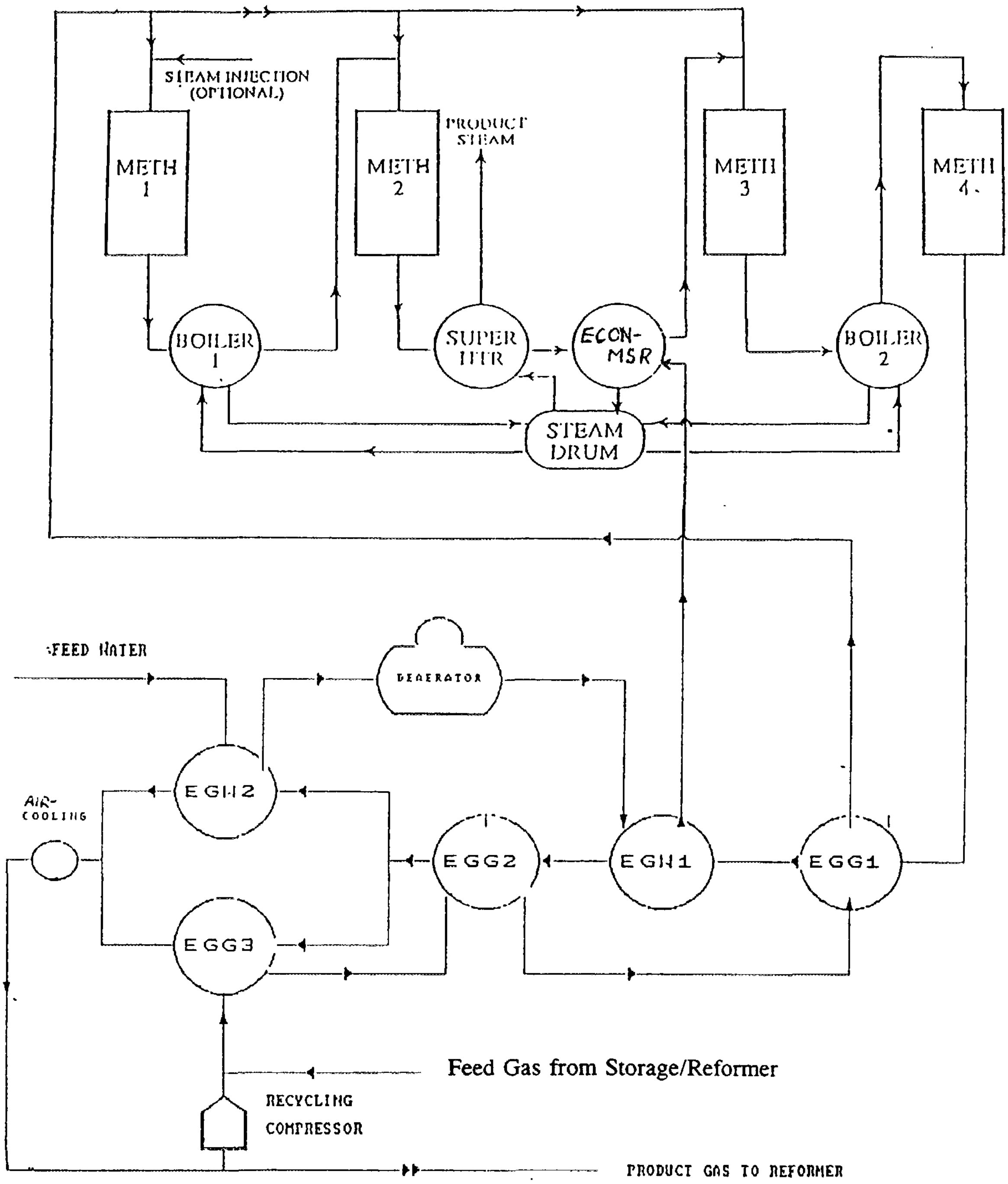

FIG. 3. Methanator plant Flowsheet.

"diluted" with the product from the previous reactor. Such a combined parallel-series connection enables the control of the reaction in the methanator without the need for a hot recycle of the products as designed in EVA-ADAM project. The fourth reactor is in series with the other three and is used for final conversion of the CO to methane.

A computer code for a detailed design of the entire loop in a commercial size system was prepared and optimized operational conditions as well as equipment parameters (heat exchangers, compressors, reactors sizes) can be obtained. A typical input/output data based on the schematic layout of figures 2 and 3 is given in Tables 2 and 3, respectively.

TABLE 2. INPUT PARAMETERS
CO24.INP

```
'ENTER DESIRED NET PRODUCTION OF STEAM IN METHANATOR IN TONS =',200.0

'ENTER PRESSURE OF PRODUCT STEAM IN METHANATION PLANT (Atm)  =',60.0

'ENTER SUPERHEAT TEMP. OF  STEAM IN METHANATION PLANT (C)   =',480.0

'ENTER PRESSURE OF PRODUCT STEAM IN REFORMING  PLANT (Atm)  =',60.0

'ENTER SUPERHEAT TEMP. OF  STEAM IN REFORMING  PLANT (C)    =',480.0

'ENTER REFORMING PROCESS KODE (0 FOR STEAM 1 FOR CO2)       =',1

'ENTER REFORMING PROCESS CO2 TO CH4 RATIO              =',1.2

'ENTER REFORMING PROCESS STEAM TO METHANE RATIO           =',0.001

'ENTER REFORMING PROCESS OUTLET CATALIST TUBE TEMPERATURE   =',850.0

'ENTER REFORMING PLANT INLET PRESSURE IN ATM            =',20.0

'ENTER temperature approach for feed-effluent           =',300.0

'ENTER PIPELINE (TO METHANATOR) INLET PRESSURE IN ATM      =',40.0

'ENTER METHANATION PLANT INLET PRESSURE IN ATM           =',20.0

'ENTER METHANATION PLANT STEAM TO CO RATIO            =',0.2

'ENTER METHANATOR LOWEST IGNITION TEMPERATURE (DEG C)      =',250.0

'ENTER METHANATOR MAXIMUM ALLOWABLE TEMPERATURE (DEG C)    =',650.0

'ENTER FEED FRACTION IN METHANATOR NUMBER 1            =',0.2

'ENTER FEED FRACTION IN METHANATOR NUMBER 2            =',0.3

'ENTER FEED FRACTION IN METHANATOR NUMBER 3(SUM FRACTIONS=1.)=',0.5

□
```

TABLE 3. OUTPUT DATA

THIS IS A RUN WITH THE FOLLOWING CONDITIONS:

TOTAL NET SUPERHEATED STEAM PRODUCED IN METHANATOR PLANT 200.0 TONS

TOTAL NET ENERGY ABSORBED BY THE REFORMER: 254.8 MWTh COST****** M$

TOTAL NUMBER OF 95 SQ.M. HELIOSTATS : 4994

REFORMER CONDITIONS:

TEMPERATURE (C) AT INLET TO REFORMER : 550.00
EXIT TEMPERATURE (C) FROM CATALIST : 850.00
EXIT TEMPERATURE (C) FROM REFORMER HEADER : 850.00
EXIT PRESSURE (Atm) FROM REFORMER HEADER : 16.50
STEAM TO METHANE RATIO : .001
CO2 TO METHANE RATIO : 1.135

METHANATORS CONDITIONS

STEAM TO CO RATIO : .200
EXIT TEMPERATURE(C) FROM LAST METHANATOR : 516.19
EXIT PRESSURE (Atm) FROM LAST METHANATOR : 15.00

MATERIAL BALANCE:REFORMER AND METHANATOR OVERALL STAGES

	INPUT		OUTPUT	
REFORMER	WET FRACT.	DRY FRAC.	WET FRACT.	DRY FRAC.
CH4	.4213	.4214	.1043	.1110
H2O	.0004	.0000	.0611	.0000
CO	.0775	.0775	.4557	.4854
CO2	.4781	.4783	.0807	.0859
H2	.0228	.0228	.2982	.3176
TOTAL MOLES	1.0118		1.5426	
METHANATOR:				
CH4	.1012	.1110	.4083	.4214
H2O	.0885	.0000	.0311	.0000
CO	.4424	.4854	.0751	.0775
CO2	.0783	.0859	.4634	.4783
H2	.2895	.3176	.0221	.0228
TOTAL MOLES	1.5890		1.0439	

TABLE 3 (cont.)

DRY MOLES FLOW TO METHANATOR IN KG-MOLES/HR =14751 3
AVERAGE MOLECULAR WEIGHT = 19 801

DRY MOLES FLOW TO REFORMER IN KG-MOLES/HR =10300 7
AVERAGE MOLECULAR WEIGHT = 30 027

ENERGY BALANCE FOR THE METHANATOR PLANT

METHANATOR PLANT INLET PRESSURE (ATM) = 20 00

METHANATOR PLANT INLET PRESSURE (ATM) = 15 00

GROSS TONNAGE OF STEAM PRODUCED IN THE PLANT221 50

METHANATOR RECYCLE RATIO 6268

RECYCLE FLOW RATE IN KGMOL/HR 6456 91

RECYCLING COMPRESSOR POWER IN METHANATOR PLANT 1956 3 KWTh

THE COST OF THE COMPRESSOR IN 1994 DOLLARS IS 91975 1

BALANCE FOR METHANATOR REACTOR NUMBER 1 OUT OF 4 REACTORS

	INPUT		OUTPUT	
	WET FRACT	DRY FRAC	WET FRACT	DRY FRAC
CH4	1537	2055	2295	2896
H2O	2524	0000	2076	0000
CO	2700	3612	1113	1404
CO2	1536	2054	3035	3830
H2	1703	2279	1482	1870
TOTAL MOLES	5571		4992	

WET MOLES FLOW INLET METHANATOR IN KG-MOLES/HR = 5673 7
AVERAGE MOLECULAR WEIGHT,INLET TO METHANATOR= 21 678

WET MOLES FLOW OUT OF METHANATOR IN KG-MOLES/HR = 5083 8
AVERAGE MOLECULAR WEIGHT,EXIT OF METHANATOR = 24 193

BALANCE FOR METHANATOR REACTOR NUMBER 2 OUT OF 4 REACTORS

TABLE 3 (cont.)

	INPUT		OUTPUT	
	WET FRACT.	DRY FRAC.	WET FRACT.	DRY FRAC.
CH4	.2162	.2381	.3077	.3419
H2O	.0922	.0000	.0999	.0000
CO	.2502	.2756	.1503	.1670
CO2	.2490	.2742	.3487	.3874
H2	.1925	.2120	.0933	.1037
TOTAL MOLES	1.1239		.9965	

WET MOLES FLOW INLET METHANATOR IN KG-MOLES/HR. =11446.3
AVERAGE MOLECULAR WEIGHT,INLET TO METHANATOR= 23.482

WET MOLES FLOW OUT OF METHANATOR IN KG-MOLES/HR. =10149.3
AVERAGE MOLECULAR WEIGHT,EXIT OF METHANATOR = 26.483

BALANCE FOR METHANATOR REACTOR NUMBER 3 OUT OF 4 REACTORS

	INPUT		OUTPUT	
	WET FRACT.	DRY FRAC.	WET FRACT.	DRY FRAC.
CH4	.2555	.2686	.3477	.3677
H2O	.0489	.0000	.0544	.0000
CO	.2581	.2713	.1671	.1767
CO2	.2755	.2896	.3706	.3919
H2	.1621	.1704	.0603	.0638
TOTAL MOLES	2.0377		1.8161	

WET MOLES FLOW INLET METHANATOR IN KG-MOLES/HR. =20753.4
AVERAGE MOLECULAR WEIGHT,INLET TO METHANATOR= 24.659

WET MOLES FLOW OUT OF METHANATOR IN KG-MOLES/HR. =18496.8
AVERAGE MOLECULAR WEIGHT,EXIT OF METHANATOR = 27.668

BALANCE FOR METHANATOR REACTOR NUMBER 4 OUT OF 4 REACTORS

TABLE 3 (cont.)

	INPUT WET FRACT	INPUT DRY FRAC	OUTPUT WET FRACT	OUTPUT DRY FRAC
CH4	3477	3677	4094	4216
H2O	0544	0000	0290	0000
CO	1671	1767	0771	0794
CO2	3706	3919	4633	4771
H2	0603	0638	0212	0218
TOTAL MOLES	1 8161		1 6928	

WET MOLES FLOW INLET METHANATOR IN KG-MOLES/HR =18496 8
AVERAGE MOLECULAR WEIGHT,INLET TO METHANATOR= 27 668

WET MOLES FLOW OUT OF METHANATOR IN KG-MOLES/HR =17241 0
AVERAGE MOLECULAR WEIGHT,EXIT OF METHANATOR = 29 683

UNIT	TEMP RANGE DEG C			DUTY MWtH
BOILER1	650 0	TO	306 7	21 78
BOILER1	276 7	TO	276 7	21 78
SUPERHT	629 4	TO	396 3	36 41
SUPERHT	480 0	TO	276 7	36 41
ECONMSR	396 3	TO	306 7	6 51
ECONMSR	276 7	TO	253 8	6 51
BOILER2	606 3	TO	306 7	74 19
BOILER2	276 7	TO	276 7	74 19
GASGAS1	515 6	TO	406 2	27 10
GASGAS1	120 0	TO	250 0	27 10
GASWAT1	406 2	TO	244 5	36 65
GASWAT1	120 0	TO	253 8	36 65
GASGAS2	244 5	TO	244 5	00
GASGAS2	120 0	TO	120 0	00
GASGAS3	244 5	TO	50 9	18 12
GASGAS3	27 0	TO	120 0	18 12
GASWAT2	244 5	TO	50 9	23 95
GASWAT2	27 0	TO	120 0	23 95
EAIRCOO	50 9	TO	27 0	5 43
EAIRCOO	12 0	TO	27 0	5 43

TABLE 3 (cont.)

ENERGY BALANCE FOR THE REFORMER PLANT

REFORMER PLANT INLET PRESSURE (ATM) = 20 00
REFORMER PLANT OUTLET PRESSURE (ATM) = 14 00

KG OF SATURATED STEAM REQUIRED FOR REFORMING 80 04
(AT PRESSURE OF REFORMER INLET)

KG OF SUPERHEAT STEAM PRODUCED IN THE PLANT 63950 07
AT PRESSURE OF 60 04 ATM, AND 480 00 SUPERHEAT TEMPERATURE

COMPRESSOR POWER INTO PIPELINE AT 40 00 Atm 18661 9 KWTh

THE COST OF THE COMPRESSOR IN 1994 DOLLARS IS 373695 7

	INPUT		OUTPUT	
	WET FRACT	DRY FRAC	WET FRACT	DRY FRAC
CH4	4213	4214	1043	1110
H2O	0004	0000	0611	0000
CO	0775	0775	4557	4854
CO2	4781	4783	0807	0859
H2	0228	0228	2982	3176
TOTAL MOLES		1 0118		1 5426

DRY MOLES FLOW TO REFORMER IN KG-MOLES/HR =10300 7
AVERAGE MOLECULAR WEIGHT,INLET TO REFORMER= 30 027

DRY MOLES FLOW OUT OF REFORMER IN KG-MOLES/HR =14751 3
AVERAGE MOLECULAR WEIGHT,EXIT OF REFORMER = 19 801

UNIT	TEMP RANGE DEG C			DUTY MWtH
BOILER1	850 0	TO	686 7	27 73
BOILER1	276 5	TO	276 5	27 73
SUPERHEATE	686 7	TO	615 0	11 65
SUPERHEATE	276 5	TO	480 0	11 65
FEEDEFFLUE	615 0	TO	362 9	39 61
FEEDEFFLUE	276 5	TO	550 0	39 61
GASGAS1	362 9	TO	145 4	19 23
GASGAS1	120 0	TO	276 5	19 23

TABLE 3 (cont.)

GASGAS2	145 4	TO	73 1	10 06
GASGAS2	27 0	TO	120 0	10 06
ECONMISER	362 9	TO	145 4	12 38
ECONMISER	120 0	TO	276 5	12 38
WATERGAS	145 4	TO	69 7	6 92
WATERGAS	27 0	TO	120 0	6 92
AIRCOOLER	71 4	TO	27 0	10 43
AIRCOOLER	12 0	TO	27 0	10 43

JAPANESE HTTR PROGRAM FOR DEMONSTRATION OF HIGH TEMPERATURE APPLICATIONS OF NUCLEAR ENERGY

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Abstract

Construction works of the HTTR started in March 1991 in order to establish and upgrade the HTGR technology basis, to carry out innovative basic researches on high temperature engineering and to demonstrate high temperature heat utilization and application of nuclear heat. This report describes the demonstration program of high temperature heat utilization and application.

Introduction

Consumption of a huge amount of fossil fuels resulted from human activities since the industrial revolution causes an enhanced global warming. Concerning about global warming due to emission of CO_2, it is essentially important to make efforts to obtain more reliable and stable energy by extended use of nuclear energy including high temperature heat from nuclear reactors, because it can supply a large amount of energy with little amount of CO_2 emission during their plant life.

First Japanese R&D program on HTGR-heat utilization system for demonstration of the direct steel making and multi purpose such as hydrogen production and steam reforming had performed since 1969. In this program, the following R&D was done ; design of experimental very high temperature reactor (VHTR), research of reactor physics, development of fuels, materials of graphite and heat resistant alloys, high temperature components and etc.. Unfortunately this program was discontinued in 1980 for the reason that industries did not require the direct steel making at that time.

Next program for demonstration of high temperature application of nuclear energy was decided by Japan Atomic Energy Commission in 1987 and recommended of early construction of test reactor of VHTR which is High Temperature Engineering Test Reactor (HTTR).

Construction works of the HTTR started in March 1991 in order to establish and upgrade the HTGR technology basis, to carry out innovative basic researches on high temperature engineering and to demonstrate high temperature heat utilization and application of nuclear heat.[1]

This report describes the demonstration program of high temperature heat utilization and application.

Outline of the HTTR

The HTTR is a test reactor with thermal output of 30MW and outlet coolant temperature of 850°C at rated operational condition and of 950°C at the high temperature testing condition. The HTTR plant is composed of a reactor building, a spent fuel storage building, a machinery and so on. The HTTR reactor building is 48m×50m in size with two floors aboveground and three floors underground. A reactor vessel, an intermediate heat exchanger and other heat exchangers in cooling system are installed in the reactor containment vessel. The major specification of the HTTR are listed in Table 1.

Table 1 Major Specifications of the HTTR

Thermal power	30MW
Outlet coolant temperature	850°C/950°C
Inlet coolant temperature	395°C
Fuel	Low enriched UO_2
Fuel element type	Prismatic block
Direction of coolant flow	Downward
Pressure vessel	Steel
Number of cooling loop	1
Heat removal	IHX and PWC (parallel loaded)
Primary coolant pressure	4MPa
Containment type	Steel containment
Plant lifetime	20 years

Block type fuel element such as pin-in-block is adopted since it has the advantage of fuel zoning, controllability of coolant flow rate in each column, operability of control rods, etc.. The core consist of 30 fuel columns and 7 control rod guide columns as shown Fig. 1 and is cooled by helium gas of 4MPa flowing downward. Replaceable reflector blocks including 9 control rod guide columns and 3 irradiation test columns surround the core. The core and replaceable reflector blocks are installed within the permanent reflector blocks fixed by the core restraint mechanism. These core structure components are placed on the graphite core support structures and the metallic core support structures as shown Fig. 2.

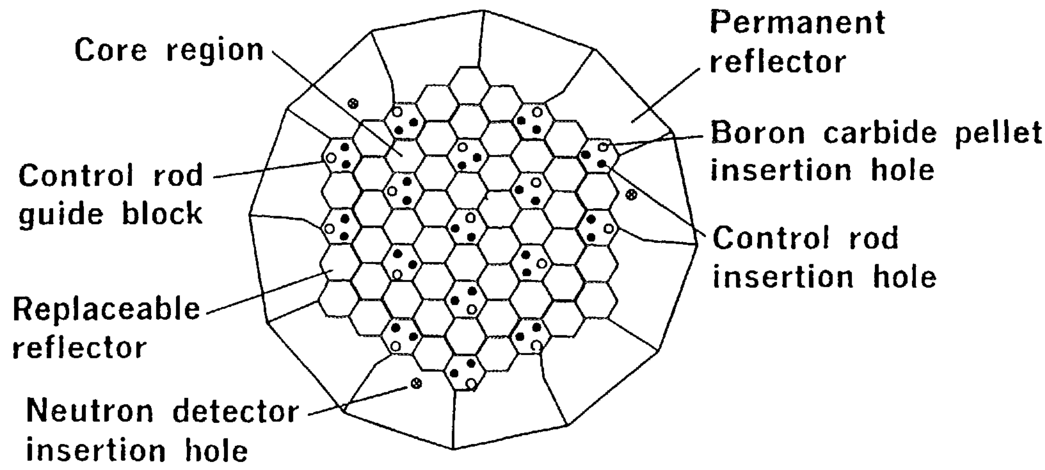


Fig. 1 Cross Section of the HTTR Core

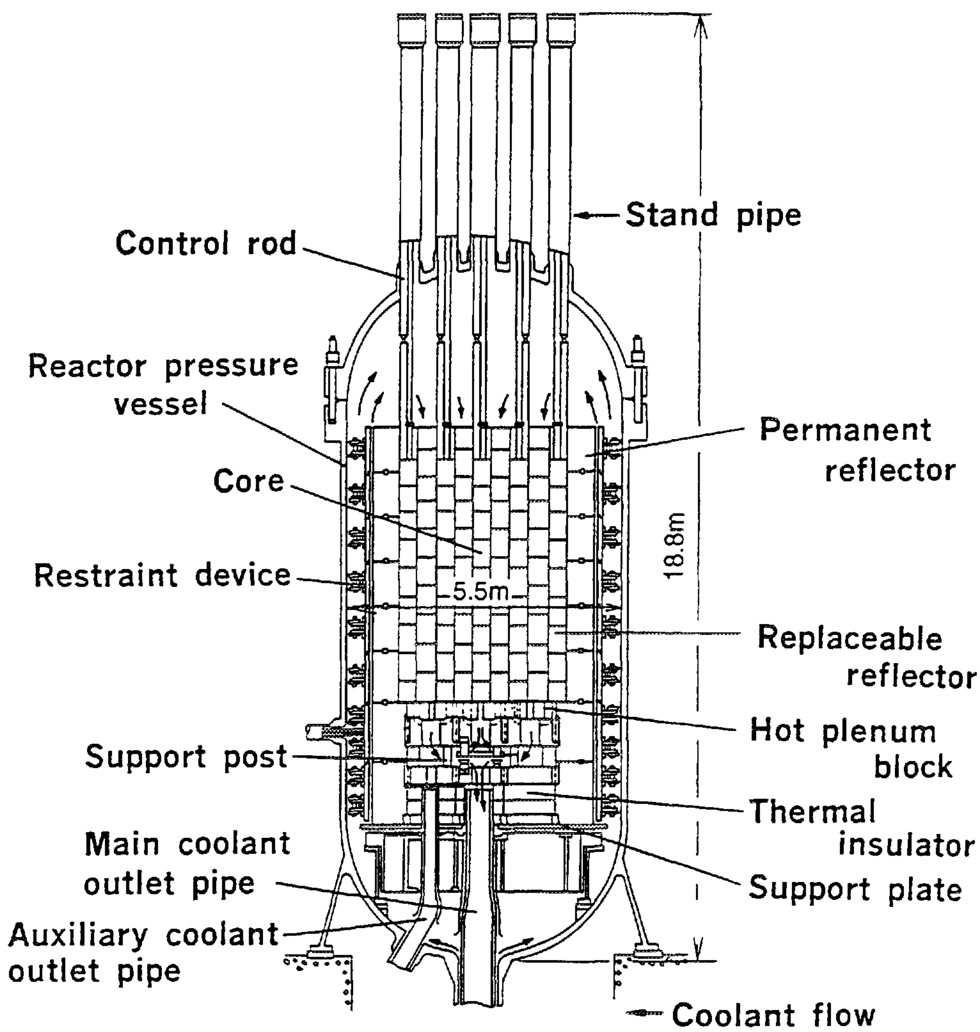


Fig. 2 Vertical Section of the HTTR Reactor Vessel

Flow diagram of cooling system in the HTTR is shown in Fig. 3. The main cooling system of the HTTR is composed of a primary cooling system, a secondary helium cooling system and a pressurized water cooling system. Two heat exchanger such as a He-He intermediate heat exchanger (IHX) and a primary pressurized water cooler (PPWC) are installed on the primary cooling system. The heat from the core is transferred to the IHX and PPWC through the concentric hot gas duct in which outlet helium gas at temperature of 850°C/950°C flows inside the inner tube and inlet gas of 400°C flows in the annular path Pressurized water is cooled by air cooler

The HTTR is planed to be operated in two loading modes. One is a parallel loaded operation in which the IHX and the PPWC are operated simultaneously. Their heat removal rate are 10 and 20MW, respectively. The other is single loaded operation in which the PPWC is only operated and remove the heat of 30MW.

Auxiliary cooling system (ACS) is operated to remove the residual heat from the core at reactor scram.

Heat utilization system will be connected to the IHX. The nuclear heat of 10MW at temperature of 905°C and pressure of 4 1MPa is transported to the heat utilization system.

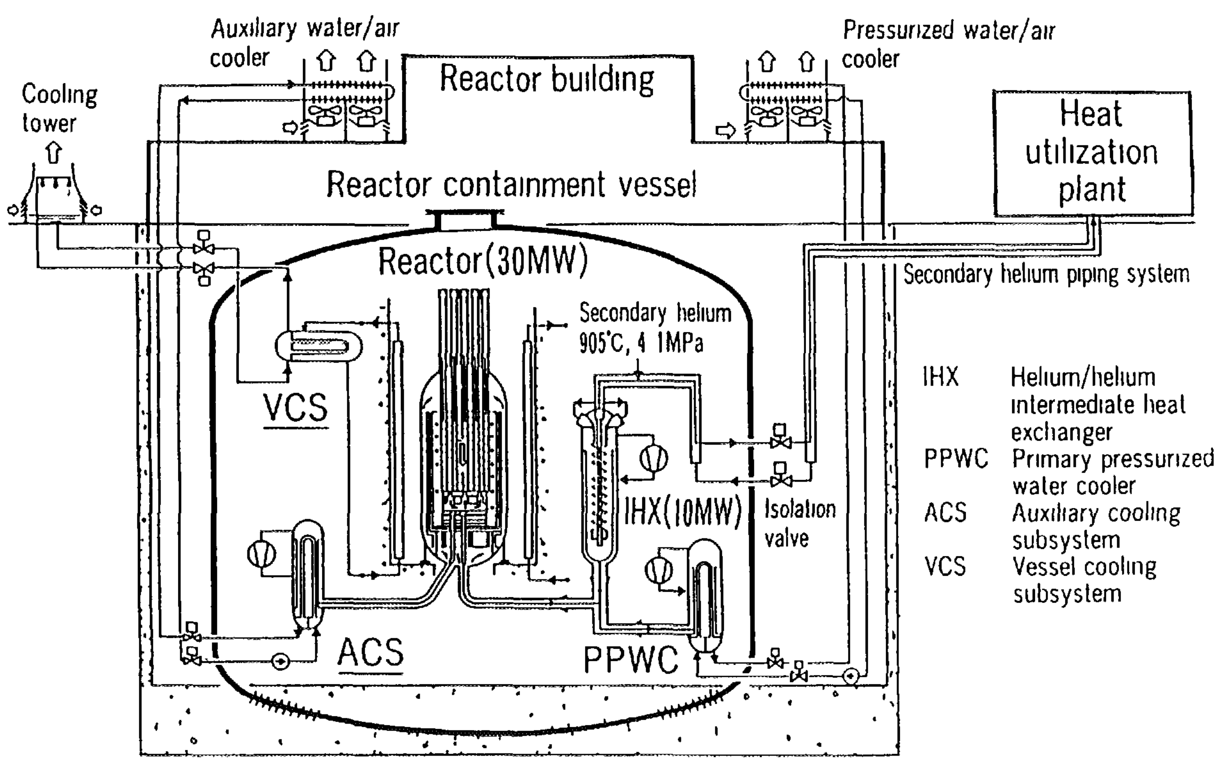


Fig 3 Simplified Flow Diagram of Cooling System in the HTTR

The construction of the HTTR started in March 1991 as shown Table 2. A functional test operation of the reactor cooling system has been performed since May 1996. Fuels will be loaded into the core around in September 1997 and first criticality is expected in December 1997.

HTTR heat application

Top priority objective for development the heat utilization system connected to the HTTR is to demonstrate technical feasibility of a nuclear process heat utilization system for the first time in the world. From a technical point of view, the following feasibility and reliability should be demonstrated.

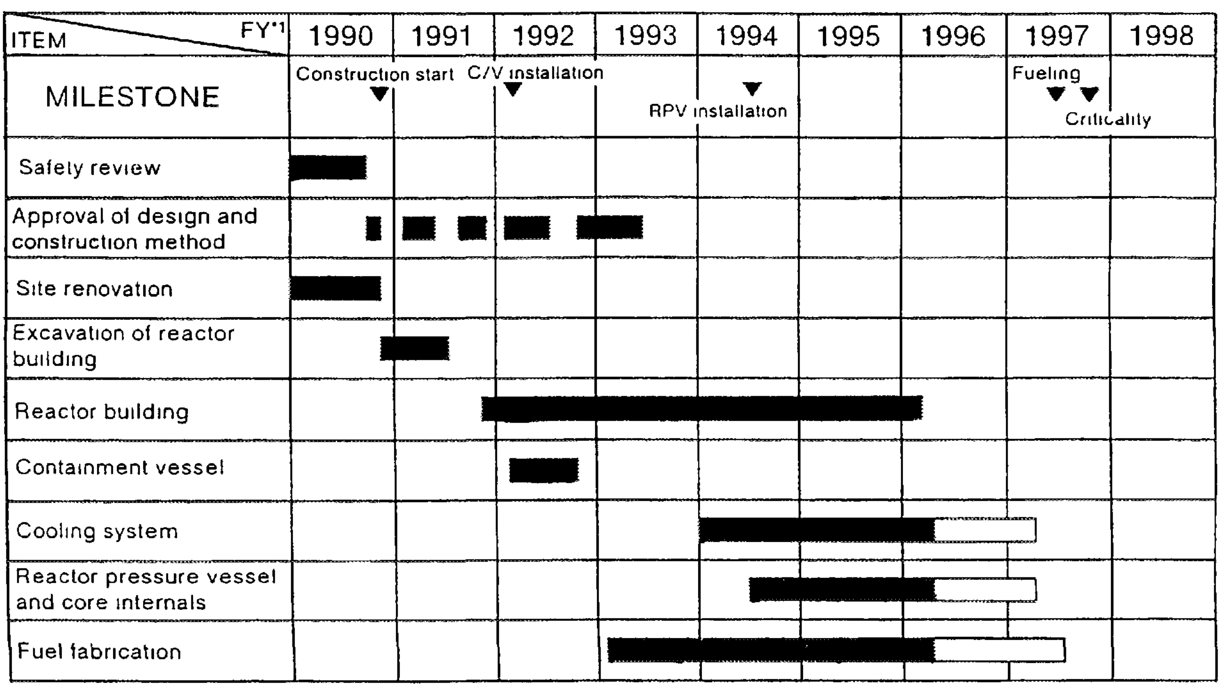
(1) Feasibility of control design concept for the total system including start-up and shutdown procedure.

(2) Feasibility of safety design concept for the total system including interface concept.

(3) Reliability of helium-heated components.

The primary candidate of the first HTTR heat utilization system must have the universality of control and safety design concepts to be demonstrated. Because basic features of these design concepts shall be applicable to other candidates of nuclear process heat chemical systems. And technologies of helium-heated components must have been proven in order to demonstrate the first HTTR heat utilization system as soon as possible.

Table 2 Construction Schedule of the HTTR



*1 Fiscal year of Japan starts in April and ends in March

We have chosen the steam reforming system as the primary candidate because the steam reforming system has a similarity to other candidate systems with respect to the system arrangement and the heat of endothermic chemical reaction. Candidate systems have high temperature endothermic reactor plus steam generator (SG), and the their heat of reaction are as high as 200kJ/mol. And Helium-heated steam reformer has been basically developed in the former project. Furthermore the steam reforming system is an economical and a mature technology. Then technical solusions demonstrated in the HTTR will contribute to other candidates.

At a preliminary design conducted from 1990 through 1995, we has developed a framework of the HTTR-steam reforming system. Key design achievements were as follows.[2]

(1) By applying a new concept of steam reformer (SR) and by optimizing arrangement of helium-heated components and related heat-material balance conditions of the system, high heat utilization efficiency of 78% is achieved and is competitive to the efficiency of 80-85% of a fossil-fueled plant of steam reforming.

(2) A SG was allocated downstream the SR to achieve sufficient system controllability. At start-up of the system, helium gas temperature increses in proportion to reactor power. On the other hand, in an endothermic chemical reaction, a heat input enough to cause the reaction dramatically increses with incresing reaction temperature due to the Arrenhius type temperature dependence of reaction rate. It is necessary to balance such a quite difference in thermal dynamics between the nuclear reactor and the chemical reactor at start-up condition without reactor scram. We found that the outlet temperature of the SG is not depend on the outlet temperature of the SR and inlet of the SG due to a large latent heat of the hold up water in the SG as shown in Fig. 4. It is possible to control the feed gas flow rate to balance the difference of thermal dynamics. The SG can adsorp the quite difference in thermal dymanics so that the safety and stable start-up of the system would be performed.

The conceptual and detail design will be carried out for the safety review and construction of the heat utilization system. The draft plan of the HTTR-steam reforming system development is shown Table 3.

International cooperation

In order to promote the HTGR R&D efficiently, the JAERI has proceeded with international cooperation with research organizations in China, Germany,

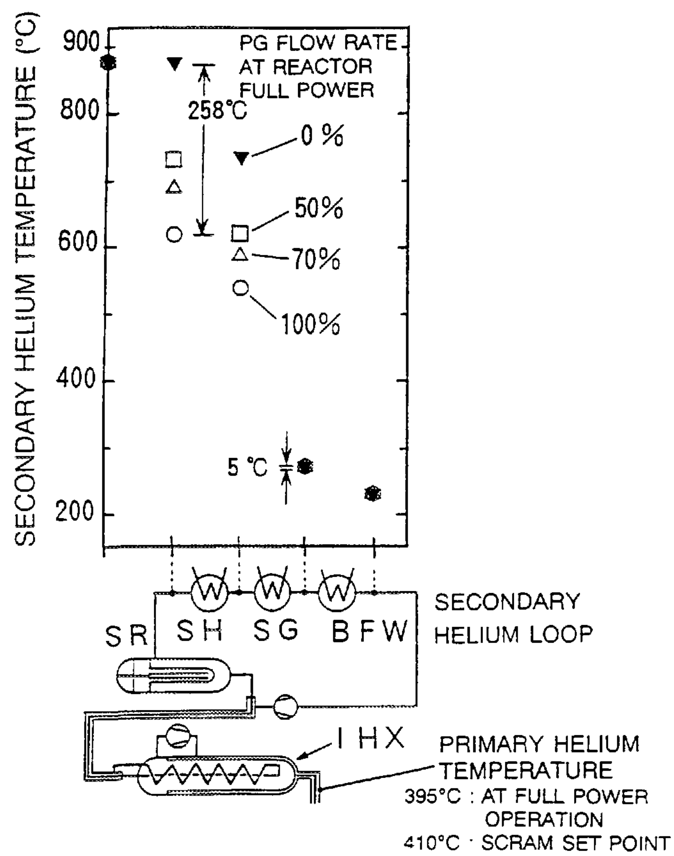


Fig. 4 Helium Temperature Variation in the Hydrogen Production System

Table 3 Draft Plan of the HTTR-Steam Reforming Hydrogen Production System Development

Item	H7	H8	H9	H10	H11	H12	H13	H14	H15	H16
1. HTTR	Construction		Ascent-to -power (▲ Criticality)		Initial core			Second core		
2. Design and construction of hydrogen production system (Steam reforming system)	Conceptual design		Detailed design		Safety review	Construction		Demonstration test		
3. Out of pile demonstration test	Design			Test						
		Construction								
4. IAEA CRP-4	Conceptual design and safety evaluation				Next CRP (Demonstration tests at out-of-pile test facility and at the HTTR)					

United Kingdom and USA. In these R&D cooperation, we have exchange the technology information, irradiation test and heat utilization test, and we will be able to transfer the R&D results to be obtained in the HTTR and HTTR-steam reforming system. We have positively contributed and will contribute to the International Working Group on Gas-cooled Reactors and the Coodinated Reserch Programs organized by the IAEA.

REFERENCES

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(2) Design of steam reforming hydrogen and methanol co-production system to be connected to the HTTR, K.Hada, N.Fujimoto, Y.Sudo, IAEA TECDOC 761

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NON-ELECTRIC APPLICATIONS OF POOL-TYPE NUCLEAR REACTORS

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Abstract

This paper recommends the use of pool-type light water reactors for thermal energy production Safety and reliability of these reactors were already demonstrated to the public by the long-term operation of swimming pool research reactors The paper presents the design experience of two projects: Apatity Underground Nuclear Heating Plant and Nuclear Sea-Water Desalination Plant. The simplicity of pool-type reactors, the ease of their manufacturing and maintenance make this type of a heat source attractive to the countries without a developed nuclear industry.

1. Introduction

More than 35% of primary energy resources are consumed for the need of heat supply of towns and villages in Russia This figure illustrates the fact that the heating market in Russia is rather vast, and the demand of thermal energy is vast too At present this demand is satisfied by using fossil-fuel heat sources The contribution of nuclear sources to the heating market is negligible and connected, first of all, with district heat supply from NPPs

During the last time in Russia the trend of becoming more expensive of fossil fuel and its transportation costs is clearly seen These factors lead to increasing of the thermal energy cost. The heat is specific kind of energy - it cannot be transferred to a long distance and must be consumed at the place of its generation The burning down of a big quantity of fossil fuel at the one place leads to the local ecological problems and impacts to the health of people Therefore in Russia the population sometimes protest against new fossil-fired power plants construction (as an example, the scandal in Moscow with construction of North power plant in 1993). In the face of public opposition some local governments in Russia adopted ecological laws which obliged the power plant operators to pay compensation for environment pollution For this reason the thermal energy becomes more expensive

The mentioned above obstacles force the Russian government to find alternative of existing energy sources of heat The nuclear option was discovered as a reasonable one, therefore AST-500 NHPs were built in the Nizny Novgorod and Voronez The State Program of North Regions development was adopted in Russia This Program foresee the nuclear option for improving of North regions heat supply Russia has positive experience of nuclear heating More then 25 yrs in the small town Bilibino in Chukotka the four water-graphite reactors of Bilibino NPP (4x[12MW(e)+16Gkal/hour]) have been supplying the town by ecology clean thermal energy

However the severe accidents at Three-Mile-Island and Chernobyl NPPs shake the public trust to the national nuclear power and in spite of the fact, that the designs of AST-500 NHPs were examined by the international expertise with excellent result, both of them was not commissioned yet and its buildings and facility are used for other purposes.

During the last decade in the world, as well as in Russia, one can see the tendency of terrorism rise and the rise in number of local military conflicts As a result the public feel ourself like a hostage of the nuclear objects Such a situation bears additional objectives against the construction of NPPs in spite of the existing economic advantages

Taken into account the last affirmation it was adopted the State Program on Environmentally clean power in Russia. Along with other decisions, this program foresees the underground arrangement of NPPs Underground arrangement of nuclear facilities makes the physical defense of the object very strong and it may withstand against internal and external severe impacts including diversion and military actions

Research and Development Institute of Power Engineering (RDIPE) developed the conception of NHP supported by following main statements

- the nuclear source must be as simple as possible and supported by the well-checked technologies,
- the nuclear source must be cheap and competitiveness in comparison with other types of heat sources,
- the nuclear source must posses as much inherent safety properties as can be reached at the present level of nuclear technology development;
- the nuclear source must be protected against diversion and military conflicts,
- for the aim of acceptability, the design of NHP must be well-understood, in other words, it must be available for people without deep technical knowledge

This conception results an idea of pool-type heating reactor RUTA. The RUTA reactor design is based on the existing pool-type research reactors. It was found that RUTA reactor is convenient for underground location

The review of the problem concerning the underground location of NHP (UNHP)shows that positive decision about constructing of this kind of objects depends considerably on the local conditions of the site, namely

- local fuel price including transportation;
- the availability of heating network at the site,
- the environment conditions;
- the availability and readiness of local industry;
- the public opinion relating to nuclear power

The above mentioned conception was used in two designs of RDIPE.

- the design of RUTA UNHP for Apatity (Kola peninsula);
- The conceptual design of desalination plant for Israel

2. The Apatity Underground NHP RUTA project

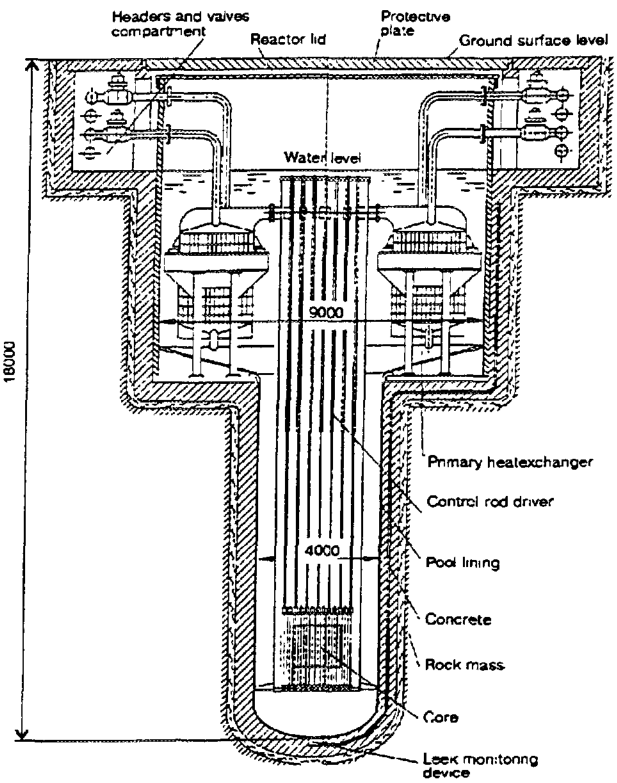
2.1. Reactor design

The RUTA.55 reactor unit is a simple nuclear heat source designed to supply 55 MW of thermal energy as water at 85C As shown in Fig 1 it is a pool-type reactor designed to operate at atmospheric pressure, thus eliminating the need for a pressure vessel.

The reactor core and a primary heat exchanges are in the pool contained inside a steel-lined concrete vault. Pool water serves as the moderator, heat transfer medium and shielding. Primary heat transport from the core is by natural circulation of the pool water through plate-type heat exchanges located in the pool.

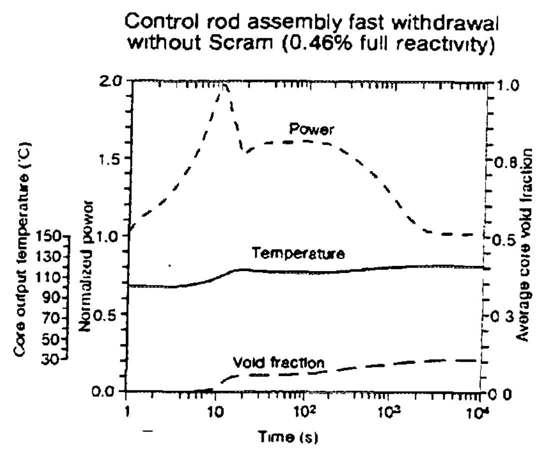
The secondary circuit delivers heat to the distribution system by way of the secondary plate-type heat exchanges. The pressure in the secondary circuit is higher then in primary circuit and the pressure in the distribution system is higher then in the secondary circuit, thus the customer protection from a radioactivity is ensured.

Absorber rods under computer control are used for load following. Periodic adjustment of these absorbers compensate for fuel burnup. All the absorber rods will fall down to the core in case of several accidents or necessity of fast reactor shut-down.

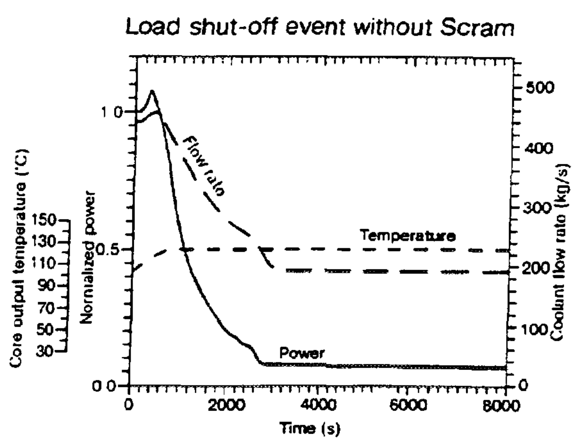


Headers and valves compartment
Reactor lid
Protective plate
Ground surface level
Water level
9000
18000
4000
Primary heatexchanger
Control rod driver
Pool lining
Concrete
Rock mass
Core
Leak monitoring device

Fig. 1.



Control rod assembly fast withdrawal without Scram (0.46% full reactivity)
Power
Temperature
Void fraction
Core output temperature (°C)
Normalized power
Average core void fraction
Time (s)



Load shut-off event without Scram
Flow rate
Temperature
Power
Core output temperature (°C)
Normalized power
Coolant flow rate (kg/s)
Time (s)

Fig.2.

Pool water is continuously pumped through ion exchange columns to maintain water chemistry and control corrosion.

The reactor pool is covered by a lid enclosing a gas space over the pool. The air and water vapor are continuously circulated through a purification system and hydrogen recombiner. The inherent safety characteristics of the RUTA reactor design include a negative fuel temperature reactivity coefficient and negative coolant temperature and void reactivity coefficients, all of which alleviate power transients following loss-of-regulation. Fig. 2 shows some of the transients. In addition to the inherent safety features:

- large volume of water in the pool delays the core temperature rise for a long period;
- natural circulation of water in the pool ensures the core cooling in any accidents;
- atmospheric pressure in the pool makes impossible loss-of-primary coolant caused by depressurization.

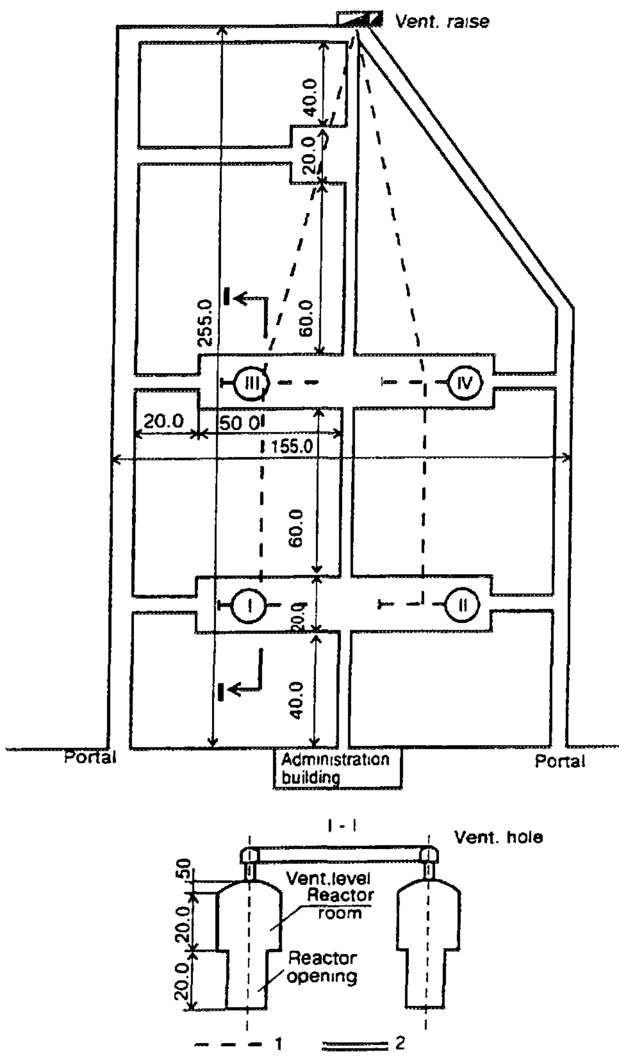
Major parameters of RUTA.55 reactor are presented in table 1.

TABLE 1. MAJOR RUTA.55MW CHARACTERISTICS

Parameter	Value
Power, MW	55
Coolant pressure, Mpa:	
in primary circiut (above the pool level)	atmosphere
in secondary circuit	0.4
in heating network	0.6 - 2.0
Coolant temperature, °C (inlet/outlet):	
in primary circuit	75/100
in secondary circuit	66/90
in heat-supply system	60/85
Number of secondary circuit loops	2
Water circulation in secondary circuit	Forced
Dimensions of the core, m	
height	1.2
equivalent diameter	2.03
Fuel	UO_2
Enrichment, %	3.6
Fuel burnup, MW×day/kg	27.5
Number of FA	169
Time interval between	
partial refuelling, years	3
Fuel lifetime, ef.days	2970
Linear heat flux, W/cm	
average	50
maximum	102

2.2. The Apatity NHP design

Apatity town is located in the Russian North in Kola peninsula, close to the Hibiny mountain massif. Apatity UNHP consist of 4 RUTA.55 reactor units. As shown in fig. 3 these units are arranged in horizontal drifting of a mountain. This mountain is located in the close vicinity of the town center (less then 4 km.). The UNHP serves for heating of the existing heating network return water. The heated water after UNHP is directed to the existing coal-fired power plant for heating up, if necessary, to ensure required temperature level (Fig.4). The load factor of UNHP will be more then 90% and UNHP supply 75-80% of annual town heating demand.



1 - ventilation level workings; 2 - haulage workings;
I - IV - reactors

Fig. 3.

Two long-term economic situations was estimated in the design:

- *continuation of the coal-fired existing power plant operation* (old mode);
- incorporation of the UNHP RUTA in the local heating network and it operation along with local power plant (new mode).

The comparison show that energy cost in new mode will be half as much the old one. As shown in Fig. 5 the thermal energy cost of UNHP depends of the unit power and if the unit power will be more then 20 MW the UNHP will be competitive in comparison with alternate available heat sources (coal-fired, gas etc.).

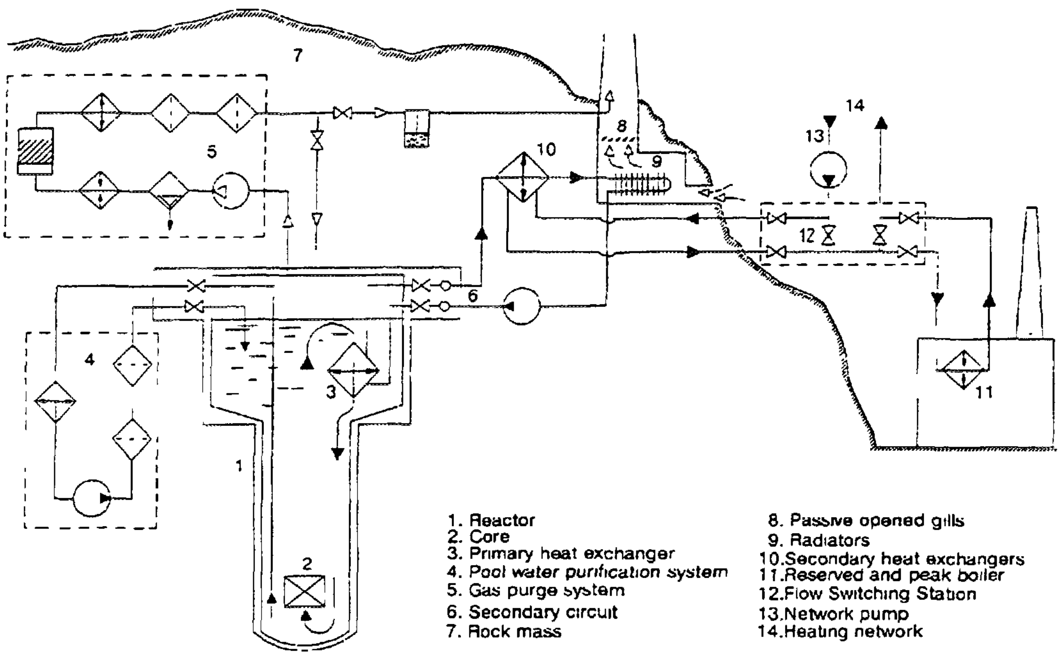
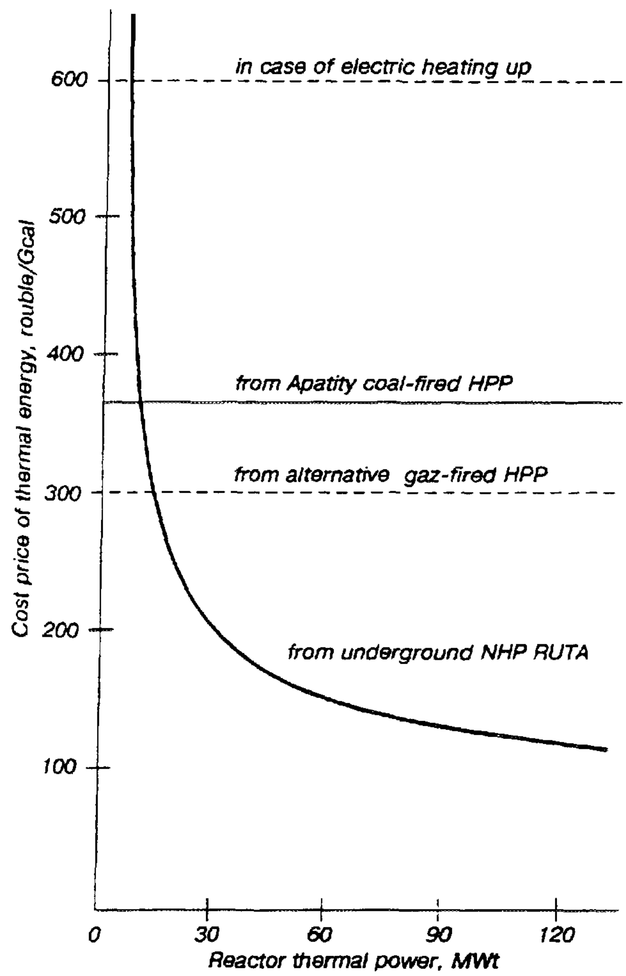


Fig. 4.



Cost price of thermal energy (1992 yr.)

Fig. 5.

Existing Apatity coal-fired power plant with thermal power 700 MW for heat supply (annual electricity output is 500 mln. kW-hour and heat output - 2 mln.Gkal.) takes about 1 mln. ton of Pechora coal. The coal is sulphide and has the high ash content. Annually the power plant throw out to the air about 10,000 ton of ash, 31,000 ton of SO_2, 5,000 ton of NO_2 and other pollutants. The application of RUTA UNHP allows to enhance cardinally the town environment.

2.3. Project status

Technical and economical investigation of the project was performed during 1992-1994 yrs. In the late 1994 a local government adopted the project. In the middle of 1995 it was created the RUTA Joint-stock company in the Apatity town for the project implementation.

3.The conceptual design of desalination plant for Israel.

3.1. Project background

It is quite clear that in the present market situation the nuclear seawater desalination plants (NSWDP) shall be competitive with conventional non-nuclear plants.

Research and Development Institute of Power Engineering (RDIPE),Mining Institute of Kola Science Center and UralNIIKhimMash offer high-safety RUTA NSWDP which meets the above mentioned requirements. In designing and construction of RUTA NSWDP the field-proven advanced technologies are used.

The RUTA NSWDP project envisages underground nuclear plant on the base of RUTA.55 reactors and ground based desalination plant. The NSWDP is located near Red Sea. With reference to the Mediterranean Sea, the performance of RUTA NSWDP will be better.

3.2. Description of RUTA NSWDP

The NSWDP operates on the principle of thermal distillation of sea water in horizontal film apparatus. Desalination is effected at water boiling temperature of 78°C in the first stage of the desalination plant. The desalinating plants of the considered design have the best performance as compared with other plants at the given level development of engineering and technology. The schematic of the NSWDP is illustrated in Fig. 6. Three circuits belong to the reactor plant and the forth circuit is designed for generation of steam used as heating agent in distillation units. The heat from the circuit-to-circuit is transferred via heat exchange surfaces. Even in case of loss of leaktightness of all heat exchange surfaces, the fouling of the coolant of the fourth loop in contact with the final product-distillate- is completely prevented due to blocking ratio of pressures in the reactor plant loops 1 to 3: the coolant pressure in secondary circuit is higher than in primary circuit,and that in third circuit, higher than in secondary circuit. The fourth loop operates under vacuum. The project is based on two unit underground nuclear plant RUTA of thermal capacity of 2x55 MW. The NSWDP RUTA uses electric power from external sources.

3.3. NSWDP Performance Data

Nominal thermal power of the plant, MW	2x55
Uranium loading, t	2x5.942
Uranium enrichment, %	3.6
Fuel lifetime, year	9
Desalinated water production, t/h	1200
Annual power consumption, mln.kWh	54

Investments, mln.$ (1994)	165
including: nuclear power plant	55
desalinating plant	65
interest on capital during construction, infrastructure, etc	45
Running costs, mln. $/y	27
Desalinated water cost, $/m^3$	2.7

In considering a non-nuclear option accidents due to fossil transportation should be taken into account which, according to the experience, could lead to contamination of vast territories of ground and sea.

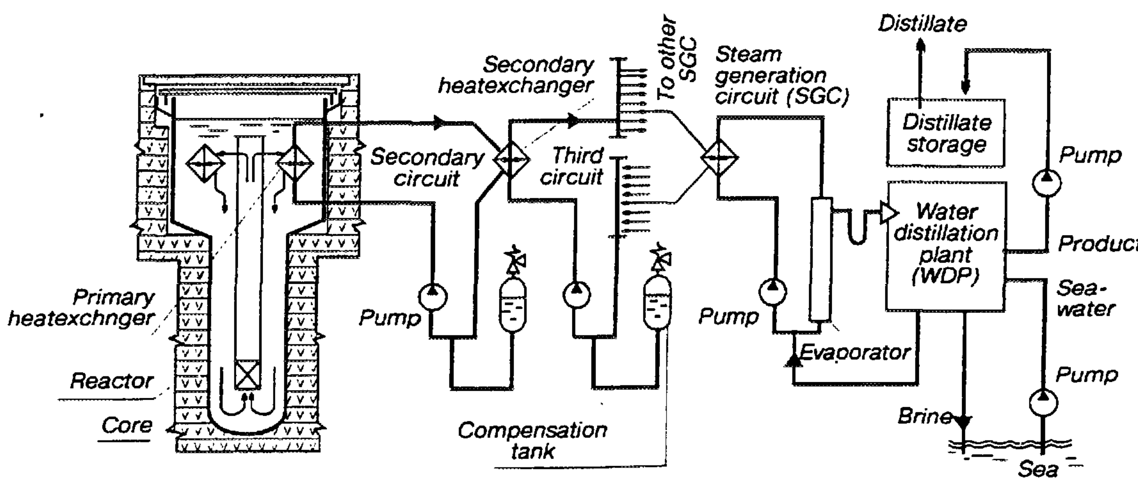


Fig. 6.

3.4. Special project features

The results presented herein are tentative and can be refined both in engineering and economical indices due to an important role of the type-design adjustment to the local area. The cost of the desalinated water can be both larger and smaller. The major factors for cost reduction:

- lower capital investment required;
- reduction of bank interest during construction;
- reduction of construction period.

The cost of uranium fuel and electricity practically no effect on the cost of the final product. Lower capital investments can be attained due to supply of equipment and construction machinery (especially for mine works) from Russia. Large-scale production of such NDPs will also reduce the cost of the desalinated water.

4. Conclusion

The heating market in Russia is vast, but nuclear contribution into this market is negligible.

The heat becomes more expensive due to rise in price of fossil fuels.

The burning of big quantity of fossil fuels leads to local ecological problems and public protests.

The nuclear alternative seems to be reasonable, but contrary the earlier development period it becomes much less popular.

Underground arrangement of NHPs allow to bring the nuclear heat closer to customer without risk.

Russia has State Programs, which foresee the non-electrical application of nuclear energy.

Nuclear source for heat generation must be simple, cheap and safe.

Pool-types reactors have a big potential for district heating, sea water desalination.

The simplicity of pool-type reactors, the easiness of its maintenance and manufacturing makes this type of heat source attractive for States without developed nuclear industry.

THE ROLE OF THE IAEA IN GAS-COOLED REACTOR DEVELOPMENT AND APPLICATION

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Abstract

Within the Statute establishing the International Atomic Energy Agency there are several functions authorized for the Agency. One of these functions is "to encourage and assist research on, and development and practical application of, atomic energy for peaceful uses throughout the world...". The development of nuclear power is deemed an important application of this function. The representatives of Member States with national gas cooled reactor (GCR) programmes advise the Agency on its activities in the development and application of the GCR. The committee of leaders in GCR technology representing these Member States is the International Working Group on Gas Cooled Reactors (IWGGCR).

The activities carried out by the Agency under the frame of the IWGGCR include technical information exchange meetings and cooperative Coordinated Research Programmes. Within the technical information exchange meetings are Specialist Meetings to review progress on selected technology areas and Technical Committee Meetings and Workshops for more general participation. Consultancies and Advisory Group Meetings are convened to provide the Agency with advise on specific technical matters. The Coordinated Research Programmes (CRPs) established within the frame of the IWGGCR for the GCR programme include:

* Validation of Safety Related Physics Calculations for Low Enriched GCRs,
* Validation of Predictive Methods for Fuel and Fission Product Behaviour in GCRs,
* Heat Transport and Afterheat Heat Removal for GCRs under Accident Conditions, and
* Design and Evaluation of Heat Utilization Systems for the High Temperature Engineering Test Reactor.

This paper summarizes the role of the International Atomic Energy Agency in GCR technology development and application.

1. Introduction

The International Atomic Energy Agency (IAEA) has the function to "foster the exchange of scientific and technical information", and "encourage and assist research on, and development and practical application of, atomic energy for peaceful uses throughout the world".

The IAEA is advised on its activities in development and application of gas-cooled reactors by the International Working Group on Gas-Cooled Reactors (IWGGCR) which is a committee of leaders in national programmes in this technology. The IWGGCR meets periodically to serve as a global forum for information exchange and progress reports on the national programmes, to identify areas for collaboration and to advise the IAEA on its programme. This regular review is conducted in an open forum in which operating experience and development programmes are frankly discussed. Countries participating in the IWGGCR include Austria, China, France, Germany, Italy, Japan, the Netherlands, Poland, the Russian Federation, Switzerland, the United Kingdom and the United States of America. In addition, the OECD-NEA and the European Union participate in the IWGGCR.

This paper describes the role of the IAEA in Gas-Cooled Reactor (GCR) technology development and application.

2. Background

Worldwide a large amount of experience has been accumulated during development, licensing, construction and operation of gas-cooled reactors. The experience forms a sound basis for programmes which are underway in several countries to develop advanced high temperature reactors for electric power generation and for process heat.

2.1. Summary of operating experience

In the United Kingdom approximately 937 reactor years of operating experience with carbon dioxide cooled reactors has been achieved[a]. Over 20% of the UK's total electricity is generated by its 20 Magnox and 14 AGR gas-cooled reactors, with the AGRs achieving a combined average annual load factor of 75.6% in 1994, the highest of all reactor types worldwide. This remarkable improvement relative to the earlier performance resulted from successful efforts by Nuclear Electric to reduce trip rates and outage times, to improve the refuelling procedures and to increase thermal efficiencies. However, no further GCRs are planned in the UK, and development work will be concentrated on further improvements in plant performance and life extension of existing plants.

In France, about 200 reactor years of experience have been acquired through operation of eight Magnox-type reactors demonstrating the soundness, from a technical and safety point of view, of this reactor technology. However, the decision was made some time ago to concentrate on large pressurized water reactors, and the last of France's Magnox reactors, Bugey 1, was shutdown in 1994.

In Japan the 159 MW(e) Tokai-1 Magnox-type reactor continues to be a very successful plant.

The experience with the early helium cooled High Temperature Gas-cooled Reactors (HTGRs), the Dragon plant in the UK, the AVR in Germany and Peach Bottom in the USA was very satisfactory. The experience with the later HTGRs, Fort St. Vrain (330 MW(e)) in the USA and the THTR-300 (300 MW(e)) in Germany, was not entirely satisfactory. The problems which resulted in the shutdown of these plants were, however, not related to the basic reactor concept of helium cooling, and the use of graphite for neutron moderation and as a structural material, nor were they related to any safety concerns, but were primarily associated with technical and economic problems with first-of-a-kind systems and components.

2.2. Summary of national HTGR programmes

Active technology development programmes for HTGRs are proceeding in China, Japan and the Russian Federation.

In Japan an important milestone in development of gas-cooled reactors was reached in March 1991 with the start of construction of the High Temperature Engineering Test Reactor (HTTR) at the Oarai Research Establishment of the Japan Atomic Energy Research Institute (JAERI). This 30 MW(t) reactor will produce core outlet temperatures of 850°C at rated operation and 950°C at high temperature test operation. It will be the first nuclear reactor in the world to be connected to a high temperature process heat utilization system. Criticality is expected to be attained in 1998. The reactor will be utilized to establish basic technologies for advanced HTGRs, to demonstrate nuclear process heat application, and to serve as an irradiation test facility for research in high temperature

[a] *based on IAEA PRIS data base and including the small {~50MW(e)} Calder Hall and Chapel Cross units.*

technologies. The timely completion and successful operation of the HTTR and its heat utilization system will be major milestones in gas-cooled reactor development and in development of nuclear process heat applications.

In China, the Russian Federation and the USA development efforts for electricity producing systems concentrate on small modular HTGR designs with individual power ratings in the 80 to 280 MW(e) range. Strong emphasis is placed on achieving a high level of safety through reliance on inherent features and passive systems. Satisfying this objective forms the basis for the smaller power output of individual modules and for the reactor core configuration. Emphasis has also been placed on a maximum use of factory fabrication, as opposed to field construction, for better quality control and reduction in construction time.

A promising new approach to achieve economic advantage involves use of the modular HTGR with a gas turbine to achieve a highly efficient electric generating system. Recent advances in turbomachinery and heat exchanger technology have led to plant design and development activities in the USA and Russia, with the direct helium cycle as the ultimate goal. It is recognized that the unique features of the modular HTGRs will likely require prototype demonstration prior to design certification and commercialization. With the relatively small size of each power-producing module it is possible to contemplate such a demonstration with just one module, later expanding into a multi-module plant at the same site for commercial purposes. A Technical Committee Meeting on "Design and Development of GCRs with Closed Cycle Gas-Turbines" is scheduled for 30 October to 2 November 1995 at the Institute for Nuclear Technology, Tsinghua University in Beijing, China. A decision was recently made by the USA to focus on the ALWR concept and close out their GCR activities.

China's HTR development activities are focused on the 10 MW(th) Test Module HTR. Cconstruction of the HTR-10 Test Module began in late 1994 at the Institute of Nuclear Energy Technology of Tsinghua University in Beijing. This project will provide experience in design, construction and operation of an HTR. The test module is designed for a wide range of possible applications, for example, electricity, steam and district heat generation in the first phase, and process heat generation in the second phase.

In Germany a strong HTR technology programme was performed in the 1970s and 1980s, and an HTR design with a very high degree of safety has been developed both for electricity generation and for process heat applications. Inherent features and properties of HTRs are particularly conducive to achieving a nuclear technology that is "catastrophe free" and extensive research, development and demonstration activities have been conducted on key process heat plant components. The helium heated steam reformer, the helium/helium heat exchanger and the helium heated gas generator for coal refining have been successfully tested in pilot scale (e.g., 10 MW), and the AVR reactor has demonstrated operation at 950°C core outlet helium temperature.

In Switzerland, in the past, research activities for small HTR concepts including the gas-cooled district heating reactors have been conducted. Current HTR-related activities in Switzerland involve the PROTEUS critical experiments which are being conducted by an international team of researchers at the Paul Scherrer Institute in Villigen. Activities are underway in the Netherlands to assess the potential future role of modular HTRs as a highly safe technology for electric power generation. Other countries including Poland, Italy, Indonesia, and Israel have displayed interest in HTR technology and perform related assessments.

3. International Cooperation

The early development of nuclear power was conducted to a large extent on a national basis. However, for advanced reactors, international co-operation is playing a greater role, and the IAEA promotes international co-operation in advanced reactor development and application. Especially for designs incorporating innovative features, international co-operation can play an important role allowing a pooling of resources and expertise in areas of common interest to help to meet the high costs of development.

To support the IAEA's function of encouraging development and application of atomic energy for peaceful uses throughout the world, the IAEA's nuclear power programme promotes technical information exchange and co-operation between Member States with major reactor development programmes, offers assistance to Member States with an interest in exploratory or research programmes, and publishes reports on the current status of reactor development which are available to all Member States.

The activities carried out by the IAEA within the frame of the IWGGCR include technical information exchange meetings and co-operative Co-ordinated Research Programmes (CRPs). Small Specialists Meetings are convened to review progress on selected technology areas in which there is a mutual interest. For more general participation, larger Technical Committee Meetings, Symposia or Workshops are held. Further, the IWGGCR sometimes advises the IAEA to establish international co-operative research programmes in areas of common interest. These co-operative efforts are carried out through Co-ordinated Research Programmes (CRPs), are typically 3 to 6 years in duration, and often involve experimental activities. Such CRPs allow a sharing of efforts on an international basis and benefit from the experience and expertise of researchers from the participating institutes.

The IAEA's activities in gas-cooled reactor development focus on the four technical areas which are predicted to provide advanced HTGRs with a high degree of safety, but which must be proven. These technical areas are:

a) the safe neutron physics behaviour of the reactor core
b) reliance on ceramic coated fuel particles to retain fission products even under extreme accident conditions
c) the ability of the designs to dissipate decay heat by natural heat transport mechanisms, and
d) the safe behaviour of the fuel and reactor core under chemical attack (air or water ingress).

The first three are the subjects of Coordinated Research Programmes and the last was recently addressed in an information exchange meeting.

IAEA activities in HTGR applications focus on design and evaluation of heat utilization systems for the Japanese HTTR.

3.1. Co-ordinated Research Programmes (CRPs) in GCR development and application

3.1.1. CRP on Validation of Safety Related Physics Calculations for Low-enriched GCRs

To address core physics issues for advanced gas-cooled reactor designs, the IAEA established a CRP on Validation of Safety Related Physics Calculations for Low-enriched GCRs in 1990. At the initiation of this CRP the status of experimental data and code validation for gas-cooled reactors and the remaining needs were examined in detail at the IAEA Specialists Meeting [Ref. 1]. The objective of the CRP is to fill gaps in validation data for physics methods used for core design of advanced gas-cooled reactors fueled with low enriched uranium. Countries participating in this CRP include China, France, Japan, the Netherlands, Switzerland, Germany, the USA and the Russian Federation.

The main activities of the CRP are being carried out by a team of researchers within an international project at the PROTEUS critical experiment facility at the Paul Scherrer Institute, Villigen, Switzerland. Fuel for the experiments was provided by the KFA Research Center, Juelich, Germany, and initial criticality was achieved on July 7, 1992. Experiments are being conducted for graphite moderated LEU systems over a range of experimental parameters, such as carbon-to-uranium ratio, core height-to-diameter ratio, and simulated moisture ingress concentration, which have been determined by the participating countries as validation data needs. The Paul Scherrer Institute has been highly willing to incorporate experiments as defined by the several participating countries to provide results focused on their validation data needs. Key measurements being performed at PROTEUS which are providing validation data relevant to current advanced HTGR designs are summarized in Table 1. A summary of PROTEUS conditions is given in Table 2.

Table 1: Measurements at PROTEUS

* Shutdown rod worth
  - in core
  - in side reflector
* Effects of moisture ingress - for range of amount of moisture
  - on reactivity
  - on shutdown rod worth
* Critical loadings
* Reaction rate ratios (U-235, U-238, Pu-239)
* Neutron flux distribution

Table 2: PROTEUS Conditions

* UO_2 pebble fuel with 16.76% enrichment
* Core equivalent diameter = 1.25m
* Core H/D from 0.8 to 1.4
* C/U-235 from 5 630 to 11 120
* Water simulated by plastic inserts

Also data from the uranium fueled criticals at the Japanese VHTRC critical experiment facility on the temperature coefficient (to 200°C) of low enrichment uranium fuel have been provided by JAERI and analyzed by CRP participants. The results show that calculations of the temperature coefficient are generally accurate to within about 20 percent.

3.1.2. CRP on Validation of Predictive Methods for Fuel and Fission Product Behaviour in GCRs

The experience base for GCR fuel behaviour under accident conditions was reviewed at an IAEA Specialists Meeting in 1990 [Ref. 2], and a CRP on Validation of Predictive Methods for Fuel and Fission Product Behaviour in GCRs was initiated in 1993. Countries participating in this CRP include China, France, Japan, Poland, Germany, the USA and the Russian Federation. Within this CRP, participants are documenting the status of the experimental data base and predictive methods, cooperating in methods verification and validation and will identify and document the additional needs for methods development and experimental validation data.

Technical areas being addressed include:

* fuel performance during normal operation
* fuel performance during accidents (heatup)
  - non-oxidizing conditions
  - oxidizing conditions
* fission product behaviour during normal operation
  - behaviour of gaseous and metallic fission products
  - behaviour of plateout
* fission product behaviour during accident conditions
  - behaviour of gaseous and metallic fission products

- re-entrainment of plateout
- fission product behaviour in reactor building

* performance of advanced fuels

3.1.3. CRP on Heat Transport and Afterheat Removal for GCRs under Accident Conditions

A CRP on Heat Transport and Afterheat Removal for GCRs under Accident Conditions also began in 1993 and the experience base at its initiation was reviewed in an IAEA Technical Committee Meeting [Ref. 3]. Countries participating in the CRP include China, France, Japan, Germany, the USA and the Russian Federation. The objective of this CRP is to establish sufficient experimental data at realistic conditions and validated analytical tools to confirm the predicted safe thermal response of advanced gas-cooled reactors during accidents. The scope includes experimental and analytical investigations of heat transport by natural convection, conduction and thermal radiation within the core and reactor vessel, and afterheat removal from the reactor. Code-to-code, and code-to-experiment benchmarks are being performed for verification and validation of the analytical methods. Assessments of sensitivities of predicted performance of heat transport systems to uncertainties in key parameters are also being investigated. Countries are participating in these benchmarks and experimental activities according to their own specific interests. Table 3 lists the benchmarks and cooperation in experiments included within the CRP.

Table 3: Benchmark Exercises and Cooperation in Experiments Included within CRP

BENCHMARKS	COOPERATION IN EXPERIMENTS
■ Code-to-code (analyses of heatup accidents)	SANA-1
VGM	SANA-2 pebble / prism - open topic
GT-MHR	air / water RCCS - open topic
HTTR [(a)]	
HTR-10 [(a)]	
■ Code-to-experiment	
HTTR RCCS mockup [(a)]	
SANA-1 [(a)]	
ST-1565	
and others being considered	
■ Code-to-reactor	
HTTR RCCS	
(normal operation)	
Startup/shutdown	
HTR-10 RCCS	
(normal operation)	

[(a)] *1995 activities*

3.1.4. Coordinated Research Programme in HTGR applications

To foster international cooperation in HTGR applications the IAEA's Division of Nuclear Power and the Division of Physics and Chemistry have established a CRP on Design and Evaluation of Heat Utilization Systems for the High Temperature Engineering Test Reactor (HTTR). The ultimate potential offered HTGRs derives from their unique ability to provide heat at high-temperatures (e.g., in the range from about 550°C to 1000°C) for endothermic chemical processes and, at 850°C and above, for highly efficient generation of electricity with gas turbine technology [Ref. 4]. Heat from HTGRs can be used for production of synthesis gas and/or hydrogen and methanol by steam-methane reforming, production of hydrogen by high temperature electrolysis of steam and by thermochemical splitting of water, production of methanol by steam or hydrogasification of coal, and for processes which demand lower temperatures, such as petroleum refining, seawater desalination, district heating, and generation of steam for heavy oil recovery and tar sand mining. If the heat demand is not in the immediate vicinity of the reactor, a chemical heat pipe could be developed as a high temperature heat transporter.

Several IAEA Member States are concerned about global environmental problems which result from burning fossil fuels. The application of nuclear process heat can make a significant contribution to resolve these problems. In order to select the most promising heat utilization system(s) to be demonstrated at the HTTR, some Member States wish to cooperate in the design and evaluation of potential HTTR heat utilization systems. Countries participating in this CRP include China, Israel, Germany, Russia, Indonesia, Japan and the USA. The processes being assessed are selected by CRP participants according to their own national interests depending on status of technology, economic potential, environmental considerations, and other factors.

The following are being examined:

- Steam reforming of methane for production of hydrogen and methanol
- CO_2 reforming of methane for production of hydrogen and methanol
- Thermochemical water splitting for hydrogen production
- High temperature electrolysis of steam for hydrogen production
- Gas turbine for electricity generation
- Combined coal conversion and steam generation

In addition, testing of advanced intermediate heat exchangers will be examined.

The CRP participants are collaborating by exchanging existing technical information on the technology of the heat utilization systems, by developing design concepts and by performing evaluations of candidate systems for potential demonstration with the HTTR.

Key tasks of the CRP are to:

a) Define the R&D needs remaining prior to coupling to the HTTR
b) Define the goal of the demonstration with the HTTR
c) Prepare design concepts for coupling selected systems to the HTTR and perform preliminary safety evaluations, and
d) Check licensability of selected systems under Japanese conditions.

Based on evaluations up to now on technology status, the first priority candidate systems to be connected to the HTTR are (1) steam (and/or CO_2) methane reforming system and (2) gas-turbine system. For other cnadidate systems the R&D shall be continued to bring them to the stage in their technology development when they will be considered feasible to be demonstrated at the HTTR.

More detailed information is included in a companion paper [Ref. 5].

3.2. Information exchange meetings (1993-1996)

3.2.1. GCR response under accidental air or water ingress

The IAEA Technical Committee Meeting on "Response of Fuel, Fuel Elements and Gas-cooled Reactor Cores under Accidental Air or Water Ingress Conditions" was hosted by the Institute for

Nuclear Energy Technology (Tsinghua University, Beijing, China) in October 1993 [Ref. 6]. Some key conclusions from the Technical Committee are summarized in the following.

The response of gas cooled reactors to postulated air and water ingress accidents is highly design dependent and dependent upon the cause and sequence of events involved. Water ingress may be caused by tube ruptures inside the steam generator due to the higher pressure in the secondary loop. The core can only be affected if steam or water is transported from the steam generator to the reactor. Air ingress is possible only after a depressurization accident has already taken place and has to be looked at as an accident with a very low probability.

Considerable experimental data exists regarding behaviour of GCRs under air ingress conditions. These experiments have shown that self sustained reaction of reactor graphite with air does not occur below about 650°C and above this temperature there is a window of air flow rates: low flows supply insufficient oxidizing gas and fail to remove the reaction products, whereas convective cooling at high flows will overcome the chemical heating. Nuclear grade graphite is much more difficult to burn than coal, coke or charcoal because it has a higher thermal conductivity making it easier to dissipate the heat and because it does not contain impurities which catalyze the oxidation process.

Two serious accidents have occurred which have involved graphite combustion: Windscale (October 1957) and Chernobyl (April 1986). It is important to clearly understand these accident sequences, and the significant differences in the design of these reactors, compared to gas-cooled reactors, which use graphite as moderator and either helium or carbon-dioxide as coolant. Windscale was an air cooled, graphite moderated reactor fueled with uranium metal clad in aluminum. The accident was most likely triggered by a rapid rate of increase in nuclear heating (that was being carried out for a controlled release of the Wigner energy) which caused failure of the aluminum cladding. This exposed the uranium metal, which is extremely reactive, to the air coolant, and resulted in a uranium fire, which caused the graphite fire. Water was finally used to cool down the reactor after other efforts failed. Chernobyl was a water cooled, graphite moderated reactor. The rapid surge in nuclear power generation at Chernobyl resulted from a series of safety violations and core neutronic instabilities. Eventually liquid nitrogen was used to cool the burning debris. It must be emphasized that gas cooled reactors neither use air as coolant (as in Windscale) nor have core neutronic instabilities such as those of the Chernobyl reactor.

Safety examinations of German modular HTR design concepts are addressing even very hypothetical accidents such as the complete rupture of the coaxial hot gas duct. A large scale experiment, called NACOK, is being constructed at the KFA Research Center, Juelich, Germany to measure the natural convection of ingressing air and to provide data for validating theoretical models.

As a part of the safety review of the HTTR, extensive investigations have been carried out by JAERI of that reactor's response to air ingress accidents including rupture of the primary coaxial hot gas duct and the accident involving the rupture of a stand pipe attached to the top head closure of the reactor pressure vessel. Experimental and analytical investigations have shown that graphite structures would maintain their structural integrity because of the limited amount of oxygen within the volume of the containment which is available to oxidize graphite. Further, there is no possibility of detonation of the produced gases in the containment. Experimental test results showed that there is a large safety margin in the design of the core support posts.

JAERI has examined the response of the HTTR to a design basis accident involving rupture of a pipe in the pressurized water cooler. The ingress of water is sensed by the plant protection system instrumentation resulting in reactor scram and isolation of the pressurized water cooler. Analyses show that the amount of ingressed water is insufficient to result in opening of the primary system safety valves, and the auxiliary cooling system rapidly reduces the core temperatures thereby limiting the oxidation of the graphite structures to acceptable levels. Similar investigations have been conducted by INET for design basis accidents of the HTR-10 reactor assuming the rupture of one or two steam generator pipes.

The neutronic effects of moisture ingress on core reactivity and on control rod worth are being examined in Switzerland at the PROTEUS facility. Neutronic effects of water are simulated by inserting polyethylene (CH_2) rods into the core as this material has essentially the same hydrogen density as water. The effect of increasing amounts of "water" is first to increase the core reactivity to a maximum due to under moderation of the neutrons under normal conditions, followed by a reactivity decrease as neutron absorption by hydrogen becomes the dominating factor. Further, water addition into the core has the effect of reducing the worth of the shutdown rods. In the experiments to date, these effects have been well predicted, reflecting perhaps the mature state of reactor physics analysis methods.

To ensure the ultimate goal of a catastrophe-free nuclear energy technology, additional analyses of extreme hypothetical accident scenarios should be performed and, in parallel, methods for enhancing the passive corrosion protection of the graphite fuel elements and structures could be used. Experimental activities in Germany, China, Russia and Japan have shown that ceramic coatings can considerably increase the corrosion resistance of graphite. At the Technical University in Aachen and the KFA Research Center Jülich, Germany, a successful coating method has been developed which is a combination of silicon infiltration and slip casting methods to provide a SiC coating on the graphite. Corrosion tests have been conducted simulating accident conditions (massive water and air ingress) at temperatures to 1200°C. Future efforts are required to examine the behaviour of the ceramic coatings especially with neutron irradiation. Activities at INET have involved forming SiC coatings on graphite structures by exposing them to melted silicon. Oxidation experiments have shown very large reduction in oxidation rate compared to uncoated graphite. Other activities at INET have shown that addition of superfine SiC powder to the fuel element matrix graphite greatly reduces graphite oxidation because SiO_2 is formed by SiC-oxygen reaction thereby partly covering and isolating the graphite micropores from further corrosion. Demonstration of the high resistance to oxidation by air or water of SiC coating on graphite surfaces including successful tests on irradiated structures could result in advantages from a public acceptance point of view as well as a technical point of view for the future design of HTGRs.

The close examination of experience presented to the Technical Committee led to the conclusion that plant safety is not compromised for design basis accidents. Continued efforts to validate the predictive methods against experimental data are worthwhile. Protective coatings for fuel and graphite components which provide high corrosion resistance should continue to be developed and tested as these potentially could provide assurance of safety even for very extreme and hypothetical water or air ingress accident conditions.

3.2.2. Development status of modular HTGRs and their future role

The IAEA Technical Committee Meeting on "Development Status of Modular HTGRs and their Future Role" was hosted by the Netherlands Energy Research Foundation (ECN), Petten (the Netherlands) from 28 to 30 November 1994 on the occasion of the ECN workshop on the role of Modular High Temperature Reactors in the Netherlands, 30 November to 1 December 1994.

The Technical Committee Meeting was convened within the IAEA's Nuclear Power Programme on the recommendation of the IAEA's International Working Group on Gas-cooled Reactors (IWGGCRs). It was attended by participants from China, France, Germany, Indonesia, Japan, the Netherlands, Switzerland, Russia and the United Sates of America. The meeting reviewed the national and international status and activities of the following topics for high temperature reactors (HTRs):

* status of national GCR programmes and experience from operation of GCR's
* advanced HTR designs and predicted safety and economic performance
* future prospects for advanced HTRs and the role of national and international organizations in their development

Though considered an advanced type of nuclear power reactor, helium cooled, graphite moderated reactors have been under development for almost forty years. This Technical Committee Meeting was attended by experts from many countries in the nuclear power community, and represented a significant pooling of experience, technology development and aspirations. While the future role of helium cooled reactors cannot be stated with any certainty, this IAEA Technical Committee Meeting brought to focus the major technical issues, challenges and benefits affecting their future development and deployment.

3.2.3. 12th Meeting of IWGGCR

The 12th Meeting of the International Working Group on Gas-Cooled Reactors (IWGGCR) was hosted by the Netherlands Energy Research Foundation (ECN), Petten, the Netherlands on 2 December 1994 on the occasion of the IAEA Technical Committee Meeting on "Development Status of Modular HTGRs and their Future Role", from 28-30 November 1994 and the ECN workshop on "The Role of Modular HTRs in the Netherlands", 30 November - 1 December 1994. The meeting was attended by representatives from China, France, Germany, the Netherlands, Japan, Switzerland, the United Kingdom, the Russian Federation and the Nuclear Energy Agency of the OECD and by observers from Indonesia and the United States.

The IWGGCR welcomed the representative from the Netherlands to the Working Group as its newest official member.

The IWGGCR congratulated the Japanese Atomic Energy Research Institute (JAERI) on the good progress of the construction of the High Temperature Engineering Test Reactor (HTTR) at Oarai. The IWGGCR also congratulated the Institute of Nuclear Energy Technology (INET), Tsinghua University, Beijing on the start of construction of the HTR-10 Test Module at INET.

The meeting provided an international forum for information exchange between representatives of Member countries regarding their Gas-Cooled Reactor programmes. The members of the IWGGCR strongly felt that the present international cooperation conducted within the frame of the IWGGCR in the field of gas-cooled reactors is of benefit to their own national programmes and recommended that the Agency continue its information exchange actiities and cooperative research programmes in gas-cooled reactor development and application.

3.2.4. Graphite moderator life cycle technologies

Graphite has played an important role as a moderator and major structural component of nuclear reactors since the start of atomic energy programmes throughout the world. Currently there are many graphite moderated reactors in operation which will continue to produce power until well into the next century: also there are graphite moderated reactors currently under construction and others in the design stage.

The last IAEA Specialists Meeting on the status of graphite technology was convened in Tokai-mura, Japan in September 1991. Since that time considerable operating experience has been gained, and materials development and testing programs which are of international interest have been conducted. It is therefore considered appropriate for the international expertise in the nuclear graphite field to be brought together to exchange technical information on graphite lifecycle technologies.

The IAEA, following the recommendation of the International Working Group on Gas-cooled Reactors (IWGGCR), is planning to convene a Specialists Meeting on Graphite Moderator Lifecycle Technologies at the University of Bath, United Kingdom from 25-28 September 1995. A technical tour of an AGR reactor is also foreseen on 28 September, and a tour of the Windscale site is foreseen on 29 September.

The purpose of the meeting is to exchange information on the status of graphite development, on operation and safety procedures for existing and future graphite moderated reactors, to review experience on the influence of neutron irradiation and oxidizing conditions on key graphite properties and to exchange information useful for decommissioning activities. The meeting is planned within the frame of the International Working Group on Gas-cooled Reactors.

It is intended that the programme should involve all topics from the conception of the reactor design through the safe operation and monitoring of the core to the removal and safe disposal of the graphite cores at the end of life. The topics to be included are:

* status of national programmes in graphite technology
* carbon/carbon composites for in-core application
* core design
* core monitoring
* codes and standards
* graphite fuel element manufacture
* graphite property behaviour
* irradiation damage mechanisms
* radiolytic oxidation
* operation and safety procedures for graphite moderated cores
* seismic responses of graphite cores

3.2.5. Design and development of Gas-cooled Reactors with Closed Cycle Gas Turbine

The International Atomic Energy Agency is planning to convene a Technical Committee Meeting and Workshop on "Design and Development of Gas-cooled Reactors with Closed Cycle Gas Turbines" at the Institute of Nuclear Energy Technology, Tsinghua University, Beijing, China from 30 October to 2 November 1995.

The meeting is being convened within the frame of the IAEA's International Working Group for Gas-cooled Reactors (IWGGCR).

The purpose of the meeting is to provide the opportunity to review the status of design and technology development activities for high temperature gas-cooled reactors with closed cycle gas turbines (HTGR-GTs), and especially to identify development pathways which may take advantage of the opportunity for international cooperation on common technology elements.

Recent advances in turbomachinery and heat exchanger technology provide the potential for a quantum improvement in nuclear power generation economics by use of the HTGR with a closed cycle gas turbine. The HTGR-GT offers highly efficient generation of electrical power and a high degree of safety based on inherent features and passing systems. Enhanced international cooperation among national GCR programmes in common technology elements, or building blocks, for HTGRs with closed cycle gas turbines, could facilitate their development with overall reduced development costs. In addition to the common elements being addressed currently through IAEA Coordinated Research Programmes, the technical areas in which international cooperation could be beneficial include fabrication technology and qualification of the coated fuel particles, materials development and qualification, and development and testing of turbomachinery, magnetic bearings and heat exchangers.

The first day will consist of paper presentations on national and international activities on gas cooled reactors, and utility interest and economics of HTGR-GTs. This will be followed by two days of Workshop sessions on the following topics for HTGRs with closed cycle gas turbines:

a) power conversion
b) plant safety

c) fuel and fission product behaviour
d) materials

The Workshops will include technical paper presentations and discussions focusing on the status, needs, and proper development pathways in these technical areas. Reports will be drafted in the Workshops summarizing the status and development needs and especially identifying pathways for international cooperation in development and demonstration in common technology elements. The final day will involve presentations of reports by the Workshop chairmen to the Technical Commitee and discussion of these reports.

3.2.6. 13th meeting of IWGGCR

The 13th meeting of the IWGGCR will be convened in Spring of 1996 in Vienna. The topic for the second TCM to be convened in 1996 will be selected at this meeting.

3.3. Status report on GCR technology

At its 12th meeting the IWGGCR discussed the question of whether a new report on the status of GCR technology in 1995 should be prepared and issued. IAEA as an organization for promoting international cooperation and for providing a forum for exchange of information for advanced nuclear technologies offered coordination and publishing services for such a status report provided member countries of the IWGGCR support such activity and are willing to provide contributions about their national activities.

The last status report has been issued in 1990 and described mainly GCR designs under consideration in 1988/1989. In this report emphasis was put on technical design details and safety features. In the meantime program directions have changed in almost all member states. New developments have been initiated, others have been terminated.

In the UK significant progress has been made regarding technical performance and consequently economic figures of the AGRs. In Japan construction of the HTTR test reactor for high temperature applications has started and is proceeding on schedule. Process heat application possibilities are being prepared in an IAEA CRP. In China the decision to build a 10 MW HTR test reactor has been made and construction has started. The HTR program in the US has been modified and is now aiming at the development of a highly economic design of a modular HTGR with an integrated gas turbine. For the development and realization a cooperation agreement has been made with the Russian Federation. In the Netherlands HTR design evaluating activities have been launched within the PINK programme. In Germany, governed by strong antinuclear movements, the HTR program has been terminated, but significant know-how is available and HTR-useful R&D activities are going on.

Altogether, the working group expressed its opinion that the program redirections and the progress achieved in the last years together with very helpful contributions of IAEA within four CRPs are important and should be described in a new status report for distribution to IAEA member states. It was suspected that the new GCR achievements and the developments trends and tendencies are not sufficiently known in other interested countries. However, a next report describing the present status should also make clear that the HTR technology currently remains in a R&D status. Background and reasons for the delay of commercial HTR deployment should be included, the goals of present national strategies and their similarities, i.e. keeping open a very potential option for the future, should be elaborated.

The working group recommended that IAEA should take initiative for the preparation of a next version of a GCR status report. IAEA was willing to prepare an outline of a report for distribution to working group members for review and comments. The finally accepted outline should provide the basis for subsequent contributions of member states. An expanded outline has been prepared. The next step is to develop a first draft based on inputs from Member States. This is anticipated for early 1996.

3.4. Other forms of IAEA support

Several forms of IAEA support are also available for Member States interested in gas-cooled reactors but which do not have major development programmes. Upon official request, technical assistance can be arranged for developing countries for providing expert advice, training, fellowships and special equipment for research. This will assist developing countries to establish the expertise for incorporating advanced gas-cooled reactor technologies into their power generation programmes in the future.

4. Conclusions

Considerable gas-cooled reactor operating experience has been attained through operation of Magnox and AGR reactors, and the basic concept of helium-cooled graphite-moderated HTGRs has been technically proven with the Dragon plant in the UK, the AVR and THTR reactors in Germany and Peach Bottom and Fort St. Vrain in the USA. Construction is well underway on the HTTR engineering test reactor in Japan and completion and operation of the HTTR and its heat utilization system will be major milestones in gas-cooled reactor development and in development of nuclear process heat applications. Construction of a test module is planned to begin in 1994 in China. Further development efforts are on going in several countries including technology development for HTGRs with gas turbines for highly efficient generation of electricity, and future plants are predicted to attain a very high degree of safety through reliance on inherent features and passive systems.

IAEA programmes foster exchange of technical information and encourage cooperative research on gas-cooled reactors. Current IAEA activities focus on safety technology and heat utilization system technology. Especially for advanced reactors with innovative features, international cooperation can play an important role in their development and application.

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THE HTR-10 TEST REACTOR PROJECT AND POTENTIAL USE OF HTGR FOR NON-ELECTRIC APPLICATION IN CHINA

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Abstract

Coal is the dominant source of energy in China. This use of coal results in two significant problems for China; it is a major burden on the train, road and waterway transportation infrastructures and it is a significant source of environmental pollution. In order to ease the problems caused by the burning of coal and to help reduce the energy supply shortage in China, national policy has directed the development of nuclear power. This includes the erection of nuclear power plants with water cooled reactors and the development of advanced nuclear reactor types, specifically, the high temperature gas cooled reactor (HTGR).

The HTGR was chosen for its favorable safety features and its ability to provide high reactor outlet coolant temperatures for efficient power generation and high quality process heat for industrial applications. As the initial modular HTGR development activity within the Chinese High Technology Programme, a 10MW helium cooled test reactor is currently under construction on the site of the Institute of Nuclear Energy Technology northwest of Beijing. This plant features a pebble-bed helium cooled reactor with initial criticality anticipated in 1999. There will be two phases of high temperature heat utilization from the HTR-10. The first phase will utilize a reactor outlet temperature of 700°C. with a steam generator providing steam for a steam turbine cycle which works on an electrical/heat co-generation basis. The second phase is planned for a core outlet temperature of 900°C. to investigate a steam cycle/gas turbine combined cycle system with the gas turbine and the steam cycle being independently parallel in the secondary side of the plant. This paper provides a review of the technical design, licensing, safety and construction schedule for the HTR-10. It also addresses the potential uses of the HTGR for non-electric applications in China including process steam for the petrochemical industry, heavy oil recovery, coal conversion and seawater desalination.

1 The HTR-10 Project

1.1 Project background

The rapid economic development in China at present and in the future demands correspondingly rapid increases in energy supply. Coal plays the dominant role in China's energy supply systems, which causes great problems in terms of transport burden and environmental pollution. To ease the overall problem of energy supply shortage and the problems caused by coal burning, China has decided to make much use of nuclear energy. Besides the erection of nuclear power plants with water cooled reactors, the national nuclear policy also includes the development of advanced nuclear reactor types to prepare for more intensified utilization of nuclear energy in the next century.

The high temperature gas-cooled reactor (HTGR) is the only reactor type which can offer a coolant temperature over 700°C. This feature has two benefits: it makes power generation very efficient; and it can supply process heat for a variety of industrial applications. In the last decades, the development of HTGR technology has focused on modular reactor designs. These are characterized by favourable safety features, particularly in the area of inherent safety. China recognizes the advantages of the modular HTGR and has decided to develop this technology. In the energy supply systems of the next century, the HTGR will have two roles, namely to supplement water-cooled reactors for electricity generation and to provide an environmentally friendly heat source, providing process heat at different temperatures for various industrial applications.

As the first important step of the modular HTGR development, a 10 MW helium cooled test reactor (termed as HTR-10) shall be built. It is projected within the framework of China's High Technology Programme. The test reactor will be erected on the site of the Institute of Nuclear Energy Technology (INET) in a northwest suburb of Beijing.

In China, research and development work on HTGR technology started in the 1970s. Before the HTR-10 project was finally approved in 1992, R&D activities had focused on fuel fabrication, helium technology, design methodology, concept design and application potential studies.

1.2 Project objectives

The HTR-10 project is to be carried out in two phases. In the first phase, the reactor will be operated with a coolant outlet temperature of 700°C. It will be coupled with a steam generator providing steam for a steam turbine cycle which works on an electricity / heat co-generation basis. The process flow diagram of the first phase is given in Fig. 1. In the second phase, it is planned to raise the reactor coolant outlet temperature to 900°C. A gas turbine cycle, with an intermediate heat exchanger (IHX) in between, will be coupled to the reactor in addition to the steam turbine cycle. The process flow diagram of the second phase is given in Fig. 2. Experimental studies on high temperature process heat application, e.g. coal gasification, are also planned to be performed using the nuclear heat of HTR-10. Construction of HTR-10 is scheduled to be completed before the end of the century. When the HTR-10 has been erected, it will enable the following aims to be met:

- Acquiring know-how in the design, construction and operation of HTGRs.
- Establishing an irradiation and experimental facility.
- Demonstrating the inherent safety features of modular HTGR.
- Testing electricity / heat co-generation and closed gas turbine technology.
- Carrying out R&D work on high temperature process heat application.

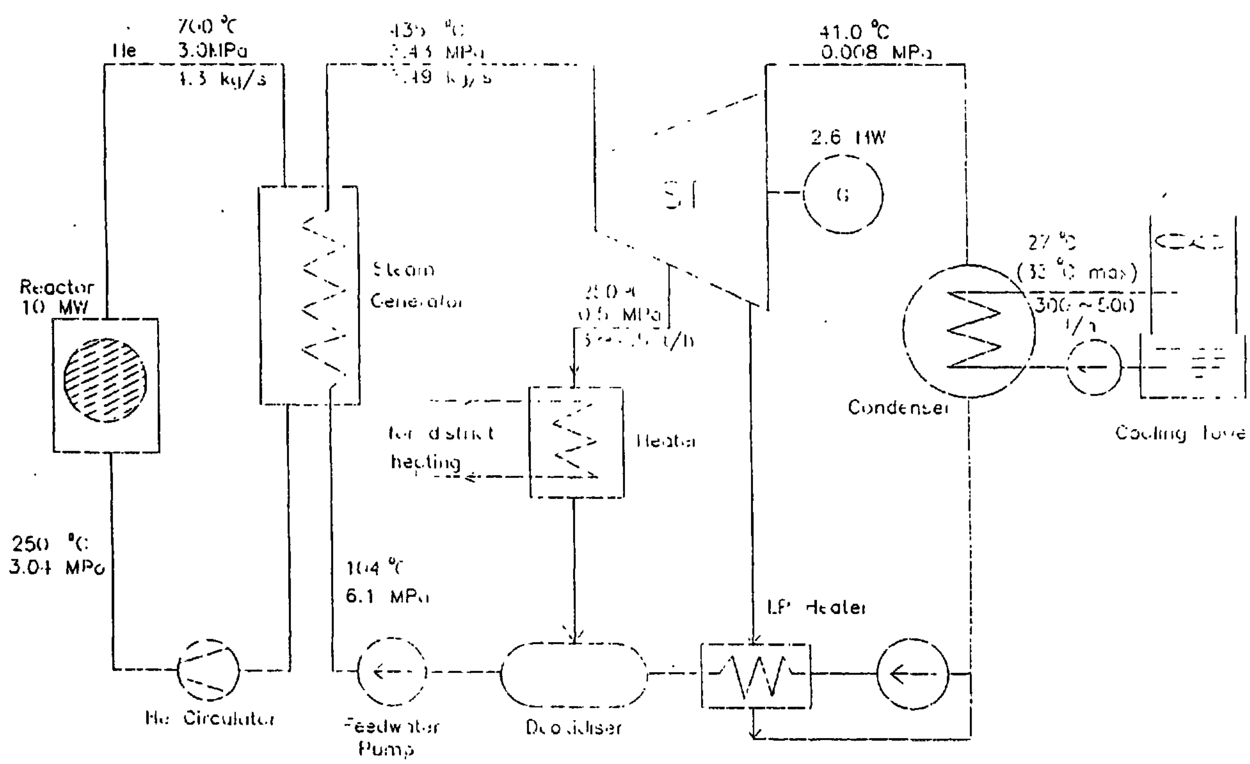


FIG. 1. Flow scheme of HTR-10 steam-turbine cycle.

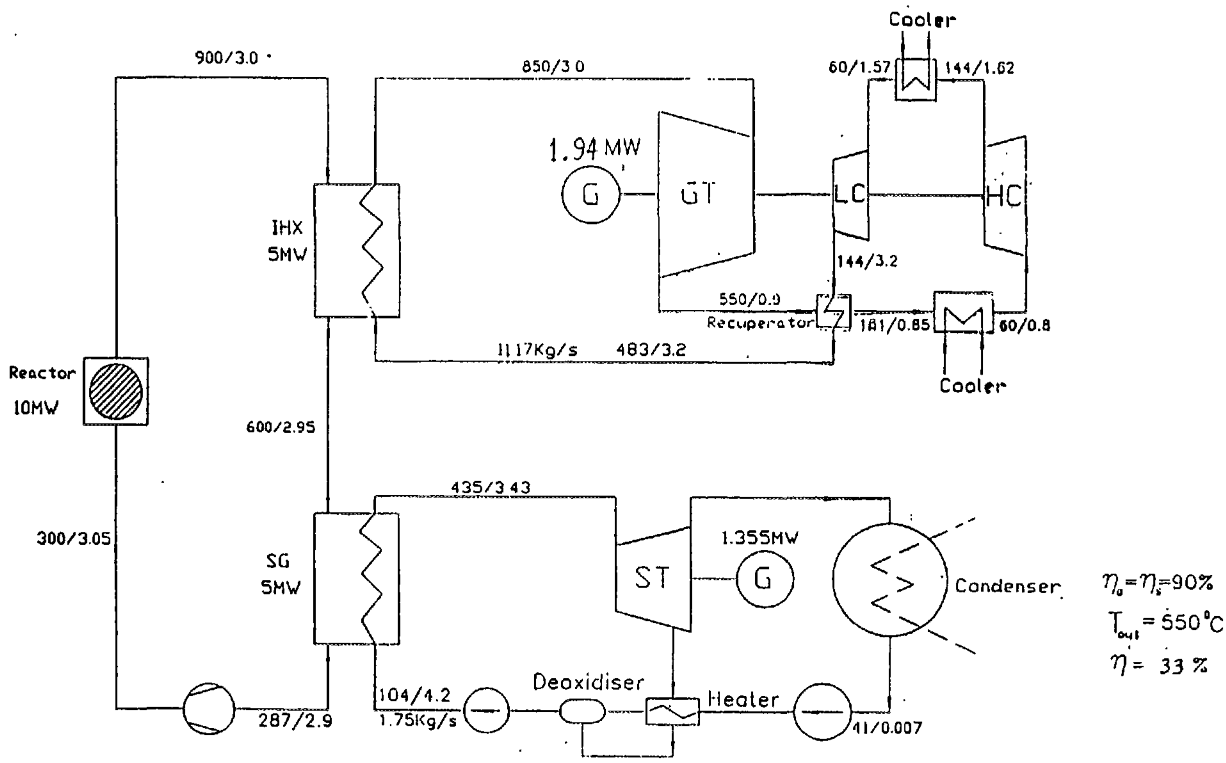


FIG. 2. The HTR-10TM/GT-ST Cycle Process.

1.3 Technical design of the HTR-10 test reactor

Technical design of the HTR-10 test reactor represents the features of modular HTGR design. Reactor core and steam generator are housed in two steel pressure vessels which are arranged in a "side-by-side" way (Fig. 3). The two vessels are connected to each other by a connecting vessel in which the hot gas duct is designed. All these steel pressure vessels are in touch with the cold helium of about 250°C coming out from the circulator which sits over the steam generator tubes in the same vessel. The key design parameters are listed in Table 1.

Spherical fuel elements (6 cm in diameter) with coated particles are used. The reactor core contains about 27,000 fuel elements forming a pebble bed which is 180 cm in diameter and 197 cm in average height. Graphite serves as the main material of core structures which mainly consist of the top, bottom and side reflectors. The ceramic core structures are housed in a metallic core vessel which is supported on the steel pressure vessel. Side reflector is 100 cm thick. In the side reflector, cold helium channels are designed in which helium flows upward after entering the reactor from between the connecting vessel and the hot gas duct. Helium flow reverses at the top of reactor core into the pebble bed, so that a downward flow pattern takes place in it. After being heated in the pebble bed, helium enters into a hot gas chamber in the bottom reflector, and from there it flows with reactor outlet temperature through hot gas duct to the heat exchanging components.

The steam generator is composed of a number of modular helical tubes which are arranged in a circle between two insulation barrels inside the steam generator pressure vessel. The place inside the inner barrel is foreseen for the IHX which is to be installed in the second phase of the project. The IHX will be a large helical tube type with the primary helium flowing outside the tubes.

Decay heat removal is accomplished on a completely passive basis. At a loss of pressure accident, against which no core cooling is foreseen at all, decay power will dissipate through the core structures by means of heat conduction and radiation to the outside of the reactor pressure vessel, where, on the wall of the concrete housing, a surface cooling system is designed. This system works on the principle of natural circulation of water and it takes the decay heat via air coolers to the atmosphere. In fact, this surface cooling system is designed to protect the vessel and concrete structures more than the ceramic reactor core from being overheated by decay power.

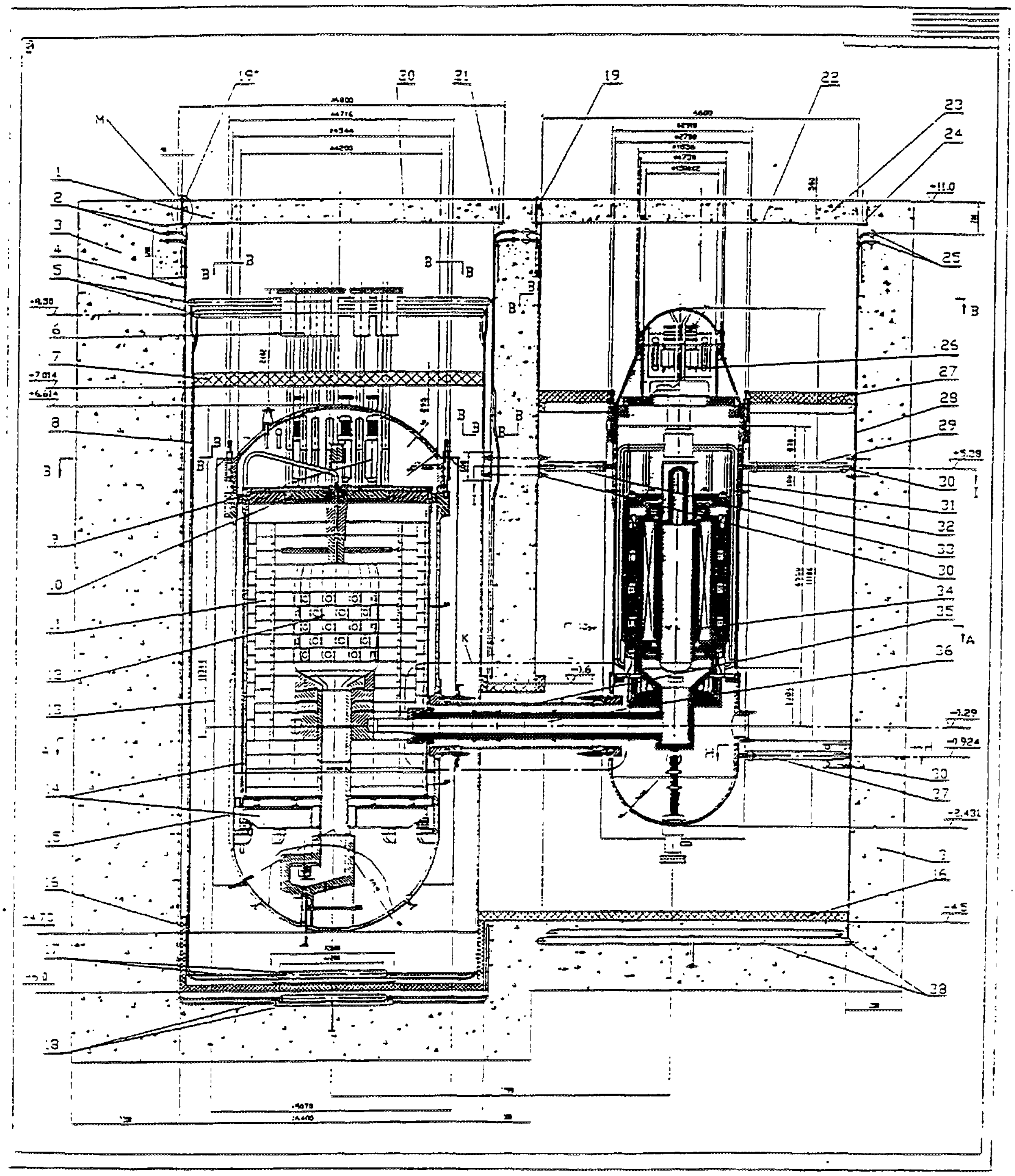


FIG. 3. HTR-10 reactor and steam generator arrangement in the primary cavity.

There are two reactor shutdown systems, one control rod system and one small absorber ball system. They are all designed in the side reflector. Both systems are able to bring the reactor to cold shutdown conditions. Since the reactor has strong negative temperature coefficients and decay heat removal does not require any circulation of the helium coolant, turning off the helium circulator can also shut down the reactor from power operating conditions.

Spherical fuel elements go through the reactor core in a "multi-pass" pattern. Fuel pebbles are continuously discharged via a pneumatic pulse single-exit gate (or better called "serializer") which is placed inside the reactor pressure vessel. The burn-up of the discharged fuel elements is measured individually and those fuel elements which have not reached the limit value will be sent back pneumatically to the reactor core.

Table 1 Key design parameters of the HTR-10 test reactor

Items		First phase	Second phase
Reactor			
Thermal power	MW	10	
Average core power density	MW/m^3	2	
Reactor core diameter	cm	180	
Average core height	cm	197	
Primary helium pressure	MPa	3.0	
Average helium temperature at reactor inlet / outlet	°C	250 / 700	300 / 900
Helium mass flow rate at full power	kg/s	4.3	3.2
Number of control rods in side reflector		10	
Number of absorber ball units in side reflector		7	
Nuclear fuel		UO_2	
Heavy metal loading per fuel element	g	5	
Enrichment of fresh fuel element	%	17	
Number of fuel elements in reactor core		27,000	
Fuel loading mode		multi-pass	
Steam generator			
Thermal power	MW	10	5
Primary helium inlet / outlet temperature	°C	700/250	600/287
Live steam pressure at steam generator outlet	MPa	4.0	4.0
Feedwater / live steam temperature	°C	104/435	104/435
Live steam flow rate	kg/s	3.47	1.75
Intermediate heat exchanger (IHX)			
Thermal power	MW		5
Primary helium inlet / outlet temperature	°C		900/600
Secondary nitrogen pressure	MPa		3.2
Secondary nitrogen inlet / outlet temperature	°C		483/850
Secondary nitrogen flow rate	kg/s		11.2

No pressure-containing and leak-tight containment is designed. The concrete compartments, which house the reactor and the steam generator as well as other parts of the primary pressure boundary and which are preferably called as confinement, together with the accident ventilation system, serve as the last barrier to the radioactivity release into the environment.

1.4 Project progress

1.4.1 Safety review and licensing

The Environmental Impact Report (EIR) of HTR-10 was compiled and submitted it to the National Environmental Protection Administration (NEPA) in the mid of 1992. The report was reviewed by an expert committee, then NEPA approved the EIR of HTR-10 in November 1992.

The Siting and Seismic Report (SSR) of HTR-10 was submitted to the National Nuclear Safety Administration (NNSA) and the reactor site was approved in December 1992.

The Preliminary Safety Analysis Report (PSAR) and the Quality Assurance Programme were completed and submitted to NNSA for the application of the construction permit (CP) in December 1993. The activities of the CP licensing procedure lasted for one year. NNSA formally issued the construction permit for HTR-10 in December 1994.

1.4.2 Design of HTR-10

For the design and licensing requirement, INET has prepared two technical documents which are the *Design Criteria for HTR-10* and the *Format and Content of the Safety Analysis Report of HTR-10*. These two documents were reviewed and approved by NNSA in August 1992 and March 1993 respectively.

The basic design and budget estimate of HTR-10 was carried out in the mid of 1994 and then examined and approved by both the State Education Commission (SEC) and the State Science and Technology Commission (SSTC) before the end of 1994.

The detailed design of the components, systems and buildings is being carried out by INET under cooperation with sub-contractors who are respectively responsible for the helium purification system and other helium auxiliary systems, the turbine generator system and its building. For the detailed design of the main components e.g. the reactor pressure vessel, the steam generator and the helium circulator, design engineers of INET have closely contacted and discussed with the manufacturing engineers to modify and improve the designs. The detailed design of HTR-10 is scheduled to be completed in the next year.

1.4.3 Engineering experiments

A programme of engineering experiments for the HTR-10 key technologies is being conducted in INET. The main aims of these engineering experiments are to verify the designed characteristics and performance of the components and systems, to give feedback on design and to obtain operational experiences.

The various experimental facilities have been set up or are being established. Some experiments are being made. The key engineering experiments are as following:

- high temperature helium test loop and the relevant helium technology
- fuel handling system test
- control rod driving mechanism test
- small absorber ball simulating system
- hot gas duct test facility
- stability test of the steam generator
- helium flow temperature mixing
- pebble bed flow pattern

The test components of the fuel handling system and the small absorber ball system, the prototype of the control rod driving apparatus and the test section of the hot gas duct are designed in 1:1 scale. The tests are to be performed at operation temperatures and under helium atmosphere condition. The tests of the fuel handling system and the small absorber ball system under air condition at room temperature have been carried out.

1.4.4 Manufacturing of the main components

The main HTR-10 components, such as the reactor pressure vessel and its metallic internals, the steam generator vessel and its internals and the helium circulator are fabricated by domestic factories which have the ability and experience of manufacturing PWR's components. Graphite blocks for core internals and part of the safety grade helium valves will be imported from foreign suppliers. Spherical fuel elements will also be made indigenously.

The reactor pressure vessel is a safety grade I component. It has an overall height of 11.4 m, and a diameter of 4.2 m. The total weight is 142 t. It is fabricated by Shanghai Boiler Works. The metallic core internals, which consist of the metallic core vessel, top thermal shielding structure and the bottom support structures, will be manufactured by Shanghai Machine Works No.1. The reflector graphite blocks will be supplied by Toyo Tanco Co. Ltd. of Japan. The final machining of the graphite blocks is to be done in the workshop of INET. The carbon bricks of the reflector will be domestically fabricated.

The steam generator pressure vessel as part of the primary pressure boundary is also a safety grade I component. It has a height of 11.2 m, a diameter of 2.5 m and the total weight is 70 t. The once-through type steam generator consists of 30 small helical heating tubes. This component (vessel and internals) is fabricated by Shanghai Power Station Auxiliary Equipment Works.

The helium circulator is a vertical single-stage centrifugal one with the impeller at the end of the shaft. The circulator has the same axle with its driving motor and is fixed in the circulator pressure vessel which is the top part of the steam generator vessel. The helium circulator is fabricated by the Shanghai Blower Works.

The original German NUKEM manufacturing apparatus for fuel elements fabrication were transferred to INET in the first half of 1995, so that fuel elements for HTR-10 are to be fabricated by INET itself.

The components of the fuel handling system, the helium purification system and other auxiliary systems will also be domestically made.

1.4.5 Building construction

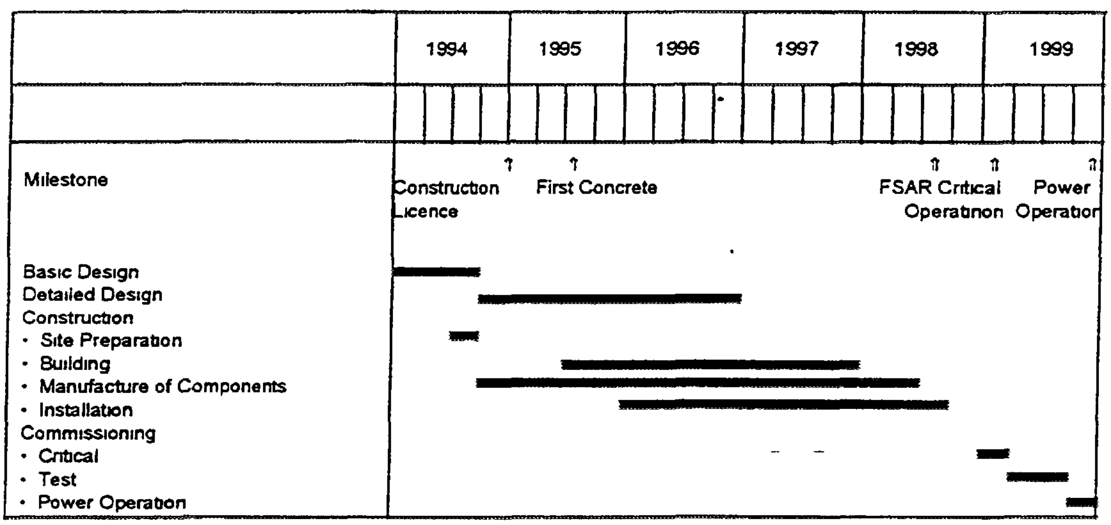
The HTR-10 test plant includes a reactor building, a turbine generator building with two cooling towers and a ventilation centre with a stack. The buildings are to be arranged and constructed on an area of $100 x 130 m^2$. Overall arrangement of these buildings is shown in Fig. 4.

Civil engineering work of the buildings are contracted to engineering companies of China National Nuclear Corporation (CNNC). The ground excavation was completed at the end of 1994. The first concrete of the reactor building fundament was poured on 14. June 1995. Civil work of building construction is now underway.

1.4.6 Time schedule

The time schedule for the HTR-10 project is shown in Table 2. The reactor building construction will last for two and a half years and is scheduled to be complete at the end of 1997. In parallel, the manufacturing and installation of components, and systems will closely follow the progress of building construction and will be complete at the end of 1998. The first criticality of the reactor is planned to be reached in the beginning of 1999.

Table 2 Time schedule of the HTR-10 test reactor project



2 Potential Use of HTGR for Non-electric Applications in China

Modem modular design of HTGR plants is characterized by excellent safety features. These plants can be built near highly populated areas. This, together with the capability to provide high temperature process heat, allows modular HTGR to be used for a variety of non-electric applications. As part of the national nuclear policy, utilization of nuclear energy for heat supply is promoted in China. Utilization of nuclear energy instead of fossil fuels for heat supply can help to ease the problems of energy supply shortages and environment pollution.

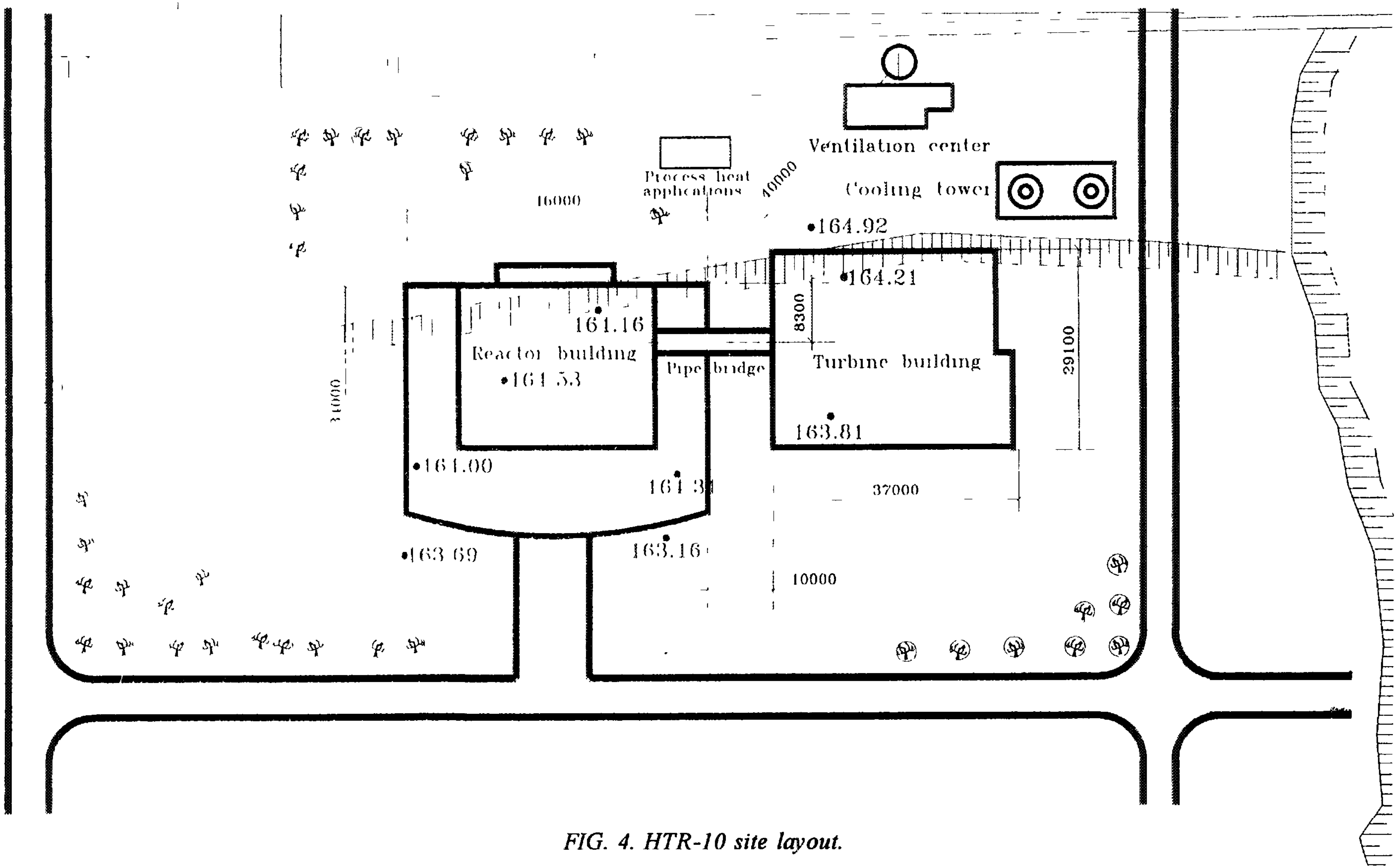


FIG. 4. HTR-10 site layout.

2.1 Process steam for petrochemical industry

Petrochemical industry is a large energy consumer in terms of both electricity and process heat consumption. HTGR plants, working on a co-generation basis, are a suitable energy supplier in this field. In the late 1980's, a Sino-German joint study was made on the application of modular HTGR in petrochemical industry. The complex of the Yan Shan Petrochemical General Corporation (YSPGC) has been selected as the reference user candidate in the study.

The annual energy consumption for supplying steam, process heat and electricity in the YSPGC complex is in the range of 1.2 million tons of oil. The total requirement of steam in the different pressure and temperature ranges is approx. 730 t/h in summer and 1650 t/h in winter. The steam parameters are 118bar / 500°C, 47~50bar / 450°C, 34~39bar / 350°C and 8~13bar / 280°C. The way of steam supply is mainly by steam-electricity co-generation. Total electricity supply capacity in the plant area was up to 120MWe in 1987 and should be increased in the following years for expanded production capacity.

Based on the above demand on steam and electricity, a HTGR-4-module plant is suggested with the following key parameters:

- Thermal power output: 4 x 200 MWth =800 MWth
- Live steam mass flow: 4 x 250 t/h = 1000 t/h
- Live steam pressure / temperature: 190 bar / 530 °C

The four modules supply the steam for operating three back-pressure turbines and for providing the heat source for four process steam systems (Fig. 5). The secondary water/steam circuit is separated from the process steam systems by heat exchanging components to avoid mixtures. The industrial process water feeding the four process steam systems is taken from a cold water storage and jointly preheated up to 170°C. The outputs of the overall plant are as follows:

- Electricity output of generator: 139 MWe
- Process steam of 118bar / 500°C: 30.24 t/h
- Process steam of 48bar / 450°C: 73.08 t/h
- Process steam of 36bar / 350°C: 310 t/h
- Process steam of 10bar / 280°C: 500 t/h

In the joint study, another reference plant design with two ABB-HRB reactor modules was also made.

The economic analysis performed within the framework of the joint study show that HTGR plants for the application in petrochemical industry are competitive with comparison to fossil fueled plants on the basis of international market price for fossil fuels. With the energy market in China becoming more and more international and due to the fact of huge energy consumption by the chemical industry, HTGR should have a large application potential in this field.

2.2 Heavy oil recovery

The heavy oil geological reserve is relatively rich with respect to the overall oil reserve in China. It is estimated that heavy oil resources constitute about one-sixth of the total crude oil reserve. Since the beginning of 1980s, heavy oil recovery by injecting steam had been practiced in several oilfields in order to increase the crude oil production. In the pilot areas of thermal recovery, the injected steam is generated with small oil-fired boilers. About 30~40% of the produced crude oil should be consumed for generating the injected steam. Using HTGR instead of oil-fired boilers is an option for the technology of heavy oil thermal recovery.

For the investigation on the use of HTGR in heavy oil recovery, a Sino-German joint study was performed in the late 1980s. In this study, the Shanjiasi section of Shengli oilfield has been selected as a reference case. The main aims of the study are to find out whether (a) the physical properties of the Shanjiasi reservoir are suited for a steam driving process with a HTGR plant and (b) the nuclear steam is economic compared to conventional steam generated by oil-fired boilers.

The heavy oil resource of the reservoir is expected to be about 66~100Mt. Production capacity by means of thermal recovery aims at about 1Mt per year with subsequent upgrading in a special refinery. In the study, a heavy oil recovery scenario with soak and drive process is proposed (Fig. 6). In this scenario, oil production capacity of 1 Mt per year may last for about 13 years with steam soak and steam drive process. Then, production with steam soak should decrease, and production with steam drive process should remain for the rest 20 years. It means that in total, a

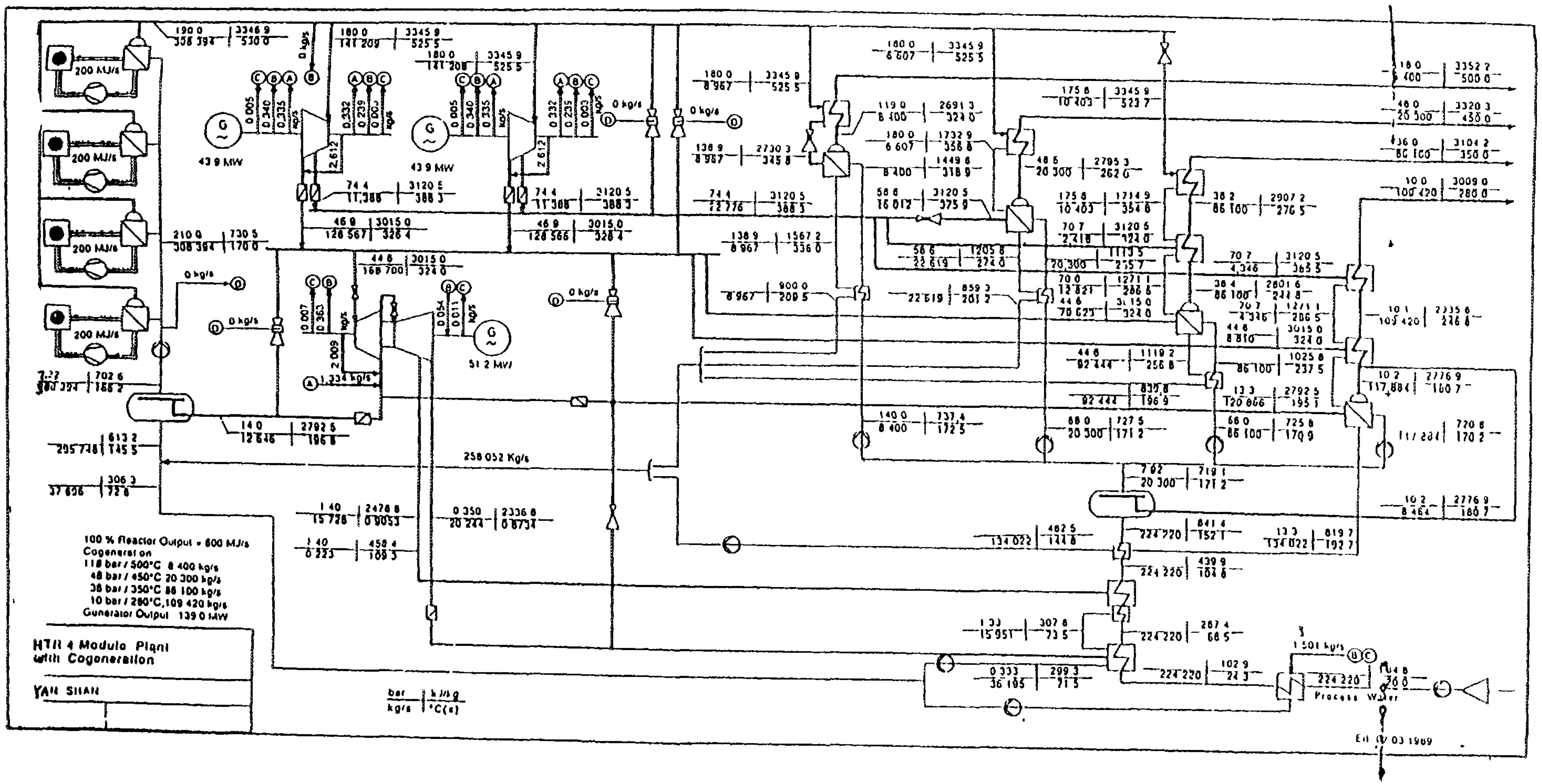


FIG. 5. 4 x 200 MW HTR-M Plant for Yan Shan Petrochemical Complex with cogeneration.

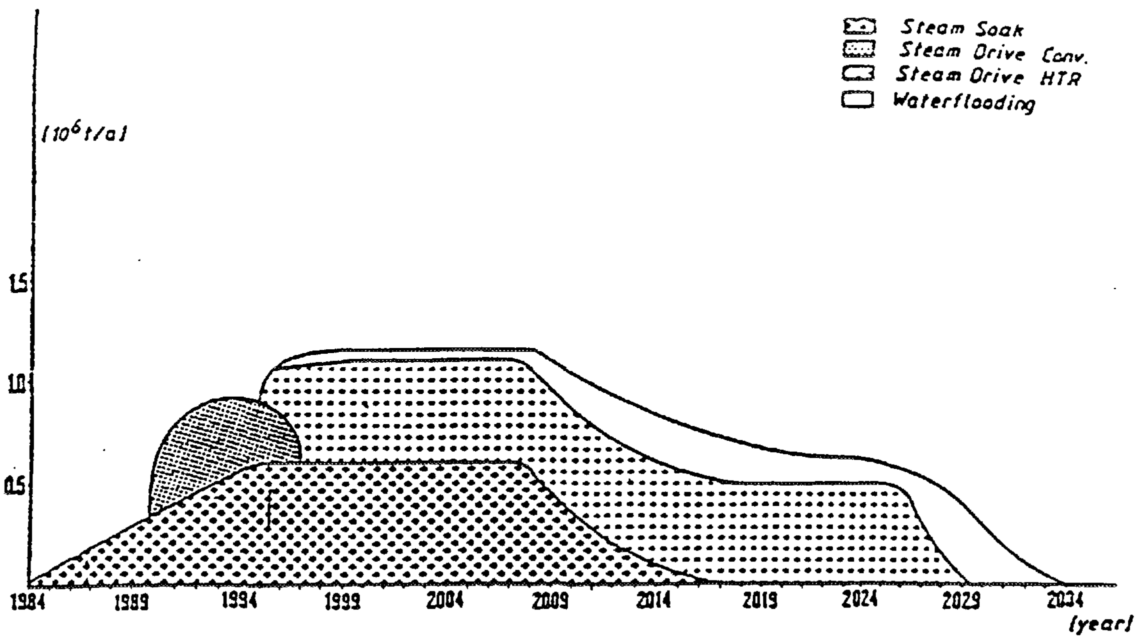


FIG. 6. The transition from conventional to HTR steam generation (1 HTR, OOIP = 66 Mt, steam-oil ratio = 4 for steam drive phase).

duration of about 33 years with a nearly continuous oil production of 0.5 Mt per year by means of nuclear steam. According to preliminary investigation, a steam-to-oil ratio of 4 can be expected. Under this boundary condition, a steam production capacity of 2 Mt/a (equivalent to 250 t/h) by HTGR is needed. This steam amount can be generated by a 200 MWth modular reactor. In the study, a 2-Module plant is proposed as an energy source for the Shanjiasi oilfield which also produces electricity to meet the electricity demand in the oilfield area. It is proposed to interconnect the water/steam circuits of the two steam generators so that the plant works on a co-generation basis (Fig. 7). The plant has an electrical output of about 75 MW. The HTGR co-generation plant for the utilization in heavy oil recovery can be a technically and economically viable option under certain conditions concerning mainly the plant properties, the oil price development and the capital investment.

The study on the case of Shanjiasi oilfield should be taken as a sample. Other oilfields with similar properties can also be good candidates for utilizing HTGR in their heavy oil recovery.

2.3 Coal conversion

It is estimated that to the mid of the next century, the gap between national demand and indigenous supply of oil in China will reach to 200~300 Mt. Therefore, the shortage in the supply of liquid form energy carriers will become an increasingly serious problem. China is richly endowed with coal resources which are estimated at about 970 billion tons. Converting coal into liquid form energy carriers will be a technical option to ease the above problem. It is estimated that about 40% of the coal resources in China is suitable for gasification process. HTGR is the only reactor type which can provide high temperature heat for coal conversion processes. Therefore, there is potential for HTGR to be used in this field. There are active R&D activities on coal conversion technology with HTGR in China and it is expected that HTGR will play an important role in this regard from a long term point of view.

2.4 Other applications

District heating with HTGR on a co-generation basis is a viable option for Chinese conditions. There are lots of highly densely inhabited cities, towns or zones. District heating is a common practice, there is a relatively good infrastructure for nuclear district heating.

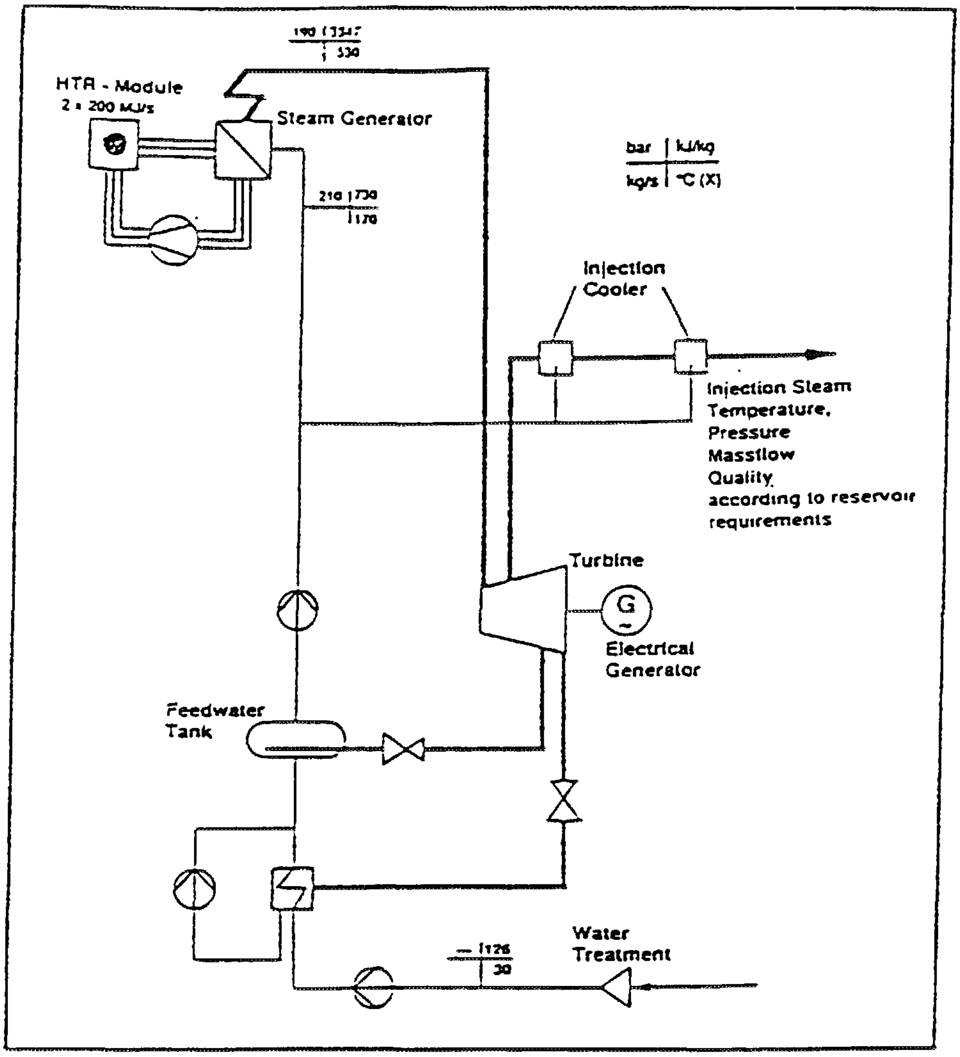


FIG. 7. HTR-2-module plant for cogeneration of injection steam and electric power.

Seawater desalination is another application aspect of modular HTGR. Shortage in fresh water supply in a number of coastal cities or areas is a serious problem. There have been recently activities in the direction of using low temperature water cooled reactors for seawater desalination. As long as modular HTGR becomes a available technology, it can also supply low parameter steam for desalination purposes with only minor design modifications in the power conversion part.

Other non-electric applications of modular HTGR from a long term point of view may include high temperature process heat supply for hydrogen production processes and for metallurgical processes.

3 Summary

Great importance is attached in China to the development of modular high temperature gas-cooled reactor technology. As the first important step, a 10 MW test reactor is now being constructed and is scheduled to be erected before the end of this century. Non-electric applications like district heating and coal conversion with nuclear energy are to be tested with the test reactor.

There is a large potential in China to use HTGR for non-electric applications in the future. These applications can cover a wide range of process temperature. Seawater desalination, district heating, heavy oil recovery, process steam for petrochemical industry, high temperature heat supply for coal conversion or other processes are possible utilization areas.

CHINESE DEVELOPMENT OF WATER-COOLED REACTORS FOR NON-ELECTRIC APPLICATIONS

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Abstract

China is a very densely inhabited land where approximately 75% of the primary energy consumption is contributed by coal. The strong dependence on coal results in two significant problems, the burden on transportation and the emission of environmental pollutants. Distances between coal production and consumption result in a burden on China's railway, road and water transport systems of approximately 40%, 25%, and 20% of their respective capacities. Environmentally, although the per capita annual CO2 emission is well under the world average, China ranks third after the USA and Russia in CO2 emission. Both of these problem can be alleviated through the increase use of nuclear energy.

A dominant consumer of China's primary energy is in the form of heat application, of which district heating is a significant portion. The State is supporting the development of nuclear heating reactors for district heating purposes. The Institute of Nuclear Energy Technology (INET), with the support of the State, completed the construction of a 5MW test nuclear heating reactor in 1989. Since then, this reactor has been successfully operated for heating purposes, safety demonstration experiments and for tests on other applications. Subsequently, a 200MW commercial nuclear heating demonstration plant was approved by the State Council and design and licensing work on this plant is currently in progress at INET. This paper provides a review of the design parameters for these two nuclear heating plants.

Other applications of the nuclear heating reactor, including seawater desalination, air conditioning and as an industrial process steam supply are currently under consideration. INET has considered two designs of a nuclear desalination plant (steam only and co-generation) coupled with the 200MW nuclear heating reactor. Also, INET is investigating use of this reactor for air conditioning and process chilled water production. The current status of these efforts are described in this paper.

1 Introduction

Coal plays the dominant role in China's primary energy supply systems. About 75% of the primary energy consumption is contributed by coal. On the spectrum of primary energy consumption, about 70% of the primary energy is consumed in the form of heat application, of which district heating takes a significant part. China is a highly densely inhabited land. Although district heating with coal is a common practice, a considerable population lacks sufficient room heating due to energy supply shortages.

The strong dependence of the primary energy supply on coal leads above all to two problems. The first one is the transport burden. Because the regions of coal production and consumption in China are in most cases rather far away from each other, the produced coal must be usually transported after a long distance to the end user. According to the statistics in 1990, the average coal transport distance was 548 km. Coal transportation takes up more than 40%, 25% and 20% respectively of the rail way, road and water transport capacity.

The second problem caused by coal burning, which is drawing worldwide rapidly increasing attention and which sees at present no practical solutions unless coal burning itself is limited, is that it results in the emission of environmental pollutants, of which carbon dioxide is of special concern in terms of the greenhouse effect. A total amount of 608 Mt carbon (in CO_2) was emitted in China in 1987, which made China ranking the third after USA and the former USSR on the world list. But because of the huge population, the per capita annual CO_2 emission with 0.6 t carbon was still under the world average of 1.3t.

If nuclear energy can be economically used for the district heating purpose, it can significantly help to ease the problems stated above. Therefor, the state has supported the development of nuclear heating reactor (NHR) technologies. In 1989, a test NHR with 5 MW power output was erected. Now, a 200 MW nuclear heating demonstration plant (NHR-200) is being projected.

Along with the development of NHR technologies, other applications are also proposed, e.g. using NHR for seawater desalination or air conditioning, to which increasing importance is being attached.

2 Development of Nuclear Heating Reactors

Under the support of the state, the Institute of Nuclear Energy Technology (INET) in Beijing has been developing water-cooled nuclear heating reactors since the 1980's In 1983 and 1984, INET conducted successful tests of nuclear district heating using the existing swimming pool type research reactor. In 1984, INET began the project of erecting a 5MW test NHR on the site of the institute which is about 40km away to the north of Beijing city. The construction of the 5MW NHR started in 1986 and was finished in 1989. In November 1989 the test reactor went critical. Since then, the reactor has been successfully operated for heating purpose. The test reactor has also been operated for safety demonstration experiments or and for tests of other applications.

On the basis of the successful 5MW test reactor, several cities and large enterprises have shown their strong interests in building NHRs. A 200MW commercial nuclear heating demonstration plant has been newly approved by the state council. The plant is going to be built In Daqing oilfield in the northeast part of China. Design and licensing work of this demonstration plant is now intensively going on.

Figure 1 shows the overall design of the 5MW test NHR and the 200MW demonstration NHR, while the main design parameters of these two reactors are listed in Table 1.

Both the 5MW and the 200MW heating reactor are of vessel type design. Their main technical and safety features are briefly summarized as follows.

- Integrated design. Both the reactor system and the primary heat exchangers are integrated into the pressure vessel. This compact integrated design minimizes the possibility of large LOCA accidents.

- Full power natural circulation cooling. At all power levels, the reactor power is designed to be carried out by means of natural circulation, eliminating circulating pumps and ensuring higher system reliability. This is also true for the reactor decay heat removal.

Table 1 Main design parameters of the nuclear heating reactors

Reactor		NHR-5	NHR-200
Thermal Power	MW	5	200
Primary pressure	MPa	1.5	2.5
Core inlet / outlet temperature	°C	146 / 186	140 / 210
Height of the active core	m	0.69	1.90
First core UO_2 loading	t	0.508	14.5
Enrichment of the first core loading	%	3.0	1.8/2.4/3.0
Enrichment of the reload fuel	%	3	3
Intermediate circuit pressure	MPa	1.7	3.0
Intermediate circuit temperature	°C	102 / 142	95 / 145
Heating grid temperature	°C	90/60	130/80

- Duel vessel design. The steel containment vessel is designed closely surrounding the pressure vessel. In case of a very unlikely failure of the pressure vessel, the containment vessel will ensure the flooding of the reactor core without any emergency cooling actions.

- Hydraulic driving mechanism of the control rods. A new driving mechanism of the control rods by hydraulic means has been developed and utilized. This design simplifies the reactor structure design and eliminates the accident of rapid rod ejection.

- Primary pressure self-regulation. With the help of a certain inventory of nitrogen in the primary loop, the primary pressure regulates itself very stable at the designed level.

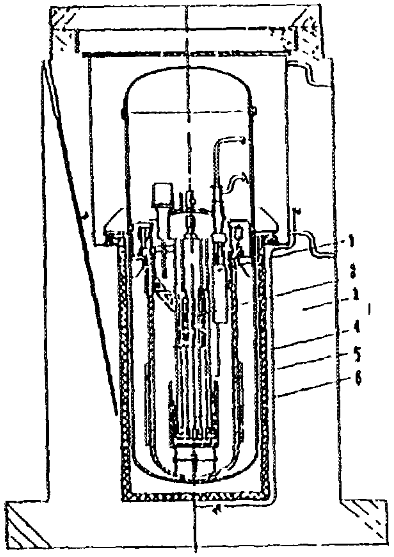
- Low parameters. The design parameters are chosen which are suitable for district heating purposes and they are much lower than those of large electricity generating reactors. This brings more safety advantages and makes the reactor operation simpler and easier.

In China, a 200MW nuclear heating reactor, with the assistance of a conventional boiler for peak load, can meet the demand of 5 million square meter heating area. This will substitute per year for 0.25 million tons of coal, which saves correspondingly the large amount of emission of pollutants from burning coal. Quantitatively it will also save the coal transportation of 150 million ton kilometers. Therefore, nuclear heating brings much social and environmental benefit.

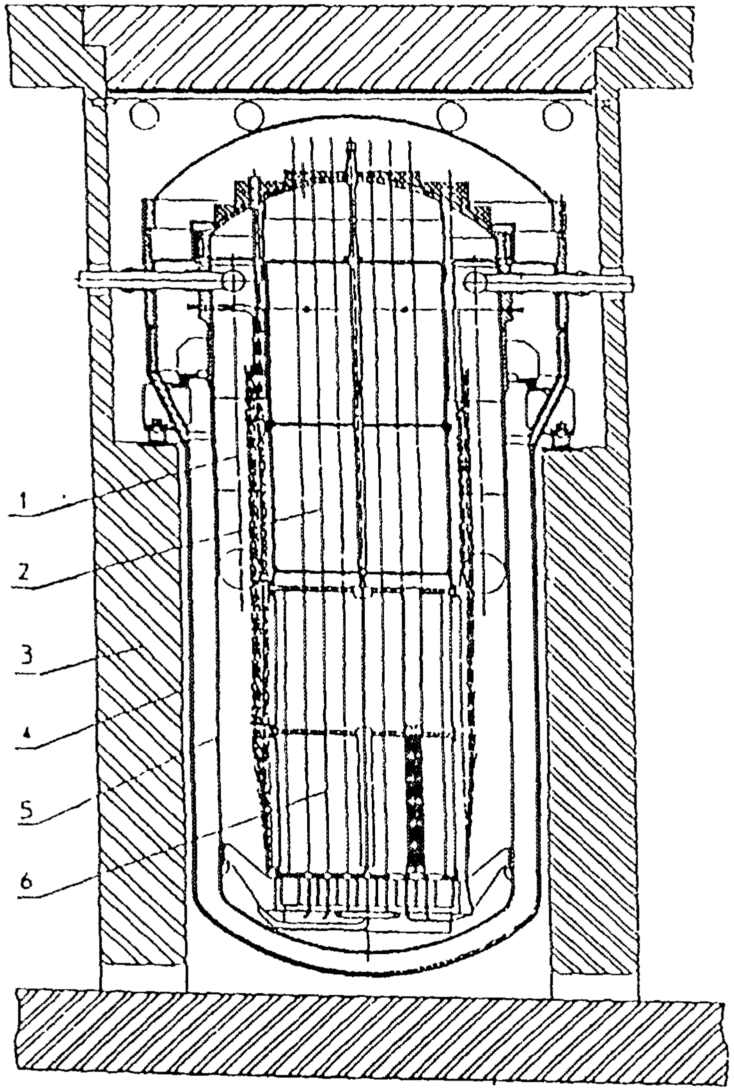
3 Other applications with NHR

3.1 Seawater desalination

The nuclear heating reactor parameters perfectly match the requirements on the heat source for seawater desalination processes. Two different processes may come into consideration: MED (Multi-Effect Distillation) and MSF (Multi-Stage Flash), both of which require a large amount of heat supply as energy source. Based on an evaluation of the technological status of these two processes, MED process is chosen for desalination using NHR.



5MW test heating reactor



1. Primary heat exchanger
2. Riser
3. Biological shield
4. Containment
5. Pressure vessel
6. Reactor core

200MW demonstration heating reactor

Figure 1 The 5MW test NHR and the 200MW demonstration NHR

If the heat source steam temperature is higher, more vaporation-condensation effects can be realized which leads to more production of fresh water per unit steam, resulting in a larger gain-output ratio (GOR). The efficiency of MED process depends heavily on the formation of a liquid film on the surface of the evaporator. In recent years, the thermal energy consumption has been around 30~60 kWh/m^3 worldwide. In addition, the small amount of electricity required for pumping the seawater and fresh water is in the range of 2~3 kWh/m^3.

A NHR power system for seawater desalination can be designed in two principal ways. In the one way, the nuclear system can be designed to provide steam only for desalination, and in the other way it could provide both steam and electricity based on a co-generation principle. The choice among these two systems depends mainly on site features. The electricity generated in the electricity/heat co-generation plant shall be used for the self-consumption of the heating reactor plant and for the electricity consumption in the desalination process.

INET has considered two designs of a nuclear desalination plant, one supplies steam only (Option 1) and the other works on co-generation basis (Option 2), both of which include a NHR of 200 MWth. The simplified schematic diagram of the NHR seawater desalination plant is shown in Figure 2. Table 2 gives the key design parameters of such nuclear desalination systems.

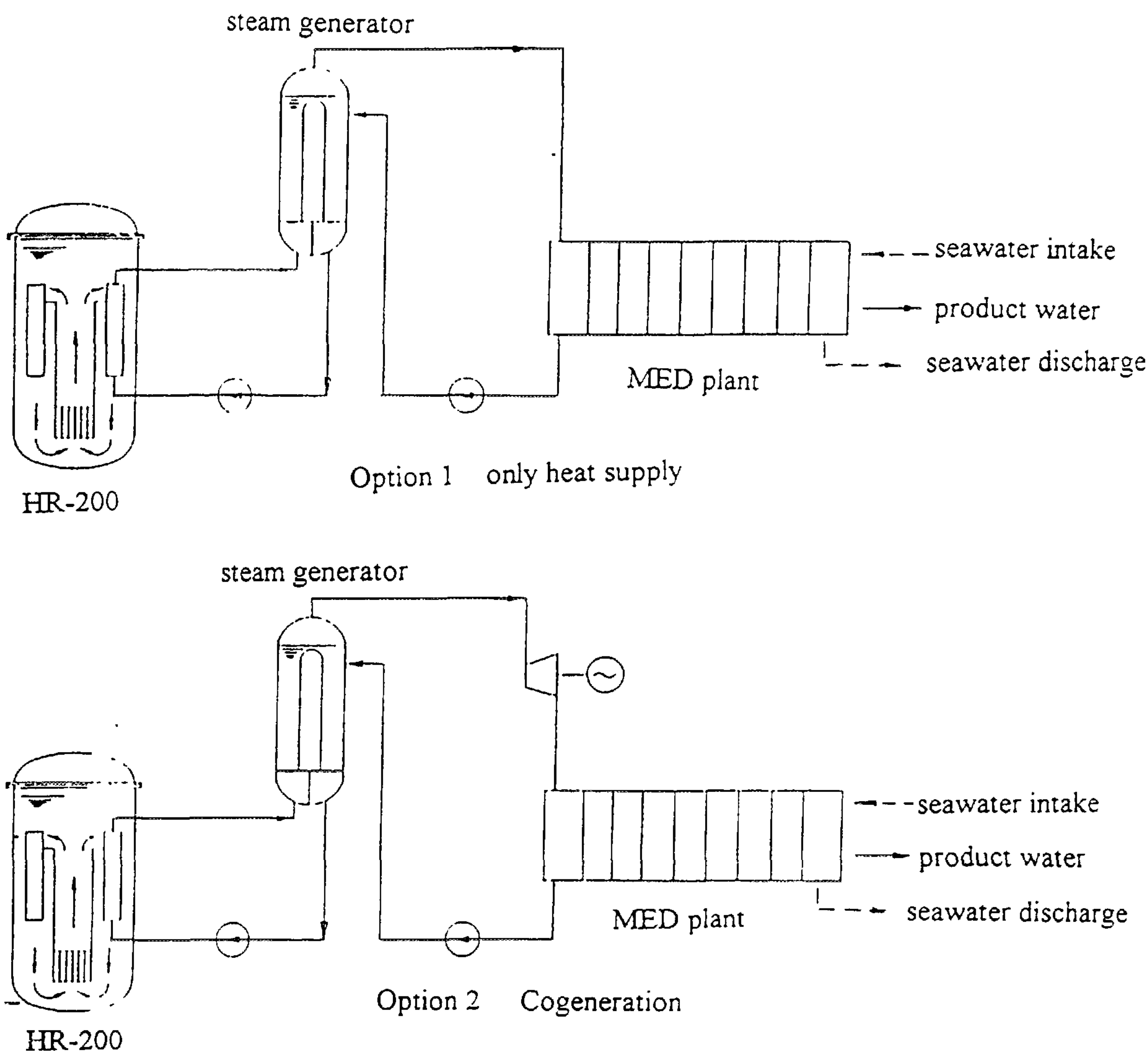


Figure 2 Simplified flow diagram of seawater desalination using NHR

Table 2 Key design parameters for 200 MW nuclear MED desalination plant

Design parameters		Steam only	Co-generation
Reactor thermal power	MW	200	200
Pressure in primary circuit	MPa	2.5	2.5
Temperature at reactor core inlet/outlet	°C	154 / 213	154 / 213
Inlet/outlet temperature of the secondary circuit	°C	135 / 163	144 / 170
Steam temperature	°C	130	141
Maximum seawater temperature	°C	120	105
Number of trains		6	5
Gain-output ratio (GOR)		20	17
Fresh water production	m^3/d	144,000	120,000

Within the first option, low pressure steam at a temperature of 130°C generated in the secondary circuit steam generator will be directly introduced to the MED desalination plant. A GOR of 20 is designed and the daily fresh water production shall be 144,000 m^3. With the second option, the generated steam at a temperature of 141°C will be firstly used for electricity generation for the electricity needs in the desalination plant and in the nuclear plant. Steam with lower pressure and temperature extracted from the last stage of the turbine will go to the sea water desalination system. The maximum fresh water output will be 120,000 m^3/d with a GOR of 17.

There are several advantages in using a nuclear heating reactor for seawater desalination. Compared with using fossil fueled plants, using nuclear heating reactor can not only save large amount of valuable coal and oil resources and ease environmental pollution, but also can be economically competitive under certain conditions. Nuclear heating reactors may be more suitable for developing countries with respect to its smaller scale, simple system design and easier component manufacturing. In China, a number of coastal cities are encountered with the problem of fresh water supply shortage. The initiation of a nuclear desalination project with NHR is in progress.

3.2 Nuclear refrigeration

If a nuclear heating reactor is utilized only for district heating in the winter season, its average load factor can be hardly higher than 50%. This brings disadvantages to the economical attractiveness of NHR. Using a nuclear heating reactor for air conditioning and process chilled water production is an important way to overcome the above mentioned problem. With the development of nuclear refrigeration, nuclear heating reactors may also be constructed for southern cities of China, where the very hot summer season lasts very long.

In the NHR refrigeration system proposed by INET, the reactor provides the energy supply for a LiBr absorption refrigeration system. This is a commercially available technology. A simplified process flow diagram is given in Figure 3 to show the working principle of such a system. Chilled water is produced and distributed to end users for e.g. air conditioning purposes.

In order to accumulate experiences in using NHR for the LiBr absorption process, a test has been made with the 5MW test NHR. A double-effect LiBr absorption refrigeration

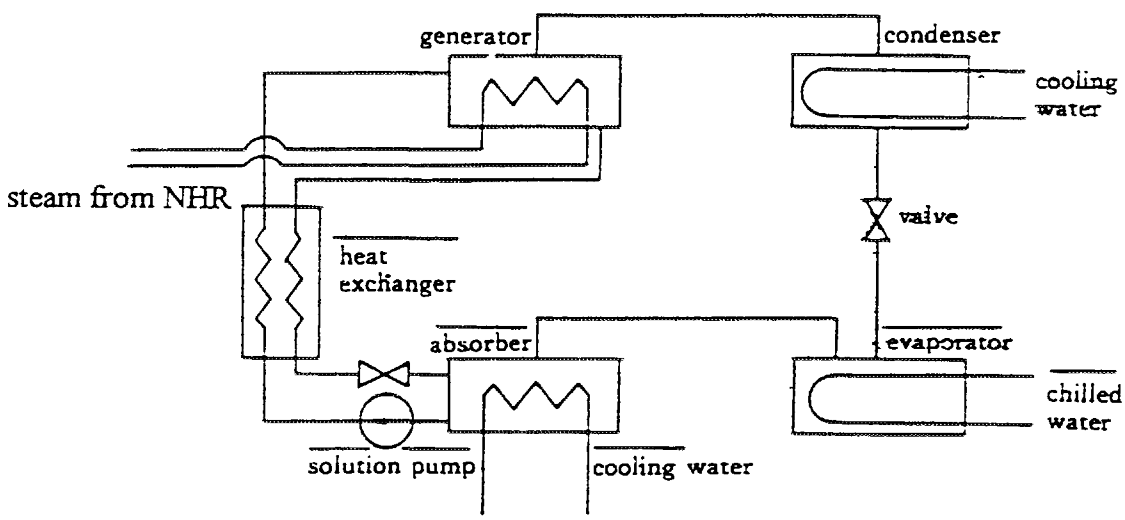


Figure 3 Principle flow diagram of LiBr refrigeration using NHR

machine with a power of 0.84GJ/h was used. The steam pressure was 0 55MPa. The chilled water temperature was 7~12°C. This chilled water has been used for air conditioning of about a 2500m^2 area. It has been estimated that a 200MW NHR - LiBr refrigeration system with a refrigeration coefficient of 0.9~1.0 can be used for the air conditioning of about 3~3.5 million square meters.

3.3 Industrial process steam supply

A large part of industrial process steam is at lower pressure and temperature parameters, e.g. 120~200°C Nuclear heating reactors can provide lower parameter steam needed in a number of industrial processes, e.g. the refining of salt or sugar, chemical industry or textile industry. Generally, fossil fuels have been used. A substitution by nuclear energy in this regard is of significance in China.

When designed for industrial process steam supply, the thermodynamic parameters of the primary and secondary circuits in the 200MW NHR can remain practically the same of a standard design. Saturated steam generated in the third circuit is sent directly to industrial consumers. The nuclear heating reactor can also be designed to work on the co-generation basis of district heat and process steam. In the winter season, more power is used to supply district heating, and in the summer season, more process steam can be generated.

4 Conclusion remarks

China has been developing nuclear heating reactor technology A test heating reactor has been erected and operated successfully. Now a 200MW nuclear demonstration heating plant is being projected. With respect to the infrastructures of primary energy supply and consumption, it is of great significance if nuclear energy can substitute fossil fueis in the area of non-electric applications. The technology of nuclear heating reactors is much simpler than large electricity generating nuclear power plants, and the smaller power rating requires less capital costs. These features are more to the advantages of developing countries or to areas with poorer technical infrastructures. There exists a large room, where nuclear heating reactors can be coupled with conventional and mature technologies for non-electrical applications. These applications should have good prospect if the NHR technology and economy have got firmly proven.

PROSPECTS FOR NON-ELECTRIC APPLICATIONS OF NUCLEAR ENERGY IN KOREA

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Abstract

Nuclear power technology and related infrastructures are already well established in Korea. Intensive efforts for technology advancements and new technology development are continuously being pursued through various R&D activities. Along with these efforts, the expansion of peaceful utilization of nuclear energy technology for non-electric applications has also been sought and related R&D program is currently underway particularly for nuclear seawater desalination. The program is mainly focused on the development of an integral advanced reactor of 330 MWt for supplying the energy for seawater desalination as well as for power generation. Approximately 40,000 m^3/d water production facility will be coupled with the reactor to compose an integrated nuclear desalination system. In order to incorporate advanced technologies such an intrinsic and passive safety features into the reactor as a way for enhancing the safety and performance, various R&D activities are concurrently in progress along with the conceptual development of the reactor. Five years are planned for the completion of system development and the construction of a demonstration plant will follow.

1. Introduction

Nuclear power in Korea since its first introduction in 1978 has revealed that it can supply the electric energy more efficiently and economically compared to the conventional fossil fueled power. In addition, the heavy dependence of fossil energy resources on the supply from abroad has resulted in receiving more attractive attention on the nuclear energy. The nation's understanding of the importance of energy security and thus of nuclear energy role based on above facts has led to the current remarkable growth in nuclear energy industry. Furthermore, the continuous growth in nuclear energy utilization made the government pursue the nuclear technology development program for the level-up of technology self-reliance which would be essential for growth and improvement of national economy. The nationwide consensus of the necessity of securing the nuclear energy technology concluded to carry out a long-term effort with close cooperations between the government and nuclear industries. Approximately ten-year long efforts came now close to the successful completion of self-reliance in nuclear technology. However, the efforts will continue for improvements and advancements in the related technology to meet the demand of advanced technology in the coming future.

To the present, the nuclear energy technology in Korea has been fundamentally developed for its utilization in electric power generation. As the result, the level of nuclear power technology, engineering capability and associated infra-structures are well advanced and fully established. Also, accumulated experiences in nuclear power plant operation largely contributed to the advancement of nuclear energy technology. Based on these well established technology and accumulated experiences, Korea is now putting other efforts to further expand the peaceful utilization of nuclear energy for the non-electric industrial applications. Some R&D activities had been previously performed with respect to possible utilization of nuclear energy for district heating and co-generation. The utilization of nuclear energy for the seawater desalination became a practical area of interest for expanding our nuclear application. Although the demand of non-electric applications of nuclear energy in Korea is not forseen to be required in the coming very near future(*in any immediate future*) in the commercial aspect, the consideration of increase in energy usage due to more complicated industrialization, change of natural environments, and concerns in energy resources brights the prospects of its future. All these non-electric application of nuclear energy basically requires a nuclear reactor which should be properly designed in accordance with its purpose of utilization. Many studies pointed out that small or medium sized nuclear reactors can be effectively and economically utilized for the non-electric applications. Hence, the previous efforts have been focused on the development of advanced small/medium-size reactors and its related technologies.

This paper will briefly look over the nuclear power program in Korea, and then previous R&D activities regarding the efforts for the application of nuclear energy to the non-electric fields. The current efforts for developing an advanced nuclear reactor to be utilized as an energy source for the seawater desalination will then subsequently be described.

2. Nuclear Power Program in Korea

2.1 Construction of Nuclear Power Plant

In 1995, ten nuclear power plants under operation produced electricity, 67,029 GWh, by sharing 36.3 % of total electricity generation in Korea. This high sharing by nuclear energy is prospected to continue for the coming another ten years, according to the plan of nuclear power plants constructions. The government announced in 1995 the modified plan of electricity demand and supply which extends the previous plan of by 2006 to 2010. According to the modified plan, eighteen more nuclear power plants will come into operation by 2010 from 1996. Table 1 summarizes the construction plan of nuclear power plants. As noticed from the Table, all 1000 MWe PWRs except Yonggwang #4 are Korean Standard Nuclear Power Plants designed by using our own technology established from the long-term efforts for self-reliance in related nuclear technology. In order to meet the growing demand of electrical energy, the large-scale power plants with Next Generation Reactor (NGR) will also be constructed. The NGR has been being developed since 1993, and the design will be completed by 2001 for the commercial operation of its first unit in 2007.

2.2 Strategy for Nuclear Power Technology Development

Nuclear energy and its related technology were considered as an essential factor for the continuous national economy growth and improvements. This fundamental understanding drove the nation to put great efforts for establishing the self-reliance in nuclear technology to be eventually independent of foreign technologies. As shown in Figure 1, the nuclear technology indigenization started in 1981, firstly for PHWR fuel localization and then expanded to the PWR system areas including manufacturing of equipments. Nuclear fuel localization was successfully completed, and the level of technology self-reliance for PWR systems reached 95% as of 1995. The efforts will be continued to enhance the capability and to improve the technology toward advancement. The continuing nationwide efforts will come up with the complete development of our own next generation reactor technology by 2001. Utilizing these well established and advanced commercial technology, the technology development for non-electric application of nuclear energy is underway in parallel with various programs for

Table 1. Construction Plan of Nuclear Power Plants

No.	Unit Name		Reactor Type	Capacity (MWe)	Commercial Operation	
1	Yonggwang	#4	PWR	1000	March	1996
2	Wolsung	#2	CANDU-PHWR	700	June	1997
3	Ulchin	#3	PWR	1000	June	1998
4	Wolsung	#3	CANDU-PHWR	700	June	1998
5	Ulchin	#4	PWR	1000	June	1999
6	Wolsung	#4	CANDU-PHWR	700	June	1999
7	Yonggwang	#5	PWR	1000	June	2001
8	Yonggwang	#6	PWR	1000	June	2002
9	Ulchin	#5	PWR	1000	June	2003
10	Ulchin	#6	PWR	1000	June	2004
11	New Unit	#1[a)]	PWR	1000	June	2005
12	New Unit	#2	PWR	1000	June	2006
13	NGR	#1[b)]	PWR	1300	June	2007
14	NGR	#2	PWR	1300	March	2008
15	NGR	#3	PWR	1300	June	2008
16	NGR	#4	PWR	1300	March	2009
17	New Unit	#3	PWR	1000	March	2009
18	New Unit	#4	PWR	1000	March	2010

a) The construction site for new units is not determined yet.

b) NGR unit represents the Next Generation Reactor.

advancement of existing nuclear technology. The current focus for non-electric application of nuclear energy is primarily on the development of small/medium-sized nuclear reactor and its associated technology to use it as an energy source for seawater desalination. In addition, various efforts for developing nuclear technology include activities for developing the liquid metal reactor and related technology, which will play a major role for electricity generation in coming a few decades in Korea.

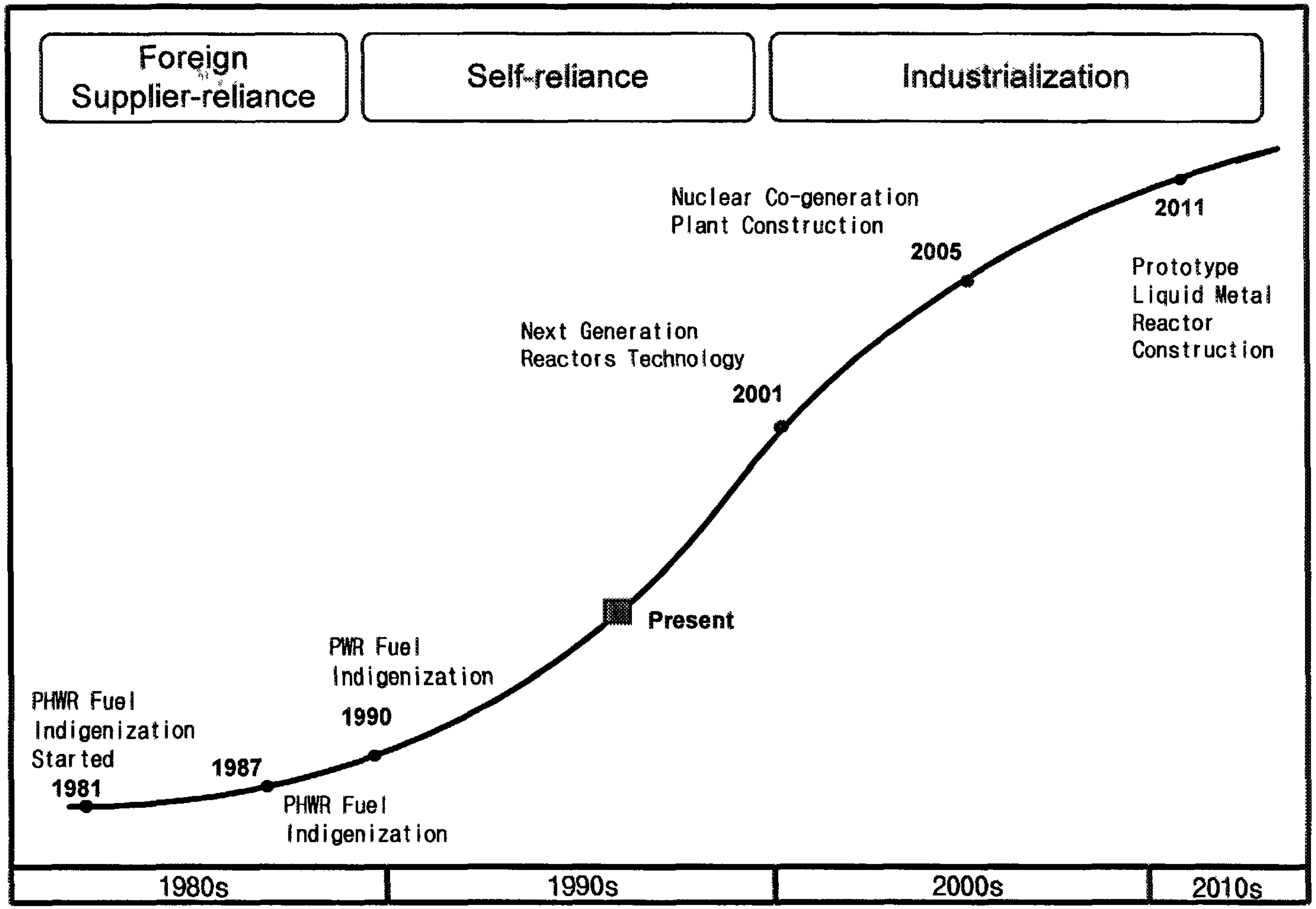

Figure 1. Strategy for Nuclear Power Technology Development in Korea

3. R&D Programs for Non-Electric Applications of Nuclear Energy

Since late 80's, Korea has been interested in expanding the application of nuclear energy to the non-electric purposes. The interests were primarily focused on the feasibility study regarding reactor development for cogeneration and/or district heating. These R&Ds were shortly carried out with the financial support from the government. The brief descriptions on the previous R&D activities are as follows :

3.1 Development of Design Technology for Co-generation Reactor

The objective of this R&D program was to study the technical feasibility for developing a 50 MWt co-generation reactor and related design technology. To investigate the necessary design technology and reactor concepts, the SECURE-P (PIUS) reactor was chosen as the reference concept. Along with various evaluations on design and safety concepts of SECURE-P reactor, a wide range of investigations on development status and technologies of advanced reactors was also carried out. The program was performed jointly with Korea Electric Corporation and Korea Electric Power Company. Based on those investigation and evaluations, the preliminary design concepts for Korea Pilot Reactor-1 (KPR1) were established with identification of design technologies to be tested and verified for the successful development. Furthermore, the study was concluded with recommendations for further R&D.

3.2 Development of Nuclear District Heating Reactor

A wide range of preliminary studies on the prospects and development status of district heating reactors was carried out in 1990. In conjunction with the preliminary study, further works continued in 1991. This R&D aimed to establish a design concept of a 10 MWt nuclear district heating reactor and to study the techno-economic feasibility for development of a nuclear district heating reactor with passive and inherent safety concepts. Studies were performed in the areas of economic evaluation compared with LNG and oil heating method, site selection, environmental assessment, compatibility with existing facilities, licensing plans, etc. Pool type reactor concepts were preliminarily established with respect to the major systems. The preliminary safety analysis showed that the reactor concepts provide higher reliability. The study recommended that the development of a nuclear district heating reactor should be carried out only after establishment of a suitable utilization plan of the reactor.

4. R&D Programs for Non-Electric Applications of Nuclear Energy

4.1 General and Purposes

Along with nationwide efforts for advancement of nuclear power generation technology, various applications of nuclear energy technology to non-electric areas have been extensively studied in an effort to expand the peaceful utilization of nuclear energy and to widen and deepen the domestic nuclear technology capability.

Among these non-electric applications of nuclear energy, the nuclear seawater desalination has been recently received most attractive attentions. No matter what areas are concerned with the nuclear energy utilization, the suitable energy source - a nuclear reactor - should be a prerequisite. In this regard, five-year R&D project for developing an advanced small/medium-size nuclear reactor was started from the middle of 1996 by Korea Atomic Energy Research Institute under the government financial support, in cooperation with domestic nuclear industries. The project aims to develop a 330 MWt advanced integral reactor (SMART : System-Integrated Modular Advanced Reactor) and to eventually couple with a desalination facility to compose of an integral nuclear desalination plant. Since the desalination technology is already well established, the major effort for the program is focused on the suitable reactor system development. The reactor will provide energy to the seawater desalination facility and also produce the electricity which will be connected to the grid.

The project consists of three phases : conceptual development phase (1996-1997) for nuclear reactor systems including fuel and plant systems, basic development phase (1998-2000), and final design and construction of a demonstration plant (2001-2005). As a demonstration purpose of seawater desalination with nuclear energy, the integral nuclear desalination plant will produce approximately 40,000 m^3/day desalted water. The remaining energy will be produced in the form of electricity. The most suitable desalination process will be also investigated and selected for the design in later phase. This paper will thus mainly describe a nuclear reactor to be developed throughout the program.

4.2 System Description of SMART

4.2.1 Reactor Core and Fuel

The core is rated at 330 MWt with potentially 57 modified Korean Optimized Fuel Assemblies, as shown in Figure 2. The average power density is approximately 63 kW/l which is much lower than that of conventional PWRs. The low power density and thus increased thermal margins with regard to critical heat flux ensure the core thermal reliability under normal operation and accident conditions. The core is designed to operate without the need for reactivity control using soluble boron over the whole power range. The elimination of soluble boron from the primary coolant is a major potential simplification for the advanced light water reactor. From the viewpoint of reactor control and safety, soluble boron free operation offers potential benefits through the presence of a strong negative moderator temperature coefficient over the entire fuel cycle and therefore improves reactor transients and load follow performance.

The fuel design will be based on the existing Korean Optimized Fuel Assembly (KOFA) design technology. Most design parameters of fuel rods are the same as those of KOFA except the effective fuel rod length which will be reduced tentatively to 200 cm. Fuel utilizes low enriched uranium dioxide which is operated at a low specific power density (24.5 kW/kgUO_2). The uranium enrichment of the fuel is selected to achieve the single batch operating cycle. The modified KOFA consists of 236 fuel rods, 24 guide tubes for control absorbers, 28 burnable poison rods, and 1 guide tube for central in-core instrument. Table 2 shows major design parameters of the conceptually designed fuel and reactor core.

4.2.2 Primary System

Figure 3 shows the general arrangement of the integral reactor vessel assembly and its internal structures which is currently under conceptual development. As generally notified, the SMART has similar concepts in major components arrangement compared to other integral reactors. Major characteristics of the SMART are represented with helically-coiled modular once-through steam generator, vertically mounted reactor coolant pumps, and self-presurizer. The current design concept is capable of reduced power operation when a pump is failed.

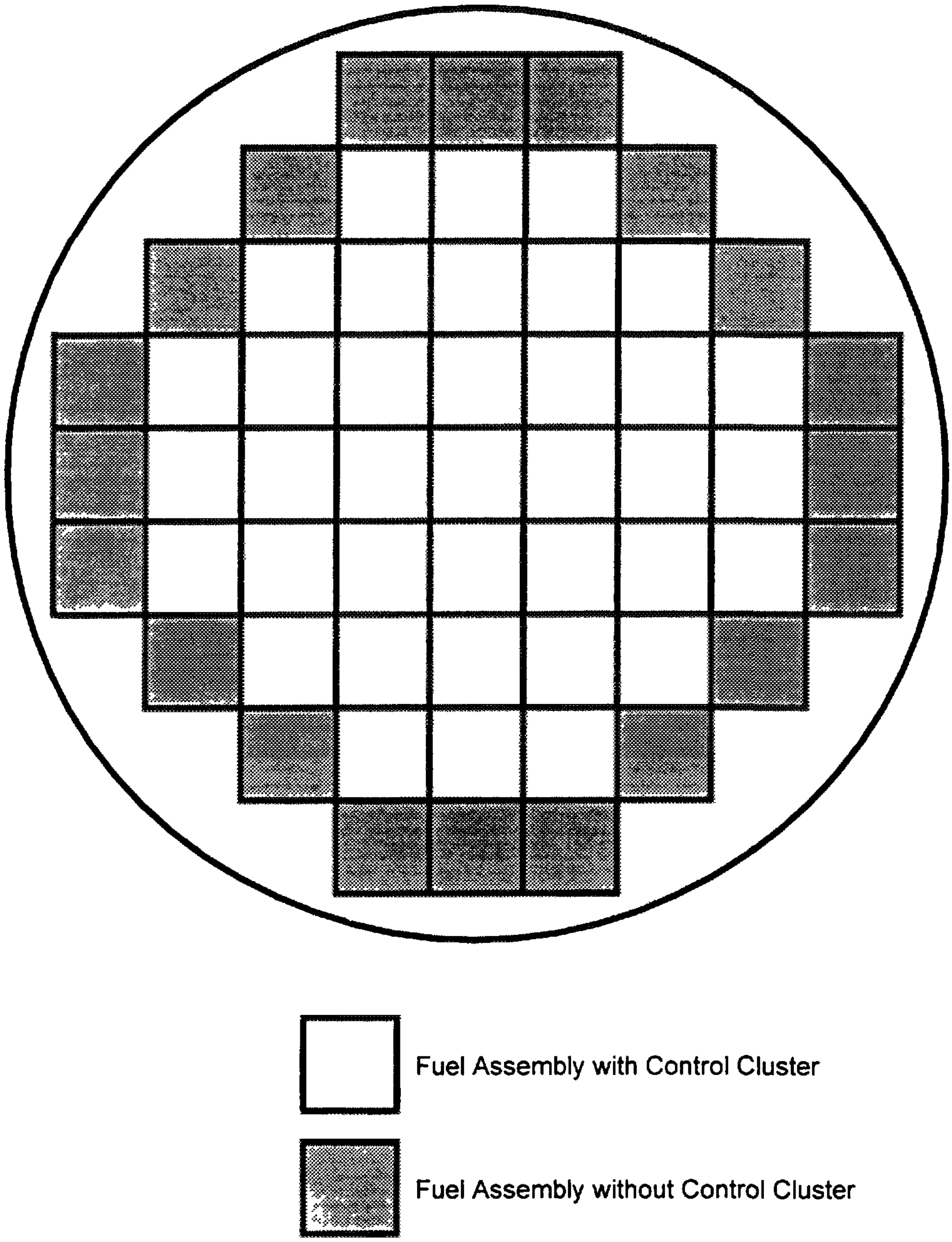

Figure 2. The Core Loading Model of SMART

■ *Steam Generator*

Twelve modular once-through steam-generators using helically-coiled tubes are located within the reactor vessel in the annular space between the core support barrel and the reactor vessel inner wall. The secondary coolant is completely evaporated in a single pass through the steam generators. Each module has 330 titanium alloy tubes with 3.515 m effective cooling height and 0.728 m in diameter. Each steam generator module also has six steam and feedwater headers, respectively.

Table 2. Basic Design Parameters of SMART

Design lifetime	60 years		**Steam Generator**	
Thermal Power	330 MWt		Type	Modular Helical Once-through
			No. of S/G modules	12
Primary Circuit			Steam Temperature	273.9 °C
Design Pressure	17 MPa		Steam Pressure	3.0 MPa
Operating Pressure	12.7 MPa		Superheat	40 °C
Coolant Flowrate	2.0×10^3 kg/sec		Feedwater Temp	180 °C
Core Inlet Temp.	285.6 °C		Feedwater Flowrate	152.7 kg/sec
Core Outlet Temp.	315.0 °C			
			Reactor Coolant Pump	
Reactor Core and Fuel			Type	Glandless, Wet winding Canned Motor
Moderator	H_2O		No. of RCPs	4
Fuel	Low Enriched UO_2			
FA Shape	Square 17x17		**Containment Overpressure Protection**	
No. of FAs	57		Type	Passive, Steam Driven Injector
Power Density	62.6 kW/l			
Avg. Linear Power Density	11.3 kW/m		**Safety Systems**	
Fuel Lifetime	1500 EFD		Decay Heat Removal	Passive, Natural Convection
Effective Core Height	2 m		Reactor Shutdown	Control rod/liquid Absorber
Effective Core Dia.	1.82 m		ECCS	Not Required
Average Burnup	36,900 MWD/MTU			

In the performance and safety aspects, six steam headers - one from each module - are connected to one steam section to construct total of twelve independent steam sections, and same number of feedwater sections. This concept is eventually to minimize the impact of steam generator tube rupture accident on the reactor system. When the tube rupture accident is detected, the associated feedwater and steam headers will be isolated to reduce the flow rate by amount of 1/72. Figure 4 shows the top view of the reactor vessel focusing on the steam generator arrangement. The different shapes of the steam generator module indicate views from different angles.

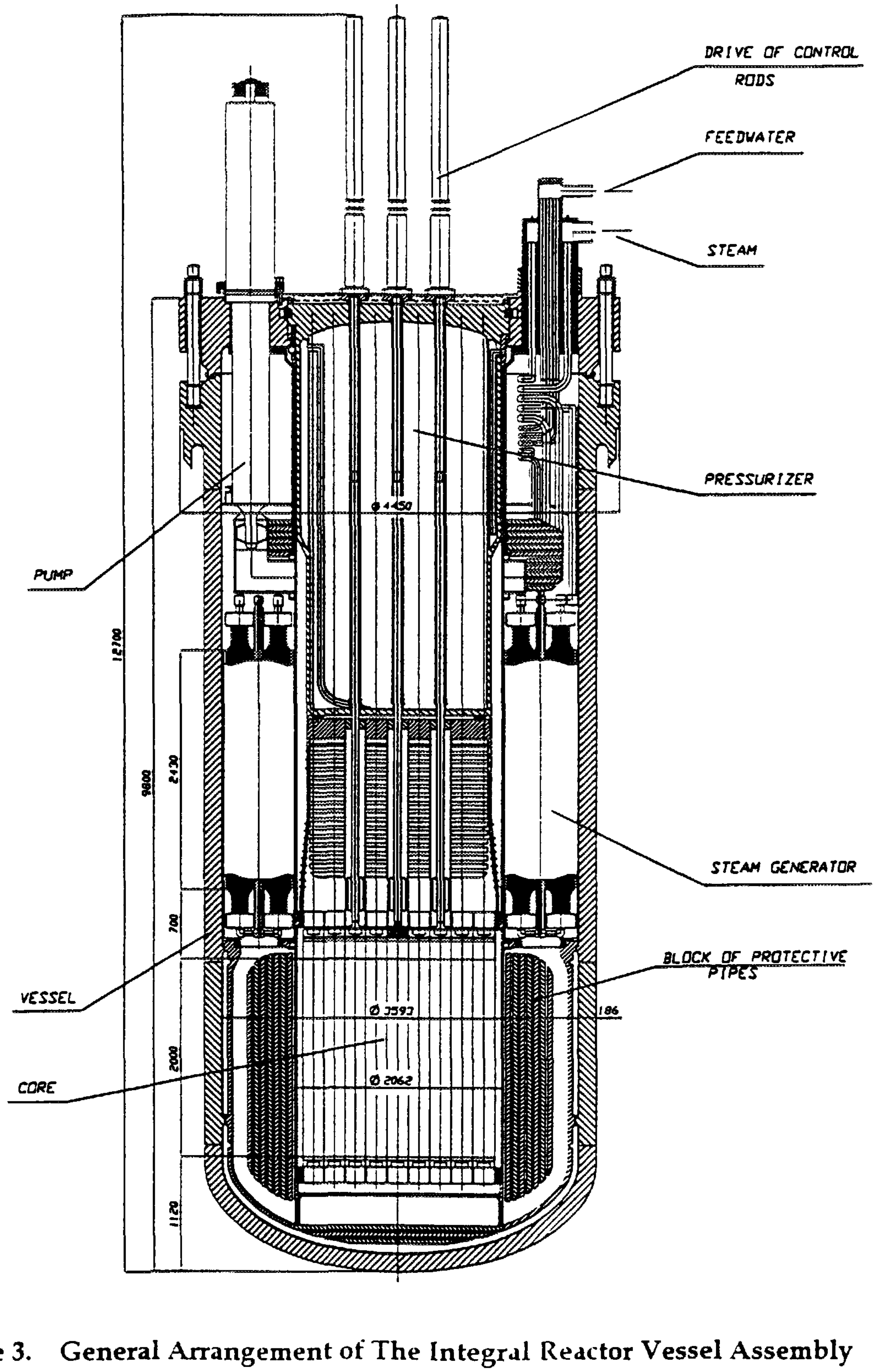

Figure 3. General Arrangement of The Integral Reactor Vessel Assembly

■ *Pressurizer*

The self-pressurizer consists of two major components. One is a compensator tank inside the reactor pressure vessel which is filled with water, steam and nitrogen gas. This compensator tank is connected to the primary system by a pipe. The primary system pressure is maintained equal to the

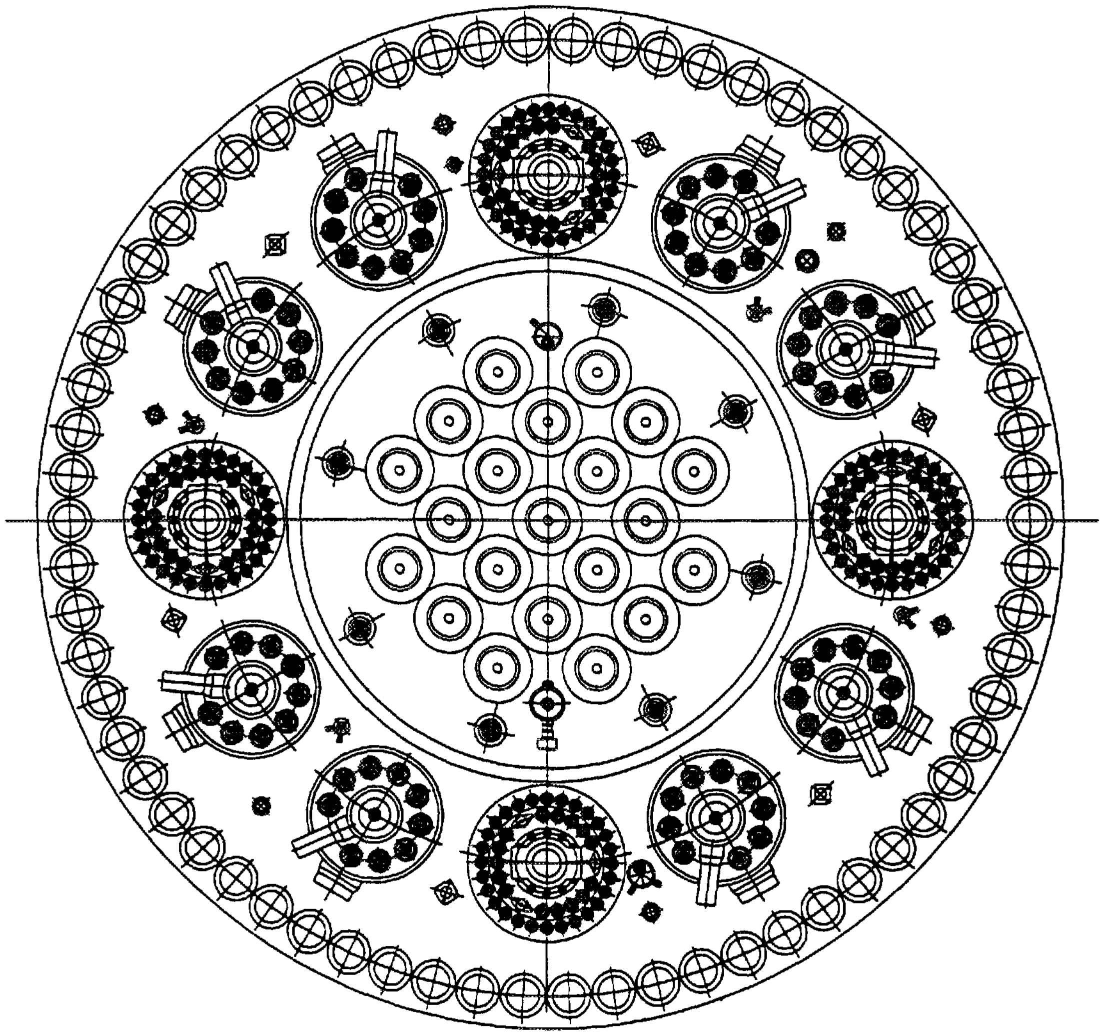

Figure 4. Top View of The Reactor Vessel Assembly

nitrogen partial pressure plus the steam pressure. The other major component is the gas tanks which is connected to the compensator tank. The gas tanks are isolated from the compensator tank in normal operation condition. To determine the sizes of the compensator tank and gas tanks, the amount of primary coolant volume change between the cold shutdown and hot full power conditions, the solubility of the Nitrogen gas, etc. are taken into account. The volume of gas space is large enough to prevent safety valves from opening during most severe design basis transient.

■ *Reactor Coolant Pumps*

Canned motor pumps are used as the RCPs. The canned motor pumps do not require pump seals, so that pipe penetrations and seal water maintenance systems, which are adopted in standard commercial NSSS design, can be removed and thus the small LOCA consideration during station blackout can be eliminated. The reactor is designed to operate reduced power level (75% rated power) when one pump is failed. A device to prevent reverse flow in this situation is installed in the suction pipe of the RCP. The RCPs are vertically installed for the efficient space utilization. During normal power operation, the speed of RCPs is maintained constant. A speed sensing device is installed to generate a RCP trip signal to protect RCP motor. The RCPs are also designed to be operated at reduced speed to remove decay heat when the reactor is shutdown.

■ *Control Element Drive Mechanism*

Soluble boron free reactivity control concept leads to an increased number of CEDM's, and reactor start-up with nuclear heating requires fine positioning capability of the control rods. The magnetic jack type CEDM used in the Korean Standard PWR is considered to be inadequate for this project because of its stepwise positioning capability and diagonal installation requirement with respect to fuel assemblies due to relatively larger size. Two different types of CEDM's are under investigation in order to meet the requirements of compactness and fine positioning. Type I is driven by a brushless DC servo motor. The rotational movement of the rotor is converted to linear movement through ball nut assembly and lead screw. The use of a brushless DC servo motor with rare earth permanent magnet rotor allows a maintenance free operation of the motor and a high seismic resistant design is possible. Type II is driven by a linear step motor. Electric current pulses applied to the linear step motor directly moves the control element assembly up and down without any conversion mechanism of rotational - translational movement. Thus a simple and compact design can be achieved. Major R&D topics for CEDM's are the development of a split ball nut assembly working at high temperature for Type I and the improvement of seismic resistance in case of Type II.

4.2.3 Engineered Safety Features

The conceptual safety design of the SMART centers around enhancing the inherent safety characteristics of the reactor. Thus, the passive safety principles on which most small and medium reactors rely are pursued. The design principles to enhance the inherent safety characteristics of the co-generation plant are:

- Design power density to heat capacity ratio to be low such that fuel element temperature rise under accident conditions is low;

- Design core with sufficiently negative moderator temperature coefficient to realize no soluble boron core and to yield beneficial effects on self-stabilization and limitation of reactor power;
- Design reactor vessel to be an Integral type to eliminate large primary coolant pipes such that the possibility of large break loss of coolant accidents by pipe break is not possible;
- Design large pressurizer operating on passive principles to significantly reduce pressure increase for decreased heat removal events;
- Design large volume of primary coolant to provide more thermal inertia such that plant is more forgiving;
- Design RCPs operating without seals to eliminate the potential for seal failures, a concern during station blackout;
- Design safety systems to be passive to simplify the design by eliminating the need for multiple redundant safety systems with associated redundant safety grade power supplies.

Reactor Shut-Down System

The reactor shut-down system is composed of the control rods and the emergency liquid absorber injection system. The reactor trip at emergency is accomplished by rapid insertion of the control rods into the core following the drive mechanism de-energization, which is actuated by trip signals from the automatic control system. In case of failure to actuate the electromechanical protection system, the reactor shutdown is accomplished by the emergency liquid absorber injection system. Activation of the system is done by manually opening valves in the pipelines connecting the system to the reactor. Both shutdown systems ensures the reactor shutdown, and its shutdown margin is sufficient enough to keep the cold clean reactor in a subcritical state.

Safeguard Vessel

The engineered safety features include a safeguard vessel which completely encloses the whole reactor vessel assembly. This feature is not shown in Fig.3. Isolation valves are installed in all pipelines penetrating safeguard vessel to confine primary coolant inside the safeguard vessel in all design basis accidents.

Residual Heat Removal System

For the normal decay heat removal as in the case of cooling down for maintenance and refueling, the steam generators with turbine bypass system are used to remove the decay heat where heat is rejected through the condensers. This can be achieved by natural circulation on the primary side but requires feed pumps and other equipments on the secondary system. If the secondary system is not available, active decay heat removal system with steam generators are used to remove decay heat and heat is rejected through the component cooling system.

Should there be no ac power available, decay heat is removed by natural convection system which only requires battery power to operate the initiation valves and passive residual heat removal system which is composed of steam generators and heat exchangers immersed in the external cooling water tank. Ultimately, the heat is rejected to the atmosphere. The water in the external cooling water tank is designed with sufficient quantity to guarantee 72 hour grace period before operator intervention is required.

Emergency Core Cooling System (ECCS)

The possibility of large break loss of coolant accident is inherently eliminated by integrating the primary system, and the compensating tank in the pressurizer is sized to be large enough such that chemical and volume control system (CVCS) could be isolated during normal power operation. These design features eliminates conventional emergency core cooling system. However, the break in the sampling line or instrument line could be the source of the small loss of primary coolant. To provide emergency coolant, the core makeup circuit is used to inject coolant into the reactor vessel. The core makeup circuit is in turn connected to the refueling water tank which contains a large quantity of water. Since the safeguard vessel retains all primary coolant and the reactor vessel is always flooded, there is no possibility of the core uncovered.

Containment Overpressure Protection System

Since the maximum pipe break is small due to the design nature of the SMART, the containment is pressurized at a slow rate in the case of related accidents. Energy released to the containment through the break point is removed using the steam injector driven containment spray system to prevent exceeding the containment design pressure. The steam injector is a simple, compact passive pump that is driven by supersonic steam jet condensation. The steam injector can operate even by atmospheric pressure steam. The steam from break point is supplied to the steam injector. The steam injector pumps up the water from a water storage tank on the ground to the spray nozzle located at the top of the containment.

Preliminary evaluations and analyses for the system performance and safety of the SMART under conceptual design are currently in progress to investigate the technical feasibility of the design concepts. Modifications and/or some changes in those concepts described above may be expected based on the results of those analyses.

4.3 Research and Development (R&D) Activities

To evaluate the characteristics of various passive safety concepts and provide the proper technical data for the conceptual design of the advanced integral reactor, the following R&D activities are being concurrently performed.

- No Boron Core Concept:

  The use of no soluble boron in the core design causes to utilize large amount of burnable absorbers to properly hold down the excess reactivity at the beginning of cycle and to install considerable number of control rods for the reactor control and operation. The optimization in the number of burnable absorbers and control rods is required with respect to the reactivity compensation with fuel burnup and reactor control through the cycle, and this study in conjunction with the extended fuel cycle are thus investigated in this R&D subject.

- Natural Circulation Phenomena for Integral Reactor:

  To investigate the core cooling capability by the natural circulation flow when motor pumps are not operable, an experimental test loop is being designed. A computer code is being developed to model the thermo-hydraulic behavior of the primary circuit.

- Noncondensible Gas Heat Transfer:

  Noncondensible gas, which can generated from the dissolved gas in the coolant or the gas filled pressurizer, generally reduce heat transfer capability. To investigate thermo-hydraulic and heat transfer phenomenon when the noncondensible gas coexists in the reactor core, an experimental test facility is being designed. A computer code is also being developed to model the behavior of the noncondensible gas.

- Flow Instability and Thermal Design of Once Through Steam Generator:

  The thermal hydraulic design and performance analysis computer code, ONCESG, for a once through steam generator has been developed.

An experimental study is being performed to generate the heat transfer correlation and pressure drop correlation of the helically coiled tube once through steam generator. To understand possible instabilities in the SG secondary side, the multi-channel flow instability experiment is being planned.

- Steam Injector Application for PCCS:

An experimental study is being conducted on a steam injector driven passive containment cooling system. A computer code is being developed to model the thermo-hydraulic behavior of the steam injector.

5. Prospects of Nuclear Energy Utilization for Non-Electric Applications

Although there are some opinions against nuclear energy utilization, it is widely understood that the nuclear energy is vital to the continuous improvements and advancements of nation's economy and industrialization, since no alternative energy option is promising at present. In this regard, nuclear power generation and its technology advancement will continue to meet the demand of electricity consumption.

Along with continuous deployment of nuclear power generation, non-electric applications of nuclear energy technology have received an attractive attention in Korea. Premature interests were focused in using nuclear energy for district heating and co-generation. However, the need was not so much crucial to drive the efforts for the favorite directions compared to the power generation. The nuclear district heating is not expected to be implemented in a near future mainly due to the strong public movement against the nuclear energy. However, the drought experienced due to the climate anomalies and the worsening level of pollution have reduced available clean inland water resources significantly for a number of years. The industries were severely impacted due to the lack of process water. Thus, securing stable supply of clean water has been an important issue in industry societies. The desalination of seawater is widely understood as a favorable solution to the water resources issue. If this is the case, the concern is an energy option for the desalination facility. The limited natural energy resources and its usefulness in other industrial areas again provide a considerable option for the energy source such as for the power generation. Since the necessity of nuclear desalination is widely understood at the present time, the prospect of its realization seems positive. Well established nuclear technology, associated infra-structures, and desalination technology in Korea will provide another good momentum going for nuclear desalination in the coming future which is not far away.

6. Summary

Nuclear energy technology has greatly contributed to the nation's economy growth and improvements in Korea. Limited natural energy resources is expected to continuously drive the nation to rely more on the nuclear energy utilization. So far, nuclear energy utilization and its technology development has been primarily focused on nuclear power generations, although a few R&Ds on the utilization of nuclear energy for non-electric applications such as nuclear district heating and co-generation were prematurely carried out with respect to basic technology development and feasibility search. However, it has been fundamentally understood that expansion of peaceful use of nuclear energy will eventually contribute to the nation's continuous development, when considered the role of nuclear energy in supplying the electricity to meet the domestic demand. In this regard, various applications of nuclear energy rather than only to power generation has drawn interests recently in the country. Nuclear energy utilization for seawater desalination has become a particular area of interest in the aspect of clean and fresh water shortage due to the pollution from industrialization and the severe drought experienced for a past few years. In order to be ready for the technology demand in the coming future, a ten-year project for developing a nuclear desalination facility has been launched in 1996 by focusing on the development of a highly safe and reliable small-sized (330 MWt) advanced nuclear reactor for supplying the energy to the desalination system. The project is executed by the government financial support and in cooperation with nuclear industries. The reactor and other systems are currently under conceptual development, and the integrated nuclear desalination system is expected to be constructed from the early turn of the century.

XA9743479

FRENCH PERSPECTIVE ON SELECTED NON-ELECTRIC APPLICATIONS

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Abstract

Lacking natural fossil energy resources, France launched a massive nuclear program in 1974 in order to achieve a 50 % energy independence. Meanwhile electricity usage was encouraged wherever possible.

Non electric heat markets were examined and led to focus on two market types i, e : Industrial and district heat.

Industry in France evolves toward a lower energy usage. As a consequence, when the relatively low energy usage concentration with respect to nuclear unit size is combined with the capital intensive cost of nuclear units and the redundancy of nuclear units to ensure very high availability of industrial heat, nuclear heat in industry is nowhere competitive in France.

Nuclear District heating is strongly handicapped due to high heat transportation cost and amortization on part time use only.

Dedicated nuclear plants for heat production are not competitive in France. Only dual electricity/heat plant may improve the economic picture but it was not studied.

1. INTRODUCTION

Before the oil crisis of 1973, France was heavily dependent on oil for electricity production. As a consequence of this crisis, it was politically decided to reach an overall energy usage independence of 50 % as soon as possible which meant constructing nuclear power units at a sustained rate. 42 units were ordered in 10 years, up to eight units were put on line in a single year. Presently, 56 units are operating (see figure 1), 4 more are under construction and between 75 % and 80 % of the electricity produced in France is from nuclear origin. Moreover, the equivalent production of 12 units is exported to neighboring countries.

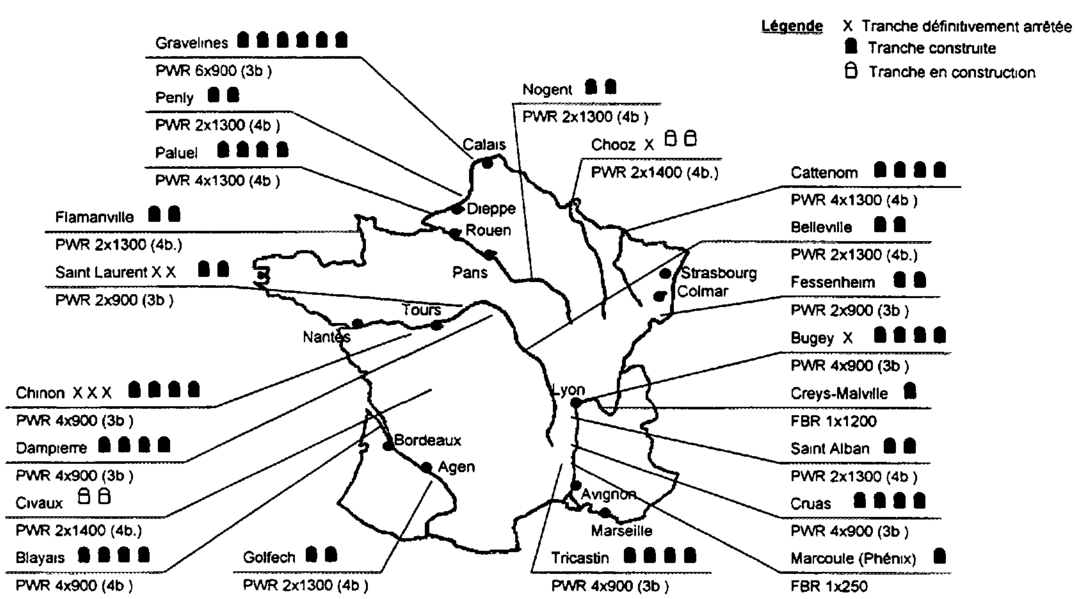

Figure 1

At the same time, electricity use was encouraged and its use in housing heating is widespread

Following the urgent task of displacing oil as a prime electricity producer, studies have been performed to assess whether oil could also be replaced in heat markets by nuclear heat production Two major potential markets were identified the industrial heat market and the district heating market

2 INDUSTRIAL HEAT MARKET

A few basic facts should be recalled first

- Nuclear units are capital intensive Nuclear fuel is inexpensive Consequently, the load factor of the unit must be high for competitive cost This means near full time operation during the year at full power
- By nature, nuclear plants are remotely located
  Heat transport systems are therefore long and expensive This reinforces the capital intensive nature of nuclear heat production
- Industrial production cannot be dependent on a single heat source if it is essential Therefore a redundant heat source must be planned and included in the overall heat production cost

A survey of the main industries using heat has been performed in 1988 for the European Union (ref 1) It reviewed the situation in 1985 and evaluated the major trends for 1990 and 2000 It is striking that the major heat using industries are at best stable or decreasing their energy consumption (see table 1 taken from ref 1) This is mostly due to modernisation of the processes which use energy more sparingly but also to relocation of some of them where manpower is cheaper

Table 1

Projection of energy consumption by industrial sectors
(figures in Megatons of oil equivalent)

	1985	1990	2000
Mining & Electrometallurgy	4 87	4 8	4 8
Glass production	1 45	1 6	1 5
Food & Agricultural products	4 94	4 8	5 1
Cements	2 93	3 0	2 6
Other construction materials	1 41	1 2	1 1
Chemical & Plastics industries	12 01	12 1	12 3
Rubber products	0 70	0 7	0 7
Paper & Cardboard production	2 85	2 1	1 7
Mechanical, Metallurgical & Electrical industries	5 43	5 8	6 2
Textile industries	1 64	1 5	1 3
Total	38 23	37 6	37 3

In order to assess which sites may be eligible for nuclear heat the survey looked at heat usage power on single sites Table 2 summarizes this survey and shows that the biggest user on a site "only" needs about 20 ktoe (kiloton of oil equivalent) or about 40 MWth This is a very small amount for a nuclear unit the smallest of which is about 10 times that amount

Very small nuclear units tend to be very expensive per MW thermal produced due to the nuclear safety infra-structure which costs whether the unit is small or big Economics demand large units but users can only accommodate small units

This poor economic match combined with high heat transportation costs and supply redundancy requirements clearly push nuclear heat production out of competitiveness

Table 2

Average energy consumption per site and industrial sector

	Number of sites	Av En Consum/site (ktoe)
Mining & Electrometallurgy	231 & 3650	14 & 0 4
Glass production	353	4 1
Food & Agricultural products	64 & 4466	13 8 & 0 9
Cements	160	18 3
Other construction materials	2773	0 5
Chemical & Plastics industries	200 & 521	20 & 14
Rubber products	345	1 7
Paper & Cardboard production	1083	2 6
Mechanical, Metallurgical & Electrical industries	1200 & 13000	1 5 & 0 3
Textile industries	8292	0 2

Nowhere in France is it presently economically justified to use nuclear heat in industry

3 DISTRICT HEATING

District heating concerns heat sources at temperatures below 200 °C

More than 330 district heating networks totaling a capacity of 18 000 MWth are installed in France However only 9 have a power level exceeding 20 MWth The Paris network is exceptional with a capacity of 3 700 MWth Two studies were performed to assess the possibility of nuclear district heating for the cities of Paris and Grenoble

The Paris study planned to locate the reactor at the CEA research center of Saclay about 25km away from the city The heat transport system was overwhelmingly expensive to justify the project

In Grenoble, the CEA research center where the reactor was to be located is nearly in town therefore transportation costs were much lower than in Paris However, guaranteeing heat supply needed the addition of back ups Besides the district heating system operates only 7 months a year, three of them only at full power Consequently amortizing the plant and its back up on such a small load factor proved uneconomical

The conclusion of this study was that district heating from a nuclear source is not economical in France

CONCLUSION

A dedicated nuclear unit for industrial heat or district heating cannot be justified in the French context due to the high capital cost of nuclear units, the need for back up systems, high cost of heat transport and in the case of district heating low load factor

The conclusion could be more favorable in the case of a dual purpose unit where electricity production is the main goal of the unit In this case, the capital investment can be better spread between both electricity and heat thereby improving the amortization scheme Due to its size and thermodynamic cycle a gas turbine modular HTR seems particularly appropriate for a dual purpose unit but the detailed study remains to be performed

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MODULAR HELIUM REACTOR FOR NON-ELECTRIC APPLICATIONS

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Abstract

The high temperature gas-cooled Modular Helium Reactor (MHR) is an advanced, high efficiency reactor system which can play a vital role in meeting the future energy needs of the world by contributing not only to the generation of electric power, but also the non-electric energy traditionally served by fossil fuels. This paper summarizes work done over 20 years, by several people at General Atomics, how the Modular Helium Reactor can be integrated to provide different non-electric applications including Process Steam/Cogeneration for industrial applications, Process Heat for transportation fuel development and Hydrogen Production for various energy applications.

The MHR integrates favorably into present petrochemical and primary metal process industries, heavy oil recovery, and future shale oil recovery and synfuel processes. The technical fit of the Process Steam/Cogeneration Modular Helium Reactor (PS/C-MHR) into these processes is excellent, since it can supply the required quantity and high quality of steam without fossil superheating.

High temperature process heat is a second example of how the MHR can be extended to use its full temperature capability. In terms of market application, transportation fuels represent the largest potential application for a Process Heat Modular Helium Reactor (PH-MHR) system. Potential fuels could include methane or synthetic gasoline using various feedstocks. One interesting application described in this paper is the production of methanol from coal.

Hydrogen can play a major role in reducing global CO_2 emissions in the 21st century. Produced using nuclear energy, hydrogen can replace many existing fossil fuels such as oil and coal, in providing a CO_2 free energy supply for many stationary and transportation uses. The Modular Helium Reactor (MHR) system can deliver the required electric energy and is unique in its capacity to supply high temperature process heat for thermochemical production of hydrogen. Three distinct hydrogen production processes and their interface with the MHR heat source in those processes are presented. Assessment of these and other nuclear approaches to the production of hydrogen can be undertaken to assure the availability of hydrogen production processes early in the 21st century.

1. INTRODUCTION

Today the world's primary energy consumption by its 5.4 billion inhabitants is about 320 quads per year (1 quad = 10^{15} BTU). Approximately two thirds of this is utilized in non-electric applications. The Modular Helium Reactor (MHR) is a second generation passively safe reactor system which can play a vital role in meeting the future energy needs of the world by contributing not only to the generation of electric power, but also to the industrial non-electric energy sector traditionally served by fossil fuels. Most energy-intensive industrial processes require considerable process steam and electric power.

In the industrial nations, transportable fuels in the form of natural gas and petroleum derivatives constitute a large energy source. Nations with large coal deposits have the option of coal conversion to meet their transportable fuel demands. But these processes themselves consume large amounts of energy and produce undesirable combustion by-products. The modular helium reactor system has the potential of providing the required energy to produce transportable fuel.

Global carbon dioxide emissions are estimated to exceed a total of 25 billion tons per year in 1995 and could reach as high as 40 billion tons per year by the year 2050. In order to mitigate this global warmup trend emissions need to be significantly curtailed. In particular, the industrialized countries' CO_2 emissions need be reduced as they presently contribute approximately 80% of total CO_2 emissions. A strong case can be presented in favor of the hydrogen fuel in meeting future world energy needs and in achieving the targeted global reduction in the CO_2 emissions. The MHR can provide the energy required for production of hydrogen.

This paper summarizes the potential non-electric application of the MHR in providing the process steam for cogeneration applications, process heat for transportation fuel production of hydrogen for various industrial applications.

2. MODULAR HELIUM REACTOR HEAT SOURCE

Efforts to enhance the nuclear energy option in the U.S. has brought about the development of a new generation of reactor designs. These advanced designs emphasize reduced complexity and passive safety in concert with economic competitiveness to modern fossil fired generation. One such advanced design is the Modular Helium Reactor (MHR). Its key characteristics of simplicity, versatility and unparalleled safety provide strong incentives for worldwide deployment as a heat source to meet diverse future energy needs.

2.1 MHR Characteristics

The MHR combines the characteristics of ceramic coated fuel, helium coolant, graphite moderator, and a unique core configuration with passive decay heat removal capability. These characteristics have been innovatively combined to meet stringent safety requirements while at the same time offering competitive energy costs. The intrinsic properties of this combination are:

- Coated Particle Fuel - The multiple ceramic coatings surrounding the fuel kernels constitute tiny independent pressure vessels which retain fission products. These coatings are capable of maintaining their integrity and fission product retention at temperatures much higher than those imposed during postulated extreme accident conditions.

- Helium Coolant - The inert and single phase helium coolant has several advantages: no flashing or boiling of coolant is possible, pressure measurements are certain, and pump cavitation cannot occur. Further, there are no reactivity or corrosive effects associated with helium and no potential chemical or energy reactions between coolant and fuel is possible.

- Graphite Core - The strengths of the graphite core at high temperatures results in a wide margin between operating temperatures and temperatures that would result in core damage. Further, the high heat capacity and low power density of the core result in very slow and predictable temperature transients.

- Core Configuration - Selection of an annular core geometry, low core power density, and core power level assures that fuel temperatures remain hundreds of degrees below the integrity limit of the coated particle fuel even if all active coolant circulation fails and even if the coolant were lost.

- Passive Decay Heat Removal System - In addition to the normally operating power conversion system and an independently powered shutdown cooling system, a completely passive, safety grade reactor cavity cooling system is provided.

The selection of helium as the coolant, graphite for the core structure, and ceramic fuel sets the MHR apart from other power reactors and is the cornerstone of its high temperature capability. This unique heat source enables high power conversion efficiency and a range of energy conversion alternatives. The modular helium reactors can produce helium at temperatures as high as 1000°C.

2.2 MHR Heat Source Design

The MHR heat source is located inside a reactor pressure vessel as shown in Figure 1 (Ref. 1). The reactor core is designed to provide 600 MW(t) at a power density of 6.6 MW/m^3. The active core consists of an assembly of hexagonal graphite fuel elements containing nuclear fuel compacts and coolant flow channels. The active fuel region of the core is arranged in the form of an annulus as shown in Figure 2. The fuel elements are stacked in the core to form columns that rest on support structures. The annular core configuration was adopted to achieve maximum power rating and still permit passive core heat removal while maintaining the fuel temperature below 1600°C during worst case accident condition of total loss of coolant and loss of flow, assuring that fuel integrity is not impaired. The active core is composed of 102 fuel columns in an annular arrangement. The design includes reflector rods for power control and in-core rods for shutdown. The addition of the in-core rods increases the reactivity shutdown margins for the larger core while accommodating vessel layout and refueling requirements. The fuel cycle is based on an LEU U235/U238 fissile/fertile cycle with a peak enrichment of 19.9%. The fuel particles are bonded together in fuel compacts which are contained in sealed vertical holes in the graphite fuel blocks which make up the fuel columns. TRISO fuel coating provides the principal fission product retaining mechanism and constitutes a major safety feature of the MHR.

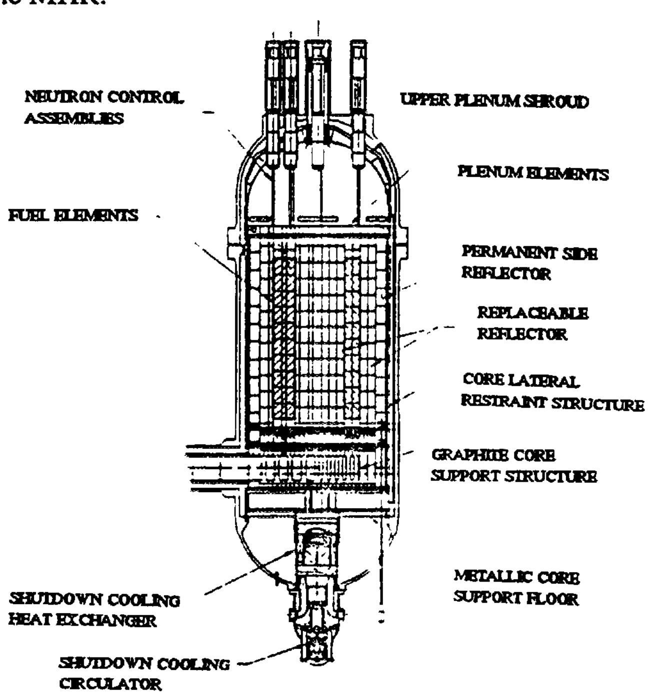

Fig. 1. MHR Reactor Core Elevation

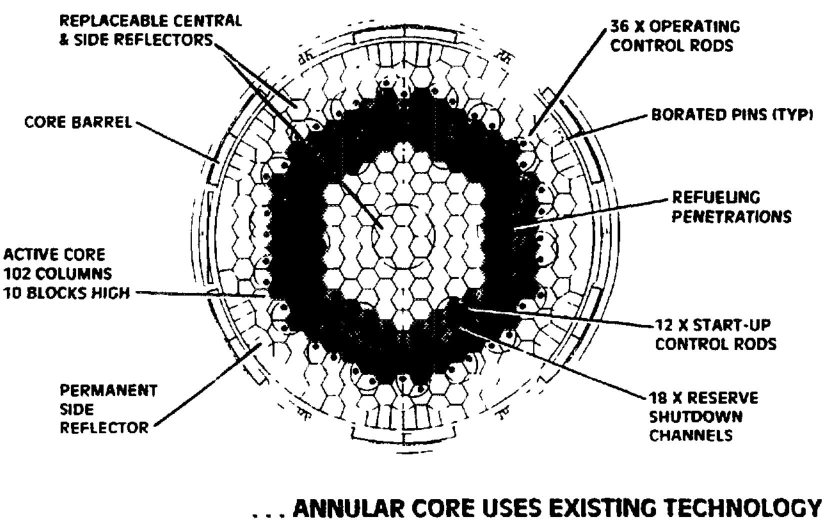

Fig. 2. MHR Reactor Annular Core Plan View

The core reactivity is controlled by a combination of burnable poison, movable control rods and a negative temperature coefficient. Independent and diverse reserve shutdown control is provided in the form of boronated pellets that may be released into channels in the active core.

The MHR system exhibits many key safety design features including the ceramic coated TRISO fuel, with its capability to retain fission products at very high temperatures, low power density annular core, factory fabricated steel vessels, and entirely passive decay heat removal. The release of large quantities of radionuclides is essentially precluded by the fuel particle ceramic coatings even under severe accident conditions. All the reactor system components are based on proven technology.

The MHR offers the broadest range of industrial uses of any reactor system. This attribute has been one of the driving forces behind its development. An overview of some of the applications is described in the following sections. In addition to electricity generation, the MHR can play a major role in the primary energy supply due to its unique capability to heat working fluids to 1000°C. Described below are three broad categories of MHRs for non-electric applications, first the Process Steam/Cogeneration Modular Helium Reactor (PS/C-MHR), second Process Heat Module Helium Reactor (PH-MHR), and third the Hydrogen Production Modular Helium Reactor (HP-MHR).

3. PROCESS STEAM/COGENERATION MODULAR HELIUM REACTOR

Energy requirements of industrial process complexes vary widely, according to varying steam conditions, capacity requirements, and the ratio of thermal to electric power. The high temperature/high pressure steam at 2500 psia (17.3 MPa) and 1000°F (540°C) produced by the PS/C-MHR can provide energy for heat cycles in a wide range of process applications and industrial complex sizes and capacities.

3.1 PS/C-MHR Plant Description

The P/SC-MHR is being designed to meet the rigorous requirements established by the Nuclear Regulatory Commission (NRC) and the electric utility-user industry for a second-generation power source for the late 1990s. The plant is expected to be equally attractive for deployment and operation in the United States, other major industrialized nations, and the developing nations of the world.

The most economic PS/C-MHR plant configuration includes an arrangement of several identical modular reactor units, each located in a single reactor building (Ref. 1). The plant is divided into two major areas: the nuclear island (NI), containing the several reactor modules, and an energy conversion area (ECA), containing turbine generators and other balance of plant equipment. The basic layout for a single reactor module is shown in Fig. 3. Each reactor module can be connected independently to steam turbine in or other steam utilizing systems. The nominal plant parameters are offered in Table 1.

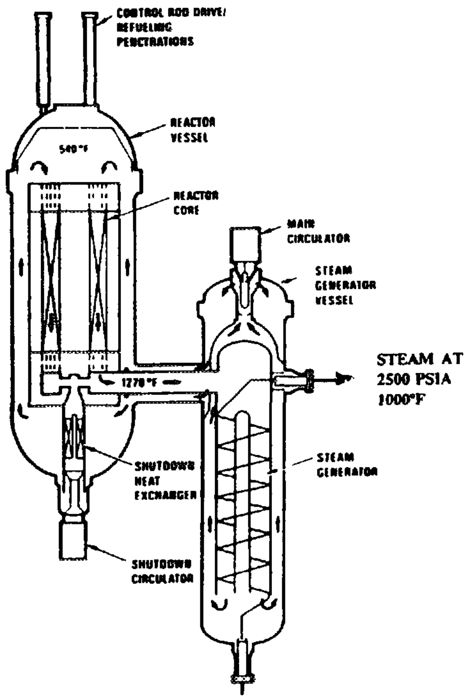

Fig. 3 PS/C-MHR Plant Module

TABLE I
PS/C-MHR PLANT PARAMETERS

Reactor Module Parameters	Recommended Design
Thermal Power, MW(t)	600
Fuel Columns	102
Fuel Cycle	LEU/Natural U
Average Power Density, W/cm^3	6.6
Primary Side Pressure, MPa (psia)	7 07 (1025)
Induced Helium Flowrate	281 kg/s
Core Inlet Temperature, °C (°F)	288(550)
Core Outlet Temperature, °C (°F)	704(1300)
Steam Temperature, °C (°F)	541(1005)
Steam Pressure, MPa (psia)	17 3(2515)
Circulator Power, MW(e)	6.0

The reactor module components are contained within three steel pressure vessels; the reactor vessel, a steam generator vessel, and connecting cross vessel. The uninsulated steel reactor pressure vessel is approximately the same size as that of a large boiling-water reactor and contains the core, reflector, and associated supports. The reactor core and the surrounding graphite reflectors are supported on a steel core support plate at the lower end of the reactor vessel. Top-mounted penetrations house the control-rod drive mechanisms and the hoppers containing boron carbide pellets for reserve shutdown. The core layout for this 600 MW(t) design is shown in Figures 1 and 2 and described earlier in Section 2.2.

The heat transport system (HTS) provides heat transfer during normal operation or under normal shutdown operation using high pressure, compressor driven helium that is heated as it flows down through the core. The coolant flows through the coaxial hot duct inside the cross vessel and downward over the once-through helical bundle steam generator. Helium then flows upward, in an annulus, between the steam generator vessel and a shroud leading to the main circulator inlet. The main circulator is a helium submerged, electric-motor-driven, two-stage axial compressor with active magnetic bearings. The circulator discharges helium through the annulus of the cross vessel and hot duct and then upward past the reactor vessel walls to the top plenum over the core.

For availability and maintenance requirements, a separate shutdown cooling system (SCS) is provided as a backup to the primary HTS. The shutdown heat exchanger and shutdown cooling circulator are mounted on the bottom of the reactor vessel. The heat removal systems allow hands-on module maintenance to begin within 24 hours after plant shutdown.

The reactor cavity cooling system (RCCS) is located in the concrete structure external to the reactor vessel to provide a passive heat sink to remove residual heat from the reactor cavity if the HTS and SCS are unavailable to perform their intended functions. The RCCS consists of above-grade intake structures that naturally convect outside air down through enclosed ducts and panels that surround the below-grade core cavity before returning the warmed air through above-grade outflow structures. The core heat is transferred by conduction, convection, and radiation from the core to the RCCS. This system has no controls, valves, circulating fans, or other active components and operates continuously during normal operation and during shutdown conditions.

Major cogeneration applications are highly energy intensive and diverse, including such processes as those associated with heavy oil recovery, tar sands oil recovery, coal liquification, coal gasification, steel mill and aluminum mill processes. Use of MHR in each of these processes has been studied at General Atomics and summarized below.

3.2 Heavy Oil Recovery

About 15% of the U.S. domestic oil reserves are in the form of heavy crude oil, defined as having an American Petroleum Institute (API) gravity of <20°. Recovering this heavy oil can be greatly improved by stimulation methods, such as steam injection. This section summarizes a study (Ref. 2) to apply 2x600 MW(t) PS/C MHR to recovering heavy oil.

The thermal energy requirements for recovering heavy oil with steam drive depend on the oil field size and the reservoir characteristics. This study based the field size on a 2x600 MW(t) PS/C-MHR providing steam for well injection, dewatering, and other process facilities and cogenerating electric power for on-site and off-site uses.

Figure 4 shows a typical field arrangement for a heavy oil recovery project using steam from a Modular Helium Reactor. If injection wells are spaced 1 m^2 (2.5 acres) apart (average), ~698 m^2 (1725 acres) of heavy oil field may be operated at a time with 2x600 MW(t) PS/C-MHR. Typically, the well injection head injects steam at ~3.4 MPa (~500 psia), which is sufficient to reach depths down to 366 m (2300 ft). However, in some locations, the reservoir characteristics and overburden thickness require injection pressures up to 4.5 MPa (650 psia). Presently, heavy oil (steam drive) operators use steam at ~80% quality (dry) to hold dissolved solids in solution. Studies have shown that the oil yield increases significantly with the steam quality. With a PS/C-MHR, which can deliver steam in excess of 538°C (1000°F), dry saturated steam can be injected into the well if desired.

As discussed above, the steam conditions desired at the injection wells are ~3.45 MPa (500 psig) with 85% or higher quality, and very little electrical power is required for the oil field operations. This design approach adapts the 2x600 MW(t) PS/C-MHR.

Figure 5 shows a typical heat cycle for heavy oil recovery. First, 538°C/16.65 MPa (1000°F/2415 psia) steam from the PS/C-MHR steam generators expanded through a turbine generator to an intermediate distribution pressure for the oil field injection wells. Part of the exhaust steam from this turbine generator is then expanded through an extraction turbine generator to provide steam for feedwater heating and to produce additional cogenerated electric power. For this study, the heat cycle was designed to produce the maximum process steam output consistent with efficient cogeneration of electrical power and feedwater heating requirements. Less process steam and more electrical power can be achieved by adding condensing turbine generator capacity; this would be desirable for specific oil field applications with attractive nearby electric power markets.

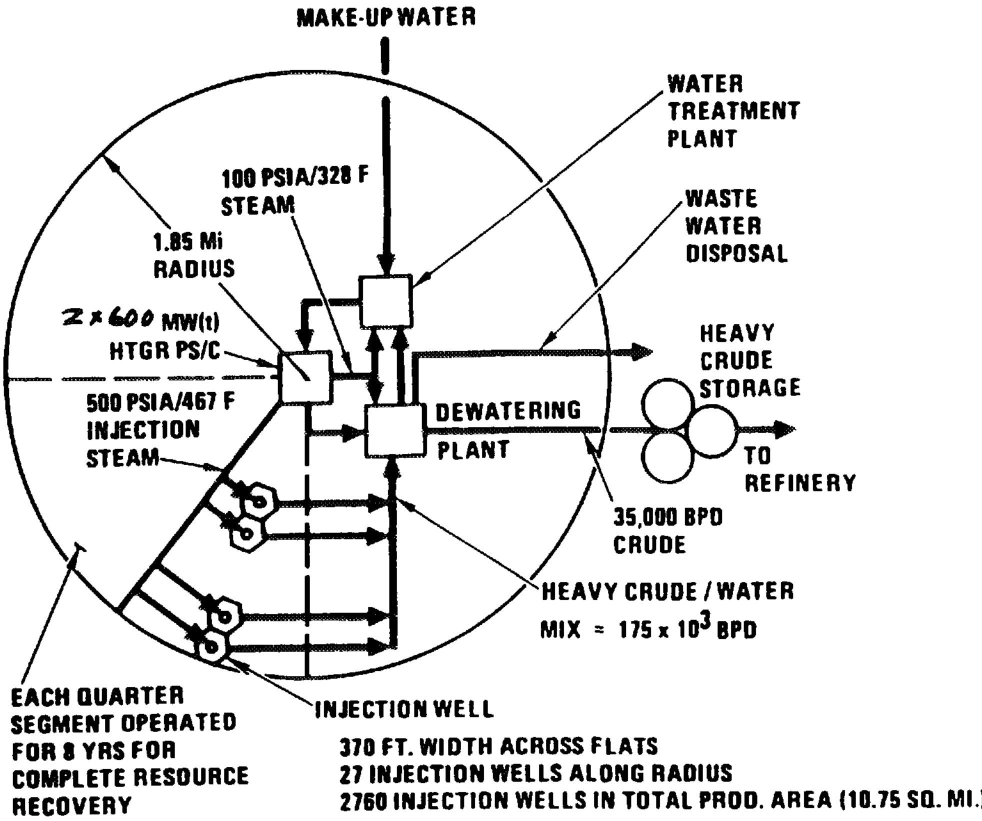

Fig. 4. Field Arrangement for 5562 m³ (35,000 barrel) per Stream Day Heavy Oil Recovery Application

The heat cycle conditions the main turbine generator exhaust steam by desuperheating before distribution to the injection wells. The amount of desuperheating can be adjusted to suit specific oil fields or different periods during the oil field production life.

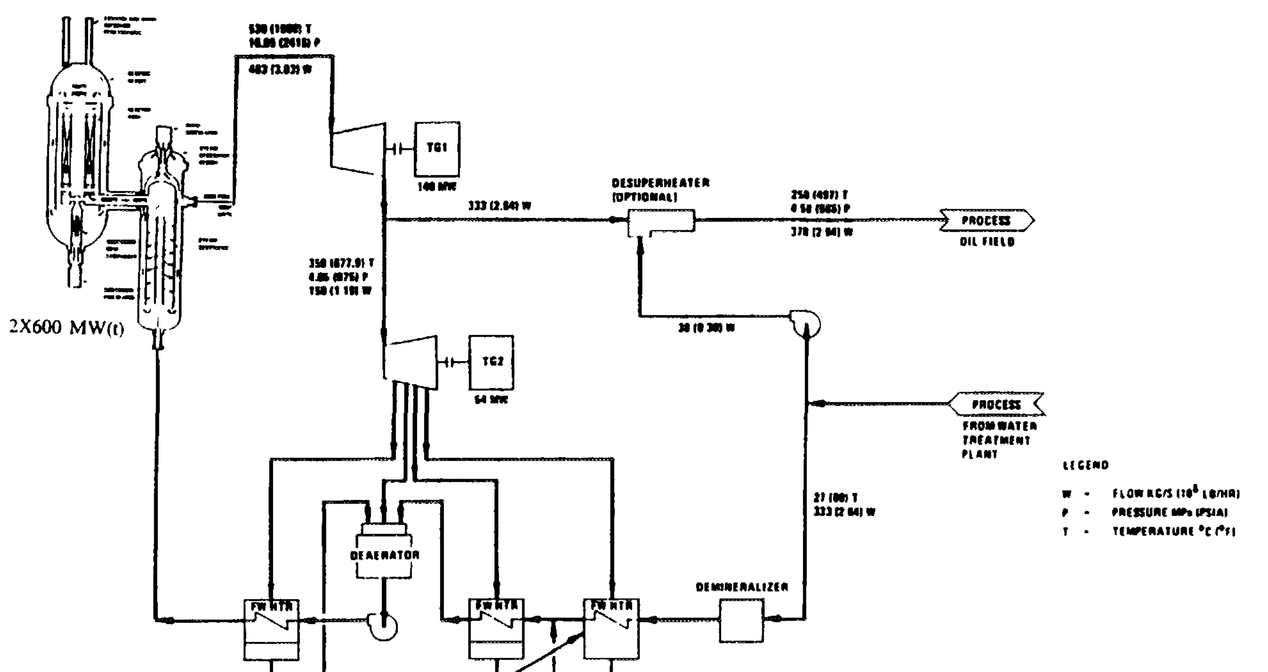

Fig. 5. Cycle Diagram for 2x600 MW(t) PS/C-MHR Plant for Heavy Oil Recovery Application

3.3 Tar Sands Oil Recovery

Tar sands represent a major energy resource that increases in importance as world supplies of crude oil become limited. The oil potential from tar sands in Canada is estimated to equal the world's known reserves of conventional oil; the potential of U.S. tar sends is smaller, but still substantial [4.8 to 5.6 x 10^9 m^3 (30 to 35 x 10^9 bbl)]. Current Canadian production is limited to deposits suitable for strip mining; however, the major reserves lie at greater depths. To exploit these deep reserves, large-scale pilot projects have investigated in-situ recovery. These projects inject saturated steam into the tar sands deposits.

This section summarizes a study (Ref. 3) to apply 2x600 MW(t) PS/C-MHR to tar sands oil recovery and upgrading. The raw product recovered from the sands is a heavy, sour bitumen; upgrading, which involves coking and hydrodesulfurization, produces a synthetic crude (refinable by current technology) and petroleum coke. Steam and electric power are required for the recovery and upgrading process.

The tar sands fields are generally located in sparsely populated areas of Canada. Therefore, the PS/C-MHR plant can be located at the center of the recovery area, minimizing the required piping and the associated pressure drops and heat losses. When the recovery is complete in one quarter of the operating field, the piping will be shifted to the next quarter until the entire field has been covered. Since it takes ~7 years to complete each quarter of the field, the PS/C-MHR will have operated most of its design life (30 years) by the time the recovery is complete.

The nominal steam conditions desired at the injection well are ~13.8 MPa (2000 psia) and 336°C (636°F). Since this steam is obtained by throttling the main steam from 16.65 MPa (2415 psia), adjusting the pressure to account for variations in the distribution pressure drop has some flexibility. A desuperheater using returned water reduces the steam temperature to the saturated condition. The steam required for upgrading, water treatment, and auxiliaries can be further conditioned as required. The balance of the steam, not used by the process, is diverted to a turbine generator, which cogenerates electric power and provides a conventional feedwater heating system for the entire condensate flow. The recovery plant processes makeup and clean condensate. To ensure the specified purity for the PS/C-MHR steam generators, the feedwater train includes a full-flow polishing demineralizer.

Figure 6 shows the cycle for the 7309 m^3/day (46,000 bpd) plant. In this case, only enough steam for feedwater heating [147 kg/s (1.16 x 10^6 lb/hr)] is diverted to the turbine generator; the recovery plant uses the balance [439 kg/s (3.48 x 10^6 lb/hr)]. The turbine generator is a noncondensing unit similar to the high pressure and intermediate pressure units of a small conventional turbine generator; its gross output is 101 MW(e), while its net output is 64 MW(e). The difference is used to drive the PS/C-MHR circulators, the feed pumps, the condensate pumps, and other nonprocess auxiliaries.

3.4 Coal Liquification

The solvent refined coal (SRC-II) process is an advanced process developed by Gulf Mineral Resources Ltd. to produce a clean, nonpolluting liquid fuel from high sulfur bituminous coals. The SRC-II commercial plant will process ~24,300 tonnes (26,800 tons) of feed coal per stream day, producing primarily fuel oil and secondary fuel gases. This summary describes (Ref. 4) the coupling of two module 600 MW(e) PS/C-MHR to the SRC-II process.

Figure 7 shows the SRC-II process flow diagram and gives the steam conditions at various process stages. It shows that the process steam is generated by direct gas-fired boilers, and the process heating by direct gas firing. The fuels utilized are hydrocarbon-rich gas, or CO-rich gas, and purified

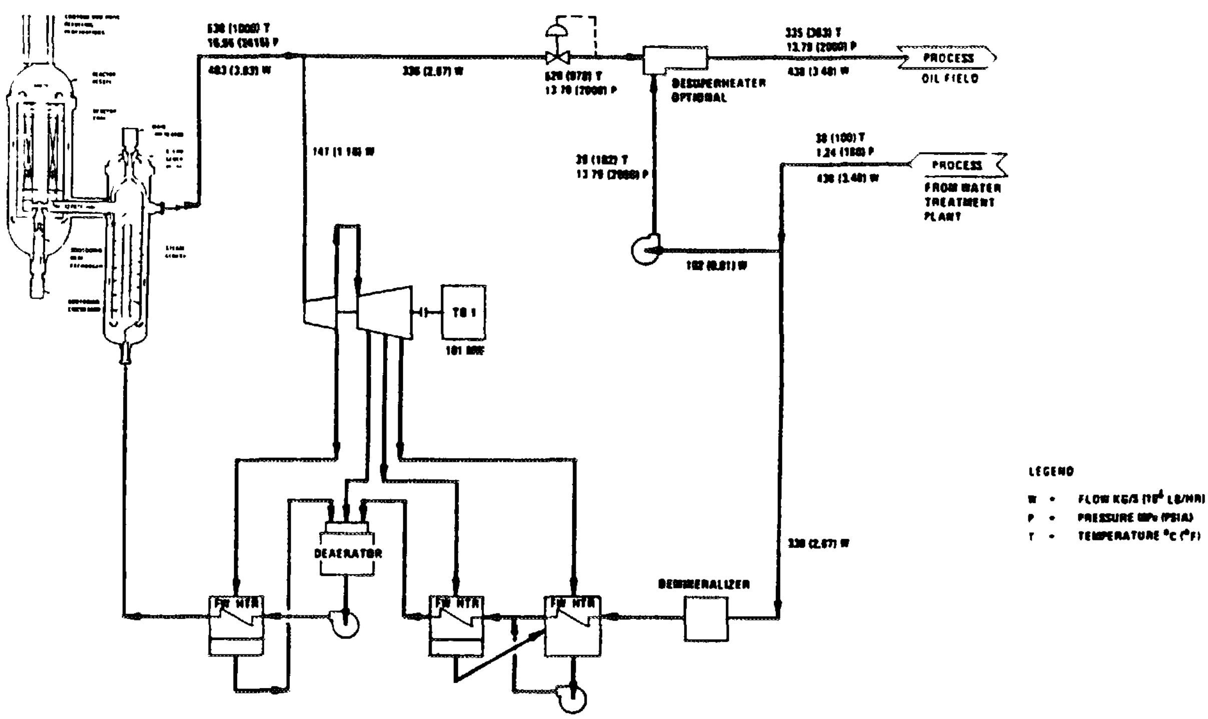

Fig. 6. Cycle Diagram for 2x600 MW(t) PS/C-MHR for Tar Sands Oil Recovery Application

syngas (i.e., no feed coal is used for fuel). It was shown that a 2x600 MW(t) PS/C-MHR can supply these thermal requirements principally by substituting for the fuel gases previously employed. The displaced gases, which are treated already, may then be marketed.

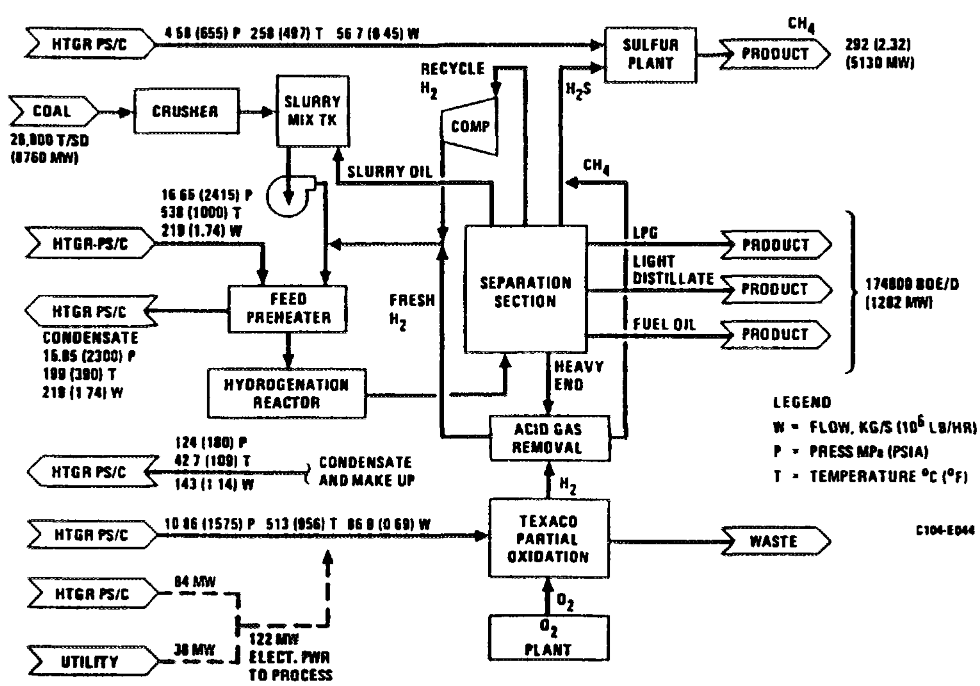

Fig. 7. Process Flow Diagram for SRC-II Coal Liquefaction Application Using 2x600 MW(t) PS/C-MHR

The 538°C (1000°F) steam supply of the PS/C-MHR provides all system thermal energy requirements in the form of process steam generation, steam superheating, and slurry heating. However, slurry heating by steam will entail the development of a new heat exchanger design. The 2x600 MW(t) PS/C-MHR does not generate all the required electrical energy, and a deficit of ~38 MW(e) results.

Figure 8 shows the PS/C-MHR plant cycle diagram. The 10.45 MPa (1515 psia) steam is supplied by throttling the main steam from 16.65 MPa (2415). After throttling, the steam temperature is 513°C (956°F). The required 4.58 MPa (665 psia) saturated steam is supplied from the high-pressure turbine exhaust, which is desuperheated using returned condensate. The remaining four heat requirements are supplied by main steam through separate heat exchangers. The high-pressure condensate from these heaters at 15.86 (2300 psia) and 199°C (390°F) is mixed with the other feedwater between the boiler feedpump and the top feedwater heater.

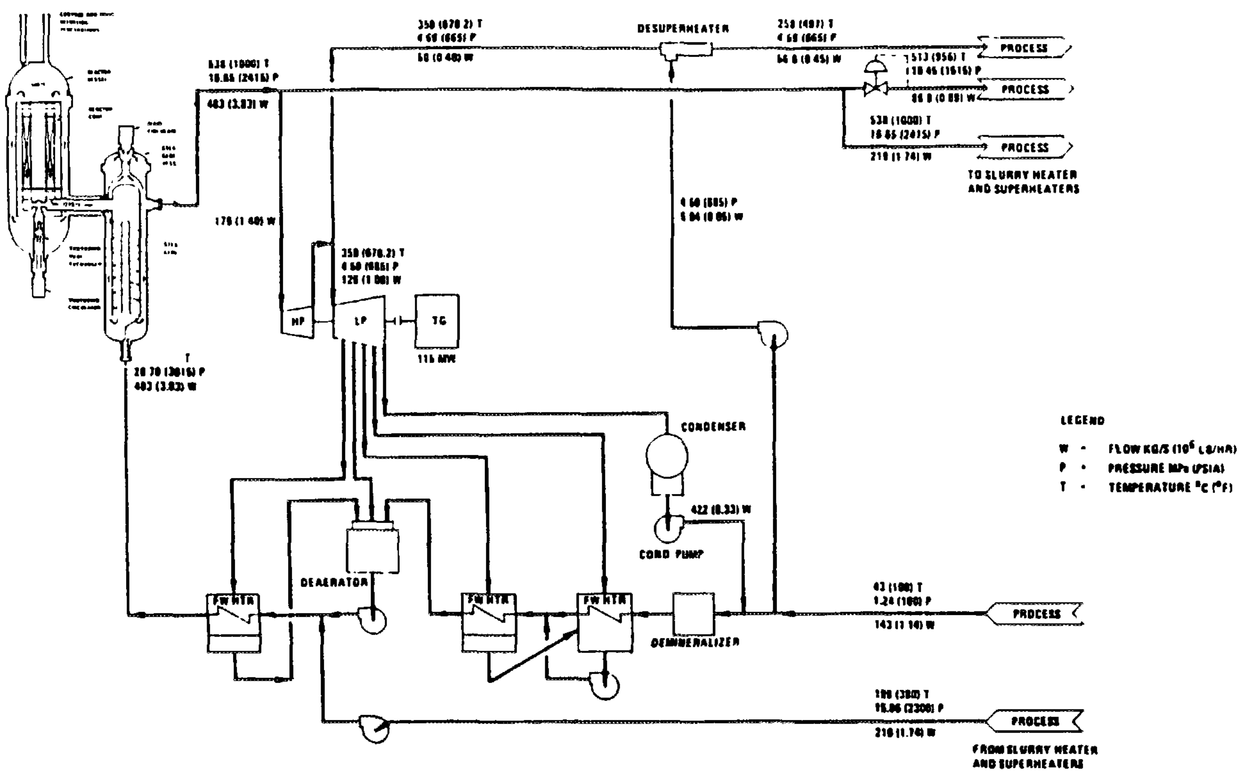

Fig. 8. Cycle Diagram for 2x600 MW(t) PS/C-MHR for SRC-II Coal Liquefaction Application

All the SRC-II plant steam and heat requirements are satisfied either directly or through the heat exchangers. Other steam supplies a condensing steam turbine generator, which produces 114,532 kW and heats all the feedwater for return to the steam generators. The net plant output is 83,509 KW(e).

3.5 H-Coal Liquefaction Process

In countries of large, coal reserves, a strong interest exists to develop and commercialize plants producing liquid and gaseous synthetic fuels derived from coal because of the national objective to reduce foreign oil imports or to export liquid coal. The H-Coal liquefaction is one process which can be used to convert coal into liquid fuel. This section summarizes a study (Ref. 5) to apply an 2x600 MW(t) PS/C-MHR to this process, based on a plant capacity of 27,200 tonnes (30,000 tons) per stream day.

The H-Coal process has several advantages over other processes, including an isothermal reactor bed, hyrogeneration of the coal with a direct, continuously replaceable catalyst (i.e., no dependence on catalytic effects of coal ash), and the absence of quench injections (which would be required with a series of fixed beds).

Figure 9 shows the process flow diagram for a 27,200 tonnes per stream day H-Coal commercial plant using an integrated 2x600 MW(t) PS/C-MHR as the energy source. The original H-Coal process employs mostly coal as its utility fuel, supplemented by high Btu gas from the product stream. Process electric power [251 MW(e)] is purchased from the grid. About 1,090 tonnes (1200 tons) per stream day of coal is required as utility fuel to provide both process heat and process steam. With an integrated PS/C-MHR plant, process heat is provided by using 16.65 MPa (2415 psia) primary steam at 538°C (1000°F) as the heat source. The thermal energy requirements of the H-Coal plant may be supplied either directly or indirectly through reboilers. However, the direct system has a better performance and has been adapted as the reference case. Only 71% of the required 251 MW(e) can be supplied by the PS/C-MHR. The deficit may be generated by increasing the reactor capacity or by purchasing from local utilities.

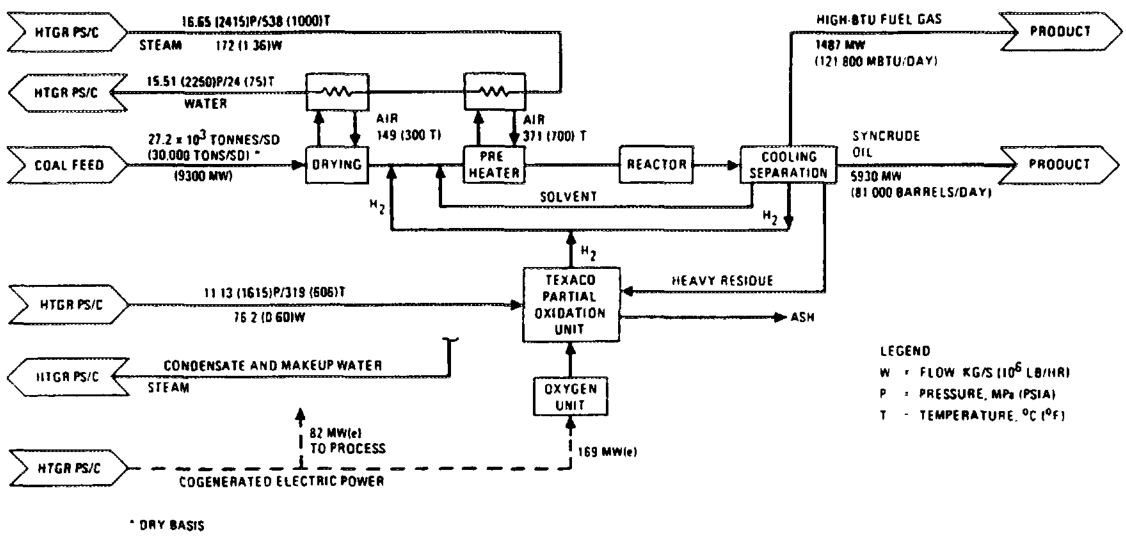

Fig. 9. Process Flow Diagram for H-Coal Process Application Using 2x600 MW(t) PS/C-MHR

Figure 10 shows the heat cycle developed to meet the application requirements. Main steam at 538°C (1000°F) and 16.65 MPA (2415 psia) supplies process heat to the H-Coal reactor feed preheater. High-pressure condensate from the feed preheater at 210°C (410°F) and 15.86 MPa (2300 psia) then cascades through the fluidized bed dryer and returns to the PS-C-MHR feedwater heating system at 24°C (75°F) and 15.51 MPa (2250 psia). Additional main steam is throttled and desuperheated to 319°C (606°F) and 11.14 MPa (16/15 psia) to supply steam to the Texaco partial oxidation reaction unit. The remainder of the steam from the PS/C-MHR is expanded through a condensing turbine generator, which produces 217 MW(e) gross and provides extraction steam for feedwater heating.

Condensate and makeup water are assumed to return from the process at 43°C (109°F) and 1.20 MPa (180 psia). Part of this water supplies desuperheating water via a booster pump. The remainder is combined with water from the turbine generator condenser hotwell, then passes through a conventional three-stage feedwater heating train. A separate high-pressure feedwater train heats condensate from the fluidized bed dryer unit. Feedpump discharge from the two trains is combined and passes through an additional high-pressure feedwater heater before returning to the PS/C-MHR steam generators at 221°C (430°F) and 20.79 MPa (3015 psia).

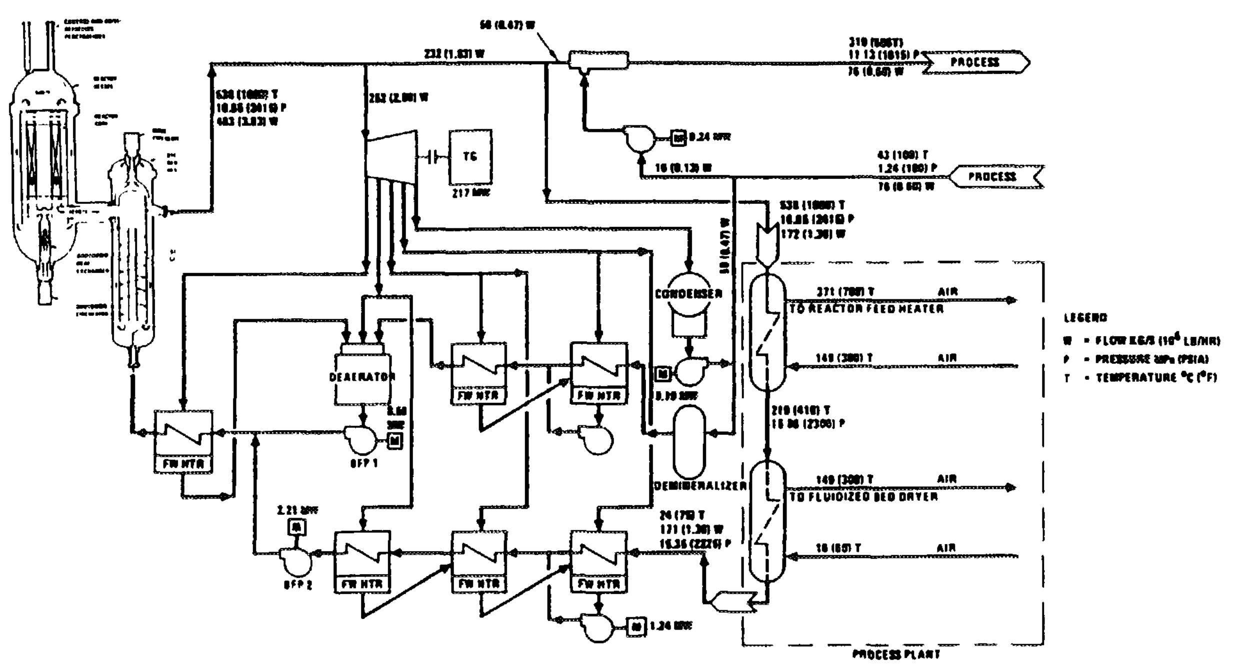

Fig. 10. Cycle Diagram for 2x600 MW(t) PS/C-MHR for H-Coal Process Application

3.6 Coal Gasification Process

This section summarizes a study to apply the PS/C-MHR to Exxon catalytic coal gasification. Several countries worldwide are interested in developing plants producing gaseous synthetic fuels derived from coal, based on the national objective to reduce foreign oil imports and to use or export the abundant coal. Exxon catalytic coal gasification (ECCG) is one gasification process developed in the United States.

Initially, coal gasification plants are expected to obtain thermal power requirements from fossil sources (coal or product liquid and gaseous fuel from the synfuel plant) and to obtain electric power partly from in-plant cogeneration and partly from local utilities. Most processes are estimated to consume 25% to 30% of the feed coal to satisfy the plant energy needs.

This study (Ref. 6) indicates that incorporating a PS/C-MHR plant could provide thermal and electrical energy for the ECCG process to benefit worldwide interests by conserving fossil fuel and reducing environmental impact.

The ECCG process uses alkali metal salts as a gasification catalyst with a novel processing sequence. Although no net heat is required for the gasification reaction, heat input is required for drying and preheating the feed coal, gasifier heat losses, and catalyst recovery operations. Mechanical drives and plant electrical power also have energy input requirements. Figure 11 plots heat input versus temperature for the process, and indicates which can be provided by the PS/C-MHR.

Figure 12 shows a conceptual arrangement for an ECCG process plant using energy from two module 2x600 MW(t) PS/C-MHR. About 13,144 tonnes (14,490 tons) of coal per stream dry (wet basis) are processed, and the plant produces ~6833 m^3/day (~43,000 bpd) oil equivalent product (3140 MW) as methane.

As indicated above, the PS/C-MHR can supply all energy requirements for the ECCG process, except for very high-temperature energy required to preheat feed to the gasification reactor. This is

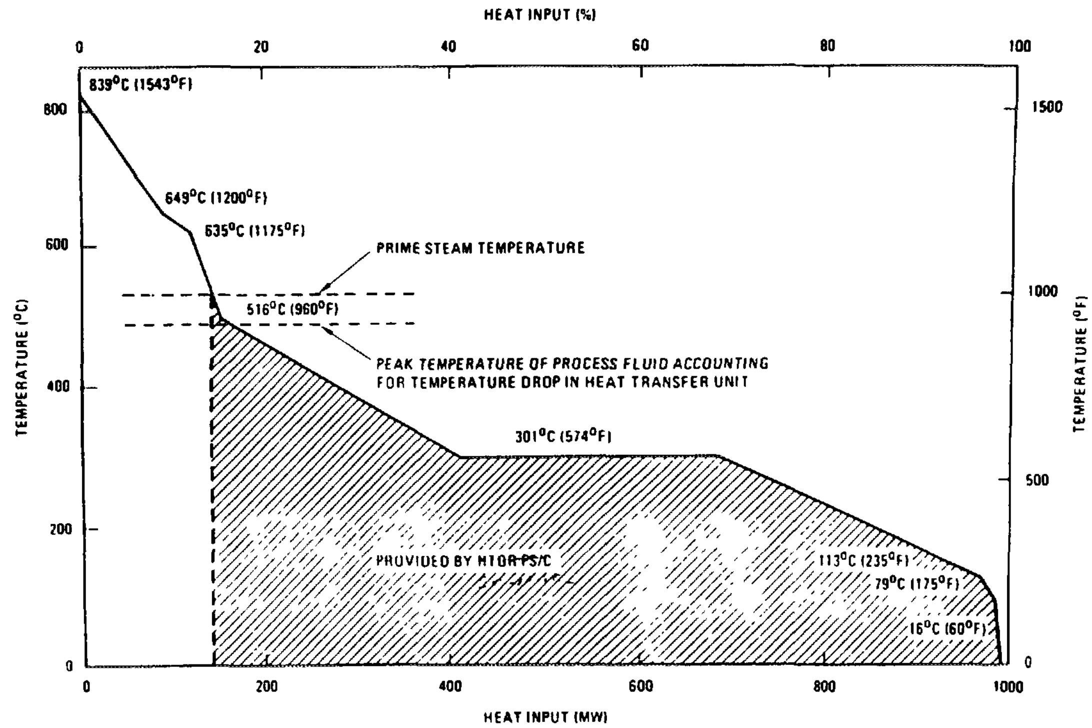

Fig. 11. Heat Input/Temperature Distribution for ECCG Process Using 2x600 MW(t) PS/C-MHR

assumed to be supplied by fossil-fired heaters. Two 600 MW(t) PS/C-MHR provides energy sufficient for the remaining process heat and mechanical power requirements and all plant electrical power requirements for the 13, 144 tonnes (14, 490 tons) per stream day ECCG plant considered in this study. In addition, surplus electrical power produced is available for other uses.

This brief study shows that the PS/C-MHR appears to make a good fit with the ECCG process.

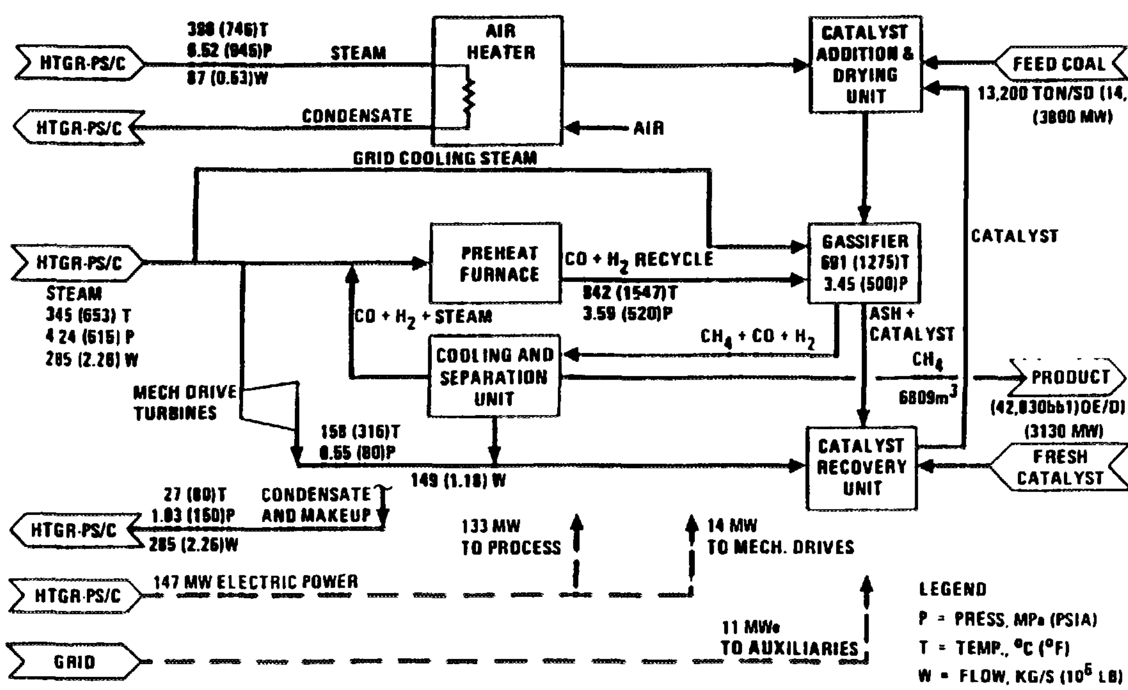

Fig. 12. Process Flow Diagram for ECCG Power Application Using 2x600 MW(t) PS/C-MHR

Figure 13 shows the proposed heat cycle. The high-pressure turbine, which exhausts at 4.4 MPA (640 psia), is similar to the high-pressure unit of a 450-MW turbine generator, except that a controlled extraction at 6.5 MPA (945 psia) provides steam for air preheating. The exhaust steam, is split: 136 kg/s (1,080,000 lb/hr) goes to the process, sufficient steam is provided to the feedwater heating extraction turbine, and the remainder is used in noncondensing mechanical drive turbines. The feedwater heating turbine is a noncondensing unit similar to portions of a conventional power plant intermediate/low pressure turbine. The backpressure on this unit is set at 58 kPa (8.42 psia) to suit feedwater heating requirements.

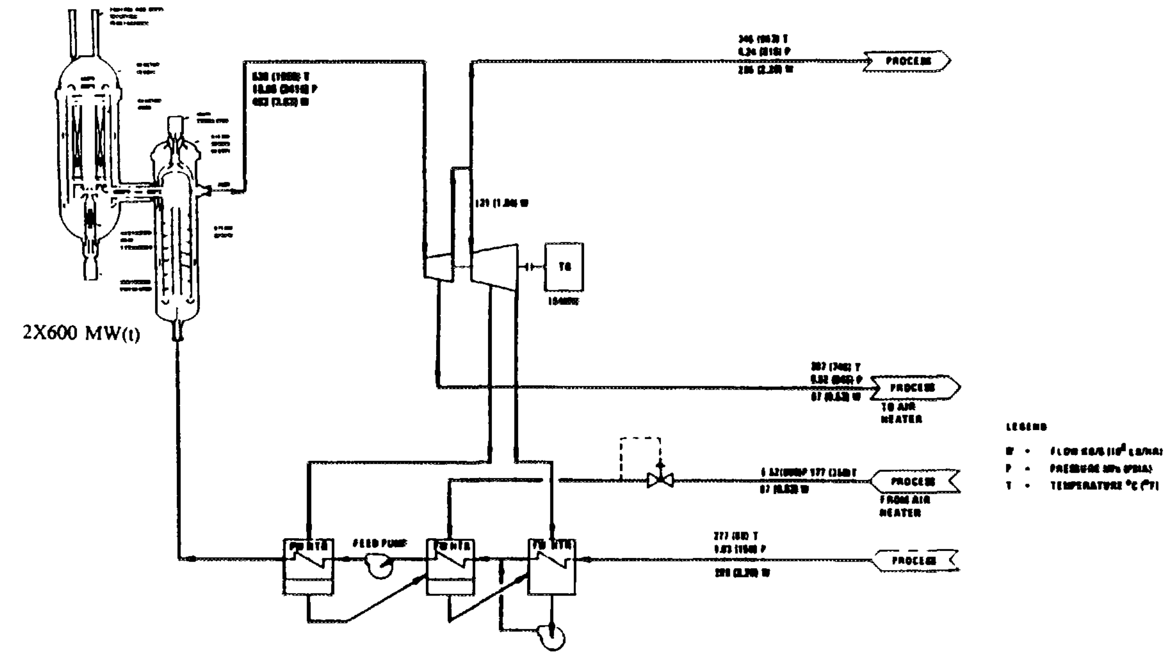

Fig. 13. Cycle Diagram for 2x600 MW(t) PS/C-MHR for ECCG Process Application

3.7 Steel Mill

The U.S. steel industry is very large and consumes large quantities of energy. It uses ~35% of this energy in the form of electricity, fuel oil, or natural gas; the balance is coal. Therefore, the supply of the non-coal energy by a PS/C-MHR can conserve scarce fossil fuel resources.

This section summarizes a study (Ref. 7) to apply two module 600 MW(t) PS/C-MHR to a 6.5×10^6 tonnes (7.2×10^6 tons) per year liquid steel plant. The SC-MHR can provide both electricity and high-temperature steam to flexibly meet steel mill needs and provide export electricity to the local utility grid.

The 2x600 MW(t) PS/C-MHR can satisfy the energy requirements for a typical commercial steel mill to produce 6.5×10^6 tonnes (7.2×10^6 tons) (liquid) of steel per year. The surplus energy, which may be generated either as steam at 5.0 MPa (725 psia) and 365°C (689°F) at 125 kg/s (10^6 lb/hr) or as electric power [~100 MW(e)], can be exported outside the plant. Depending on the steel mill location, steam could be supplied to neighboring industries or, alternatively, the electric power can be sold to a utility.

The plant design is based on the two module PS/C-MHR. Two cases were considered:

Case 1: Supply 240,000 kW and 101 kg/s (800,000 lb/hr) of steam to the steel mill with excess energy used to supply additional steam to other users at the same conditions.

Case 2: Supply 240,000 kW and 101 kg/s (800,000 lb/hr) of steam to the steel mill with excess energy used to generate additional electric power.

Figures 14 and 15 give the cycles selected to satisfy the requirements for the two cases, respectively.

For Case 1, 101 kg/s (800,000 lb/hr) of steam is supplied to the steel mill: in addition, 135 kkg/s (1,068,000 lb/hr) of steam is provided to other users. The net electrical power produced is 240,000 kW.

For Case 2, only 101 kg/s (800,000 lb/hr) of steam is produced and supplied to the steel mill, and the net electrical power produced is increased to 354,558 kW.

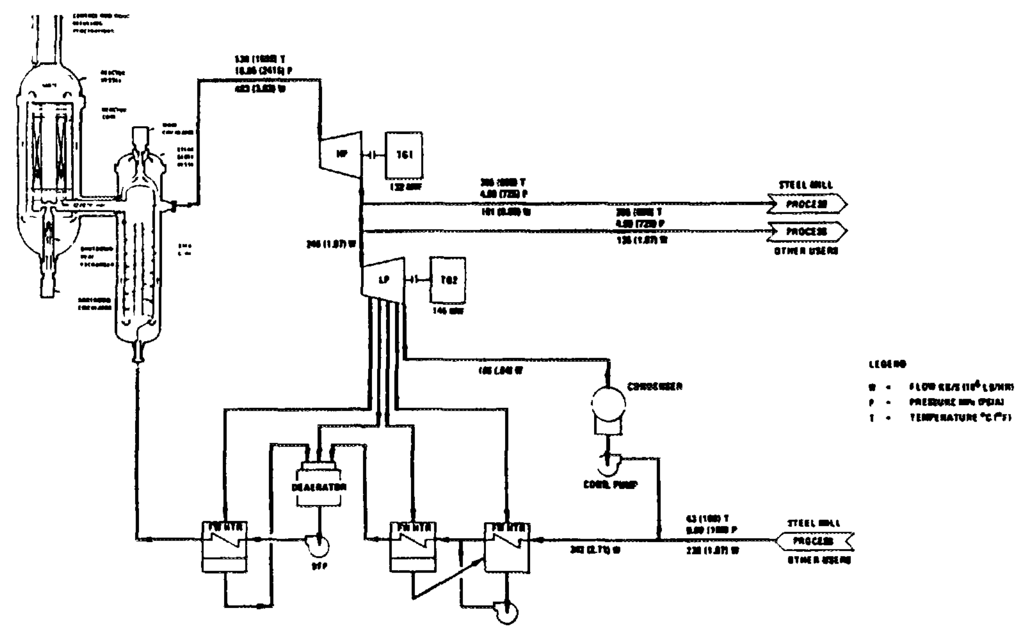

Fig. 14. Cycle Diagram for 2x600 MW(t) PS/C-MHR Plant for Steel Mill Application (Tailored Cogenerated Electrical Power)

3.8 Alumina Plant

Aluminum refining uses two major energy-intensive processes:

1. Aluminum oxide or alumina is obtained from bauxite via the Bayer chemical process. This process uses a significant amount of steam to react with bauxite and for mechanical drive. It also requires electric power.

2. Alumina is reduced to aluminum by electrolysis. This process requires large amounts of electric power.

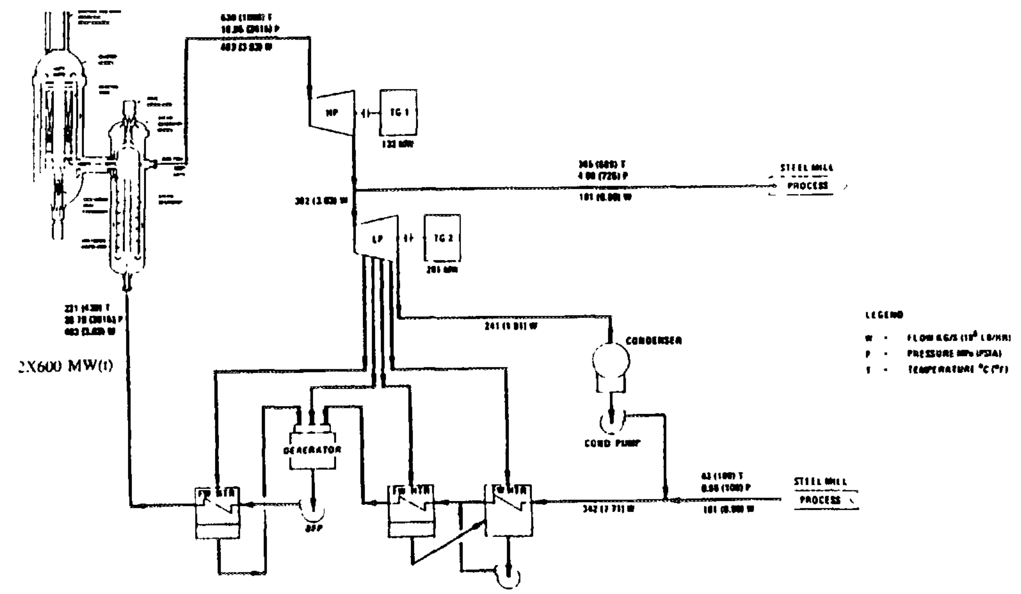

Fig. 15. Cycle Diagram for 2x600 MW(t) PS/C-MHR Plant for Steel Mill Application
(Maximum Cogenerated Electrical Power)

Figure 16 shows a schematic process flow diagram from ore reduction to aluminum production. Most existing commercial aluminum plants use energy from natural gas power plants. Hydroelectric power supplies a very small fraction of the total aluminum electric power requirements.

This section considers (Ref. 8) the PS/C-MHR application to producing alumina from bauxite. For the size alumina plant considered, the two module 600 MW(t) PS/C-MHR supplies 100% of the process steam and electrical power requirements and produces surplus electrical power and/or process steam, which can be used for other process users or electrical power production. Presently, the bauxite ore is reduced to alumina in plant geographically separated from the electrolysis plant. However, with the integration of 2x600 MW(t) PS/C-MHR units in a commercial alumina plant, the excess electric power available [~233 MW(e)] could be used for alumina electrolysis.

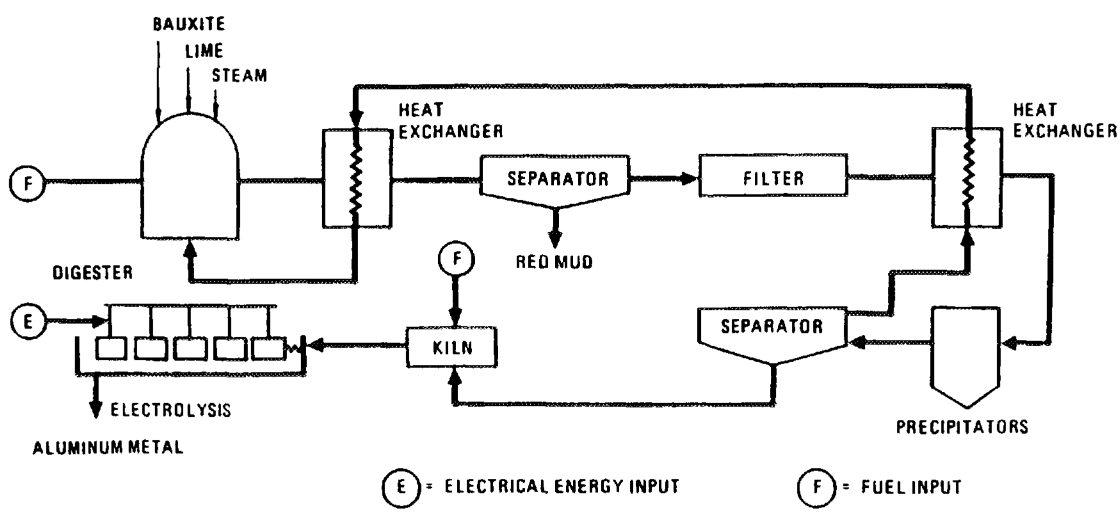

Fig. 16. Process Flow Diagram for Aluminum Mill Application

It has been shown the steam and electrical energy requirements for a typical commercial alumina plant processing 726,680 tonnes (800,000 tons) per year of alumina ($A1_20_3$) can be satisfied by two module PS/C-MHR.

A two module PS/C-MHR has excess capacity for the process steam and electrical power requirements of the 725,680 tonnes (800,000 tons) per year alumina plant considered in this study. The excess capacity can produce additional process steam for sale to other users, additional electrical power for sale to a utility or for use by the alumina electrolysis plant, or any desired combination of excess steam and electric power. The local market for other process steam uses, plant economics, proximity of the electrolysis plant, etc., would determine the cycle selected. Two limiting heat cycles have been studied: (1) maximum process steam (Fig. 17) and (2) maximum cogenerated electric power (Fig. 18).

The plant entry should have nominal steam conditions of ~4.96 MPA/321°C (720 psia/610°F); some variation is acceptable. The cycles studied produce steam at 5.45 MPA/381°C (790 psia/718°F) at the reactor plant site boundary, providing a margin for transmission losses. The alumina plant can provide additional steam conditioning by throttling and/or desuperheating as required.

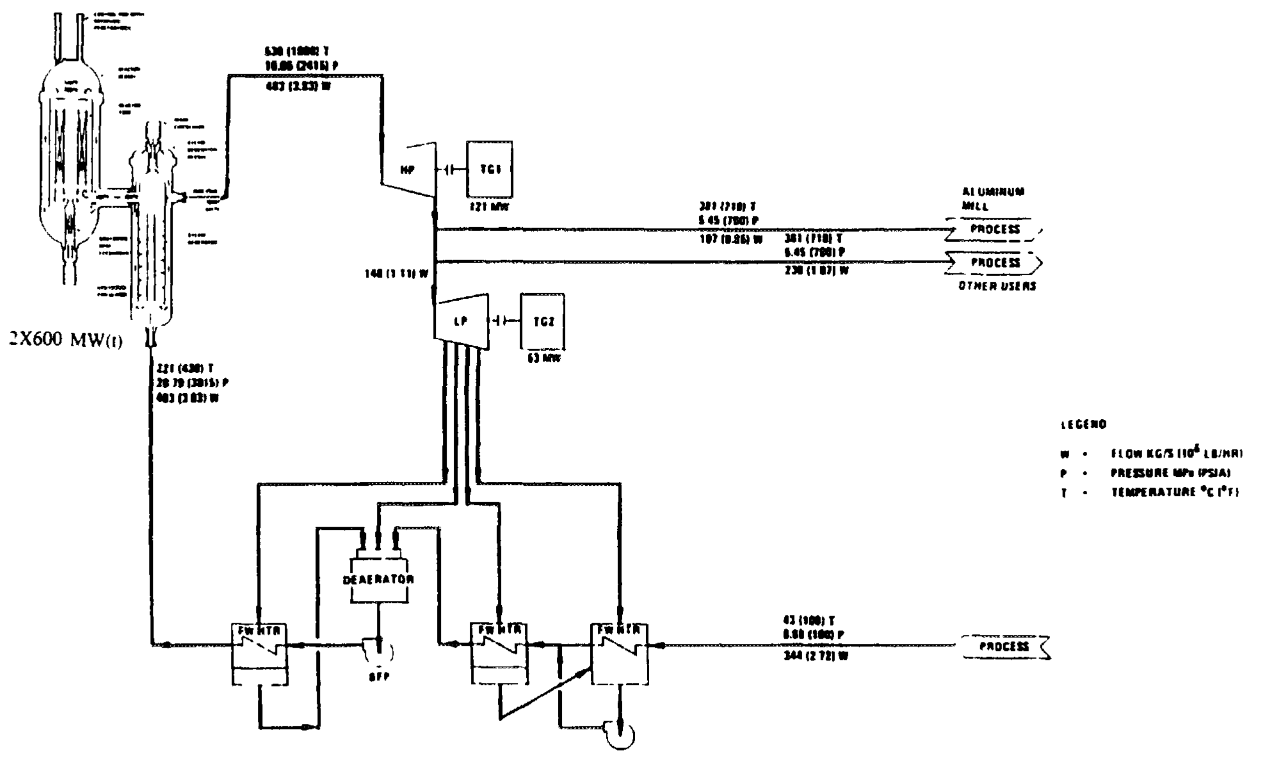

Fig. 17. Cycle Diagram for 2x600 MW(t) PS/C-MHR Plant for Aluminum Mill Application (Maximum Process Steam)

4. PROCESS HEAT APPLICATIONS

High temperature process heat is a second major example (Ref. 9) how the MHR can be extended to use its full temperature capability in non-electric applications. In terms of market application, transportation fuels represent the largest potential application for a Process Heat Modular Helium Reactor (PH-MHR) system. Potential fuels could include methane, synthetic gasoline or hydrogen itself using various feedstocks. However, one interesting application is the production of methanol from coal.

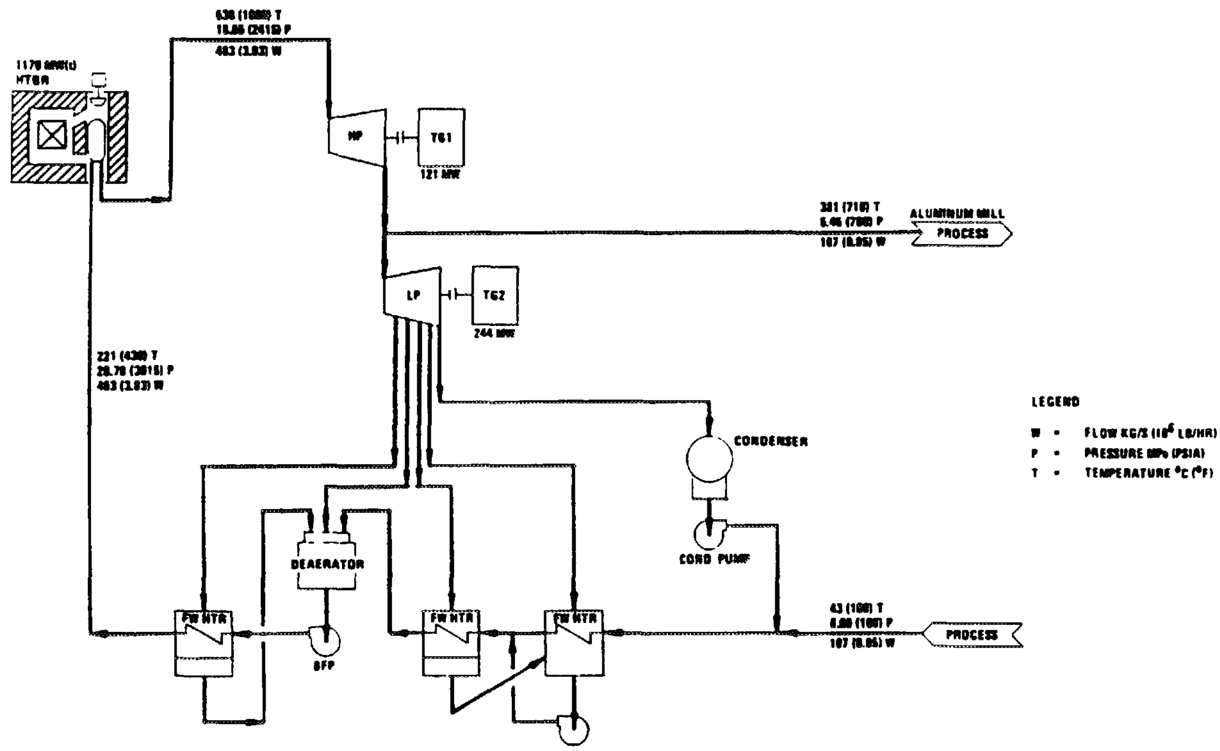

Fig. 18. Cycle Diagram for 2x600 MW(t) PS/C-MHR Plant for Aluminum Mill Application (Maximum Electrical Power)

The principal challenge to configuring an PH-MHR system for methanol production is the method of transporting heat to drive the coal to methanol reactions. Nuclear heat must be generated separately and then studied indirectly to the process steam by a heat exchanger. Two possible configuration arrangements have been studied for nuclear coal conversion schemes, steam-coal gasification and hydrogasification (Ref. 5). The preferred process for this study is hydrogasification, which has the advantage of requiring only one heat exchanger interface, a reformer, between the nuclear heat source and the coal conversion process system. The basic reactions for the hydrogasification process are shown in Figure 19 and the process arrangement is shown in Figure 20.

In a hydrogasification process, nuclear generated heat is introduced directly through the reformer, which converts CH_4 and steam to CO and H_2. For efficient reaction rates, the former requires heat at temperatures up to 788°C (1450°F), which is achievable with an MHTGR-PH with a 850°C (1562°F) core outlet helium temperature. In addition, feed steam is required at approximately 482°C (900°F) in at least 2-to-1 ratio with CH_4. This high temperature steam can be conveniently supplied by a steam generator in series with the reformer.

4.1 PH-MHR Plant Description

The proposed physical configuration of the PH-MHR for methanol production is a straight-forward adaptation of the PS/C-MHR design. Figure 21 shows the configuration of the 600 MW(t) PC-MHR primary system with the reactor in one vessel and the heat exchangers and circulator in a second vessel viz. The MHTGR-SC arrangement. Primary coolant exiting from the core at 850°C (1562°F) flows through the inner duct in the cross-vessel to the heat exchanger vessel where it gives up its heat in series to the reformer and the steam generator. The circulator, which is located at the top of the heat exchanger vessel, returns the cold helium at 343°C (650°F) to the core inlet via the outer concentric duct.

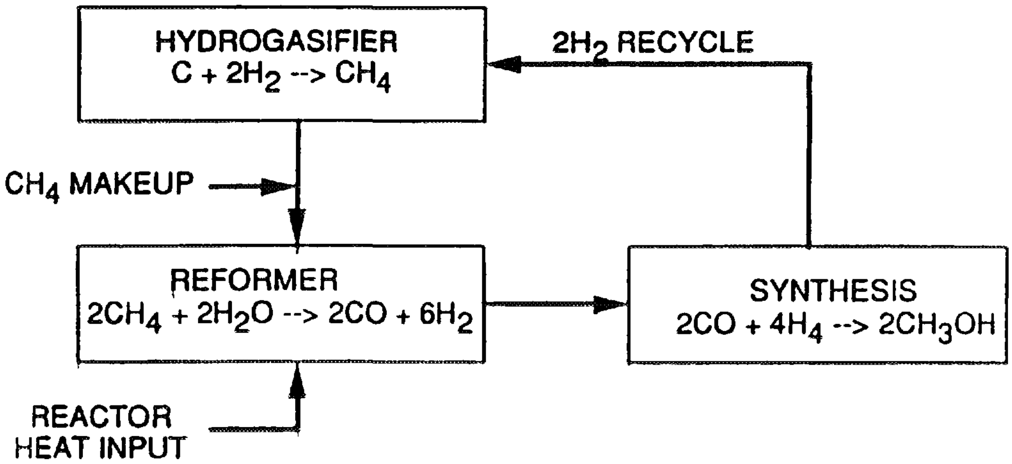

Fig. 19. Reactions for Coal to Methane by Hydrogasification

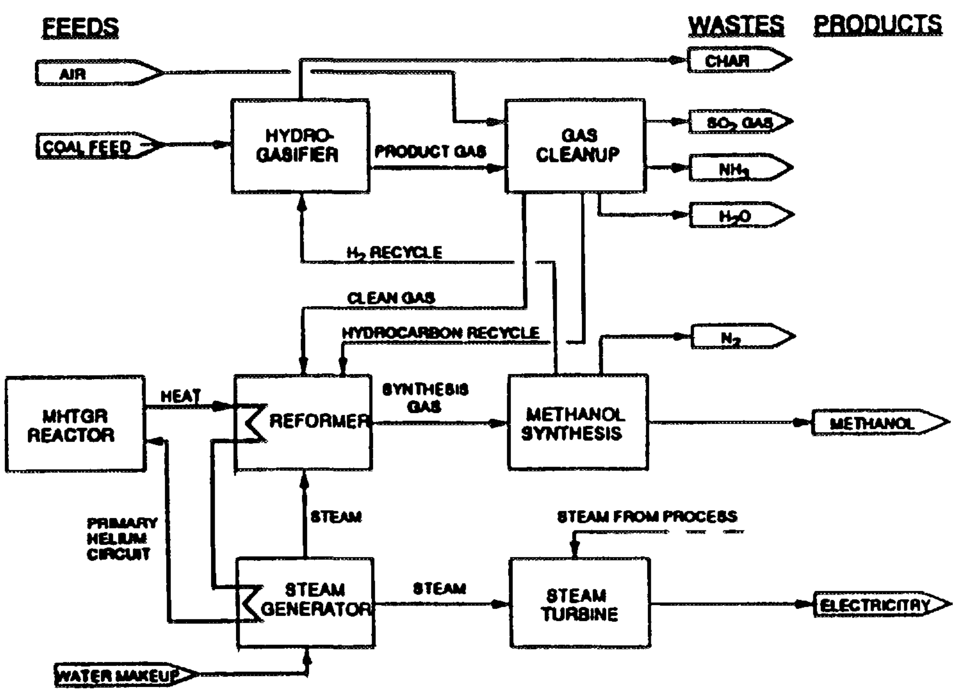

Fig. 20. Process Flow Diagram for Methanol Process Using PH-MHR Reactor Plant

Like the SC-MHR, the two-vessel system is located in a below-grade confinement structure with air-cooled heat removal panels to provide passive cooling of the reactor vessel for safety-related shutdown cooling events. The salient primary system design parameters for the PH-MHR are given in Table 2.

The PS/C-MHR reactor can be adapted to process heat application with an outlet temperature of 850°C (1562°F) with very little modification. The most significant difference for the PH-MHR is that the fuel cycle is changed from a staggered reload scheme where half of the core is replaced every 18 months to a batch reload in which the entire core is replaced every 36 months. The effect of the batch core is to reduce the age component of the radial peaking factor and thereby reduce peak fuel temperatures.

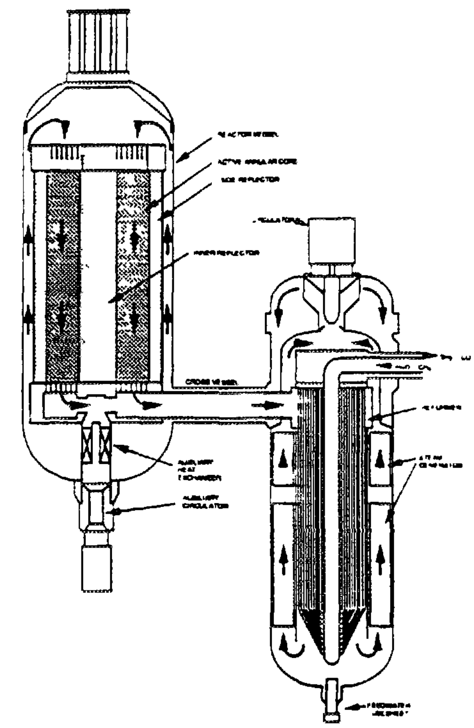

Fig. 21. PH-MHR Primary System Flow Diagram

TABLE 2
PH-MHR PRIMARY DESIGN PARAMETERS

Reactor thermal power, MW(t)	600
Core inlet pressure, MPa (psia)	7.066 (1025)
Helium flow, 10^3 kg/s (lb/hr)	231 (1832)
Core inlet temperature, °C (°F)	343 (650)
Core outlet temperature, °C (°F)	850 (1562)
Steam generator inlet temperature, °C (°F)	676 (1248)
Steam generator outlet temperature, °C (°F)	340 (644)

4.2 Methanol Production

The heat exchanger arrangement (Fig.19) is unique in that the straight tube reformer is located n the center of the helical steam generator. The hot helium from the core outlet flows down through the reformer and then up through the steam generator. Regenerative heating between the two units is limited by two shrouds and a gap.

The straight-tube reformer bundle is headered on the top by a tubesheet and on the bottom by a cylindrical manifold which is an extension of the central return duct. The large tubes, 7.6 cm (3 in.) OD, contain a nickel impregnated aluminum oxide catalyst in the form of 1.3 cm (0.5 in.) spheres for catalyzing the steam-methane reaction.

The helical steam generator surrounds the straight tube reformer. The steam generator is a down-flow unit which represents a major deviation from the MHTGR-SC design. Downflow helical bundles have been successfully built and operated in gas-cooled reactors (viz. THTR in Germany).

Reference 10 gives a description of the methanol-from-coal process system. The process features the reformer, hydrogasifier, gas cleanup system and methanol synthesizer. Excess steam from the steam generator (which is not used in the process) is used to generate electric power as a byproduct. The primary process feed is coal and methane is used as a secondary process feed to balance the stoichiometry and eliminate production of CO_2 as a byproduct.

For a typical bituminous coal, a 4x600 PH-MHR plant requires 324,000 kg/hr coal and 75,600 kg/hr methane feeds and produces 446,000 kg/hr of methanol product along with 408 MW(e) of net saleable power.

5. HYDROGEN PRODUCTION MODULAR HELIUM REACTOR (HP-MHR)

Global carbon dioxide emissions are estimated to exceed a total of 25 billion tons per year in 1995 and could reach as high as 40 billion tons per year by the year 2050. In order to mitigate this global warmup trend emissions need to be significantly curtailed. In particular, the industrialized countries' CO_2 emissions need be reduced as they presently contribute approximately 80% of total CO_2 emissions. A strong case can be presented in favor of the hydrogen fuel in meeting future world energy needs and in achieving the targeted global reduction in the CO_2 emissions.

Two forms of energy, namely, electricity and hydrogen are predicted to dominate world energy system in the long term for the following reasons.

1. Electricity and hydrogen can be derived from renewable and/or inexhaustible energy sources, namely, nuclear, wind, biomass, solar, etc.

2. If produced from the above mentioned sources, production processes are relatively environmentally benign, as are the combustion products produced (water and low-quality heat).

3. Electricity and hydrogen are interconvertible using electrolysis or fuel cells.

4. This energy system is very flexible because of variety of sources, diversity of production methods, options for storage and transportation, and spectrum of end-uses possible using this energy system.

In addition, hydrogen has very high energy release per unit mass which is particularly advantageous in aviation applications. With proper management, it should not be any more difficult to use hydrogen than conventional fossil fuels.

Several techniques are used in the production of hydrogen, namely, steam reforming of fossil fuels, high temperature electrolysis of steam and thermochemical water-splitting. All the above-mentioned techniques for hydrogen production require process heat and/or steam at temperatures ranging from 700° to 900°C. Of all existing nonfossil fuel energy sources, only the MHR system can provide process heat at the required high temperatures.

Interfacing of the MHR heat source with the hydrogen production process equipment needs further development. Previous studies on a process heat High Temperature Gas-cooled Reactor (HTGR) system have shown that an indirect cycle concept of the MHR system through a secondary heat transport loop using an Intermediate Heat Exchanger (IHX) may be used to reduce potential radioactive contamination of the process equipment.

5.1 Hydrogen Production Processes

There are several techniques used in the production of hydrogen, namely, steam reforming of fossil fuels, high temperature electrolysis of steam and thermochemical water-splitting. All the above-mentioned techniques for hydrogen production require process heat and steam at temperatures ranging from 700° to 900°C. Of all existing nonfossil fuel energy sources, only the MHR system can provide process heat at the required high temperatures. General Atomics has performed several studies of the hydrogen production techniques under the sponsorship of Gas Research Institute. They include hydrogen production from fossil fuel sources and thermochemical water splitting. Currently, a major effort is underway in Japan to demonstrate hydrogen production techniques using the high temperature process heat from a 30 MW(t) high temperature gas-cooled reactor (HTTR). Similar studies of hydrogen production using high temperature AVR reactor have been proposed in Germany.

A brief description of each of the above mentioned hydrogen production processes, and how the MHR system can be employed as a high temperature heat source in each of these processes is given below.

5.2 Steam Reforming of Methane

Currently, the steam reforming of methane is the most economically viable commercial hydrogen production technique. In this process [Figure 22(a)], methane in the form of natural gas or methane obtained using coal hydrogasification reacts with high temperature steam to form synthesis gas ($CO + H_2$). This reaction is endothermic and is optimized at a temperature of 800°C and a pressure of 175 psi. The process heat and the high temperature steam required by this reaction can be supplied by the MHR. Consequent water gas shift reaction results in maximizing the hydrogen yield.

Figure 22(b) shows a schematic of the MHR process configuration to produce hydrogen. Thermal efficiency as high as 60% to 70% can be realized using this process. It is estimated that a single 600 MW(t) unit can produce 575,000 lbm/day of hydrogen, which is equivalent to 5400 bbl/day of oil.

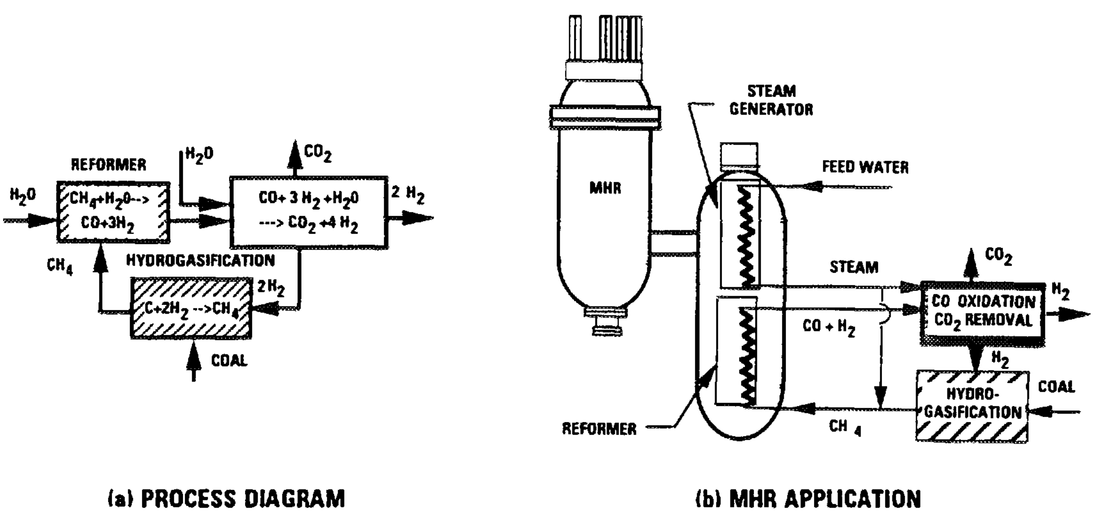

Fig. 22. Hydrogen Production by Steam Reforming of Methane

5.3 Water Electrolysis

Production of hydrogen from water using electrolysis [Figure 23(a)] on an industrial scale can be achieved at an efficiency of 50% to 60%. To improve this efficiency, methods such as high temperature electrolysis of steam or a solid electrolyte method are under development which are expected to yield efficiencies as high as 90%. If such a method can be implemented on an industrial scale, it will be economical to use surplus electricity to decompose water during off-peak periods of operation and utilize this hydrogen in a fuel cell when more electricity is required.

The MHR system in electricity generation mode can provide the required power input for water electrolysis [Figure 23(b)]. For high temperature electrolysis of steam (temperatures of 800° to 900°C), the MHR can provide both the electrical power as well as the high temperature steam.

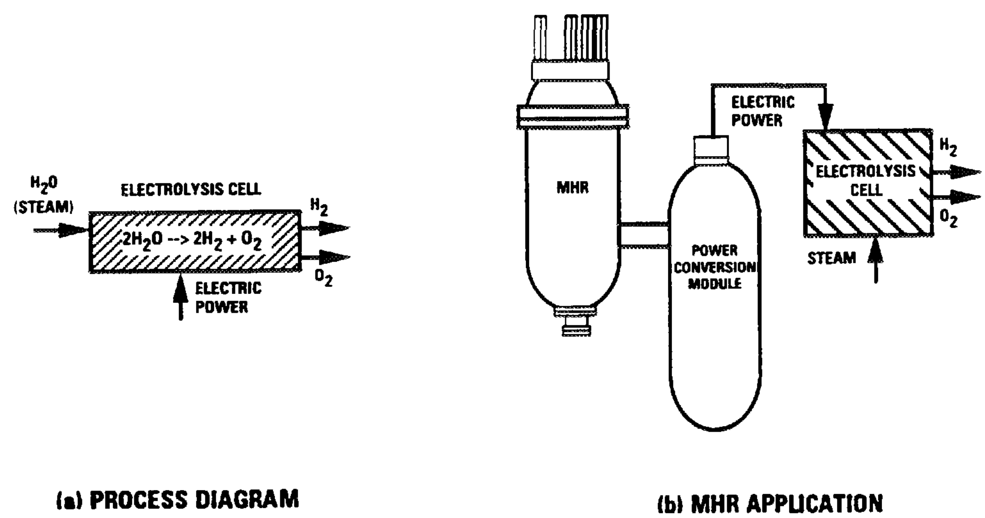

Fig. 23. Hydrogen Production Using Water Electrolysis

5.4 Thermochemical Water Splitting

Hydrogen production by thermochemical water splitting (Refs. 11, 12) involves high temperature (850°C) process chemical reactions in an iodine-sulfur cycle (Iscycle) which originally was developed by General Atomics in 1979. The classical Buunsen reaction involves [Figures 24(a) and 24(b)] the dissociation of sulfuric acid at a temperature of 850°C and the dissociation of hydriodic acid at a temperature of 500°C. In addition, acid separation requires water at a temperature of 200°C. Hydrogen is a product of the hydriodic acid (HI) decomposition. Both the sulfuric acid and the hydriodic acid are recycled. An operating process efficiency of 40% to 50% can be achieved using this chemical conversion process. Further development is required to establish this process on an industrial scale by optimizing the hydrogen production efficiency and to select required noncorrosive high temperature materials for thermochemical process.

Water electrolysis and chemical conversion of water using thermochemical water splitting processes are the preferred hydrogen processes as they do not produce CO_2 emissions. An aggressive, results-oriented, multiyear initiative should be pursued to establish the commercial viability of these hydrogen production processes and to explore the technical requirements for industrial application of hydrogen in the early 21st century.

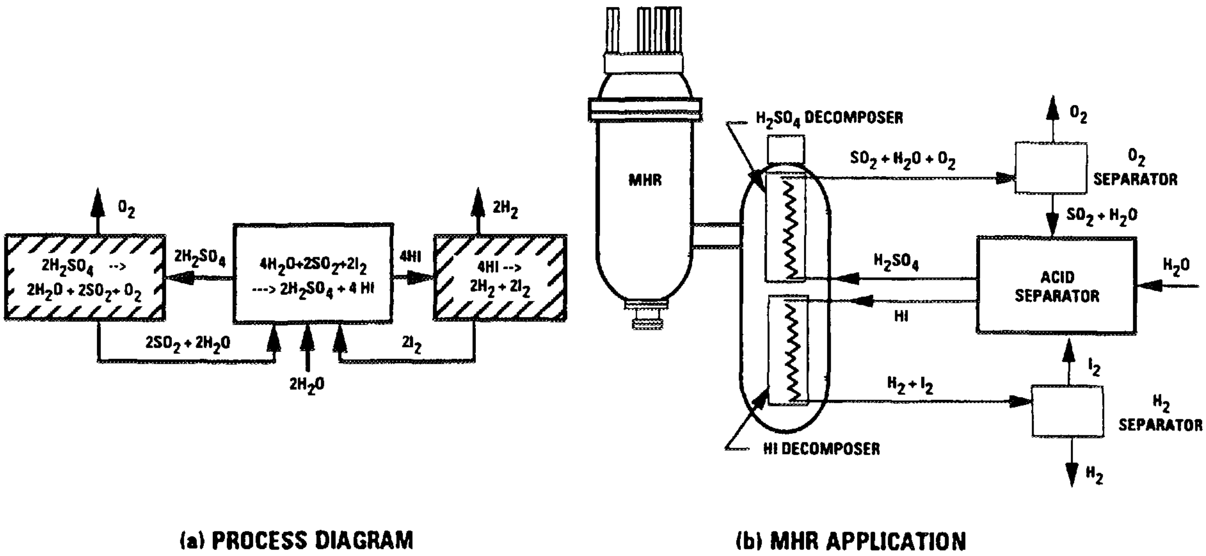

Fig. 24. Hydrogen Production Using Thermochemical Water Splitting

6. CONCLUSIONS

In the 21st century the forecast indicates significant increases in use of electrical and non-electrical energy by both developed and developing nations. All forms of energy including nuclear is required to meet this demand. Modular Helium Reactor is a unique source of nuclear energy that has large number of applications as summarized in Figure 25.

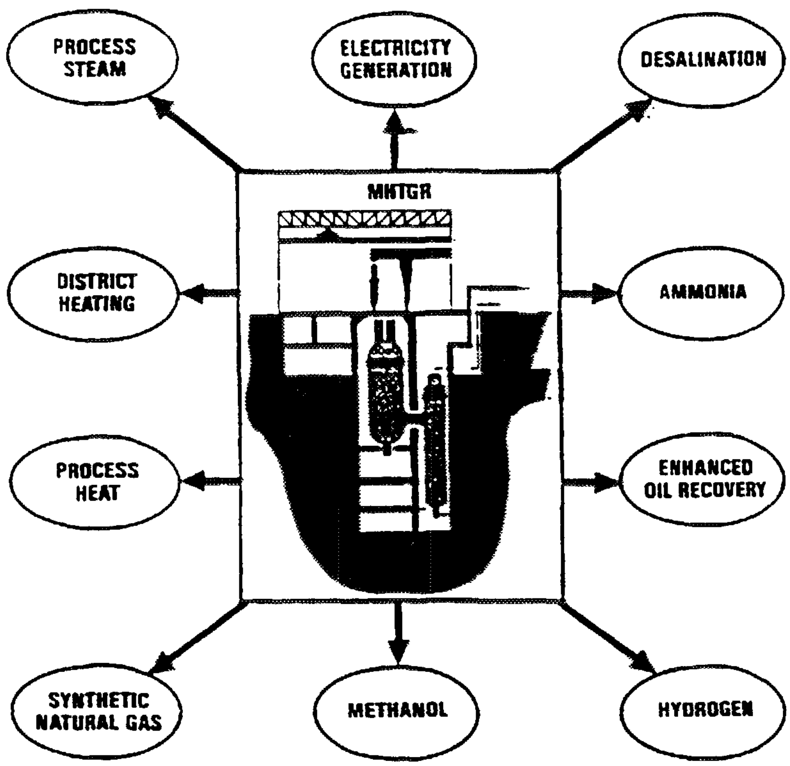

Fig. 25. Various Non-Electrical Applications of MHR Heat Source

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OTHER PAPERS SUBMITTED

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USE OF REACTOR PLANTS OF ENHANCED SAFETY FOR SEA WATER DESALINATION, INDUSTRIAL AND DISTRICT HEATING

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Abstract

Russian designers have developed and can deliver nuclear complexes to provide sea water desalination, industrial and district heating. This paper provides an overview of these designs utilizing the ABV, KLT-40 and ATETS-80 reactor plants of enhanced safety.

The most advanced nuclear powered water desalination project is the APVS-80. This design consists of a special ship equipped with the distillation desalination plant powered at a level of 160 MW(th) utilizing the type KLT-40 reactor plant. More than 20 years of experience with water desalination and reactor plants has been achieved in Aktau and Russian nuclear ships without radioactive contamination of desalinated water.

Design is also proceeding on a two structure complex consisting of a floating nuclear power station and a reverse osmosis desalination plant. This new technology for sea water desalination provides the opportunity to considerably reduce the specific consumption of power for the desalination of sea water.

The ABV reactor is utilized in the "Volnolom" type floating nuclear power station. This design also features a desalinator ship which provides sea water desalination by the reverse osmosis process. The ATETS-80 is a nuclear two-reactor cogeneration complex which incorporates the integral vessel-type PWR which can be used in the production of electricity, steam, hot and desalinated water.

As variants of non-electric use of nuclear energy, Russia design organizations and enterprises have developed and can deliver to the Customer nuclear complexes with reactor plants (RPs) of enhanced safety of ABV, KLT-40 and ATETS-80 type of 38, 160 and 250 MW(th) respectively for sea water desalination, industrial and district heating. The ratio between the amount of heat delivered and desalinated water production is determined by the Customer proceeding from maintaining the thermal power of RPs. As desalinators, distillation and reverse osmosis plants can be used. The stations can be floating and land- based.

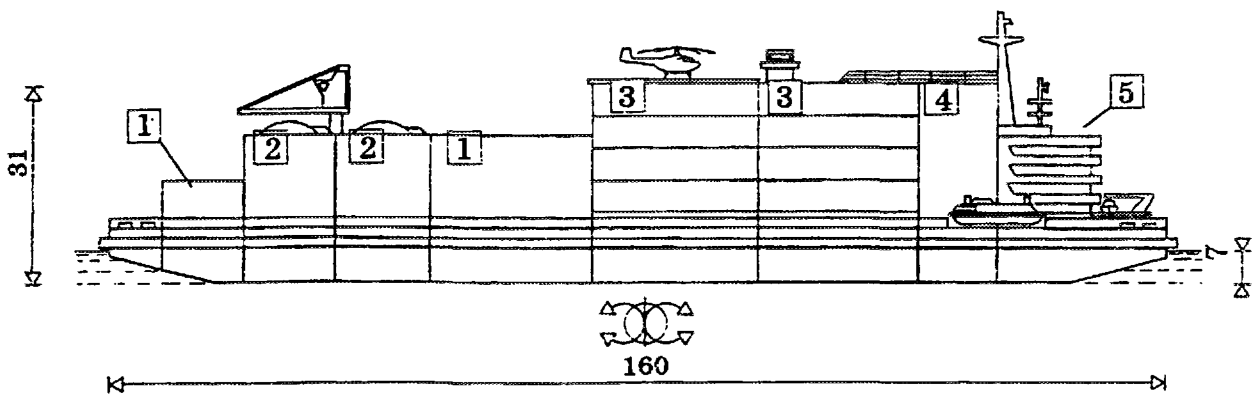
NUCLEAR WATER DESALINATION STATIONS INCORPORATING KLT-40-TYPE REACTOR PLANT

As to the level of perfection the most advanced today is the project of APVS-80 nuclear power station incorporating KLT-40-type reactor plant with distillation desalinator.

APVS-80 is a special non-self-propelled ship with two-reactor power plant destined for sea water desalination in conditions of protected water area together with a complex of external servicing structures (Fig. 1).

APVS-80 Main Technical Data

Length, m	- 160
Width, m	- 44
Draught, m	- 7
Output of desalinated water, m3/day	- 80000



1 - engine compartment

2 - central power compartment

3 - desalination plant

4 - potable water preparating plant

5 - living compartment

FIG. 1. Ship layout.

KLT-40-type RP meets international requirements for safety of ship power plants, home normative documents for NPPs, accounts for IAEA recommendations This type of modular RP (Fig 2a, 2b) has been successfully operating during decades in Russia nuclear ships going through successive evolutionary improvement for each subsequent generation on the basis of experience obtained. Now this plant is serially produced in Russia enterprises. At the Customer's request the water desalination plant can be fabricated as one reactor unit For two-reactor unit the unit power of the reactor amounts to appr 80 MW(th), for one-reactor unit it is appr 160 MW(th)

Besides the RP the station includes desalination plant, drinkable water production plant, and ship general systems

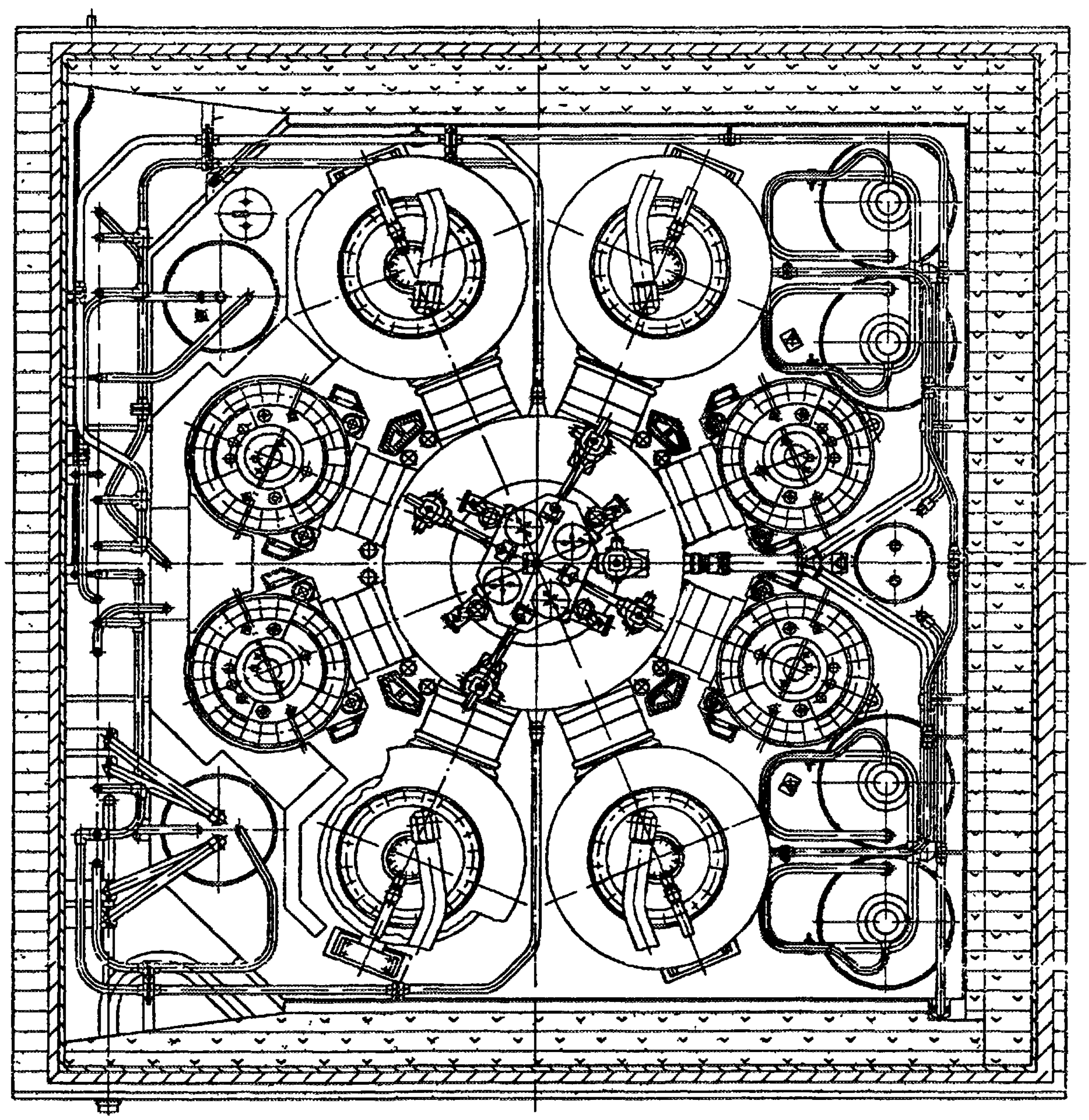


FIG. 2a.

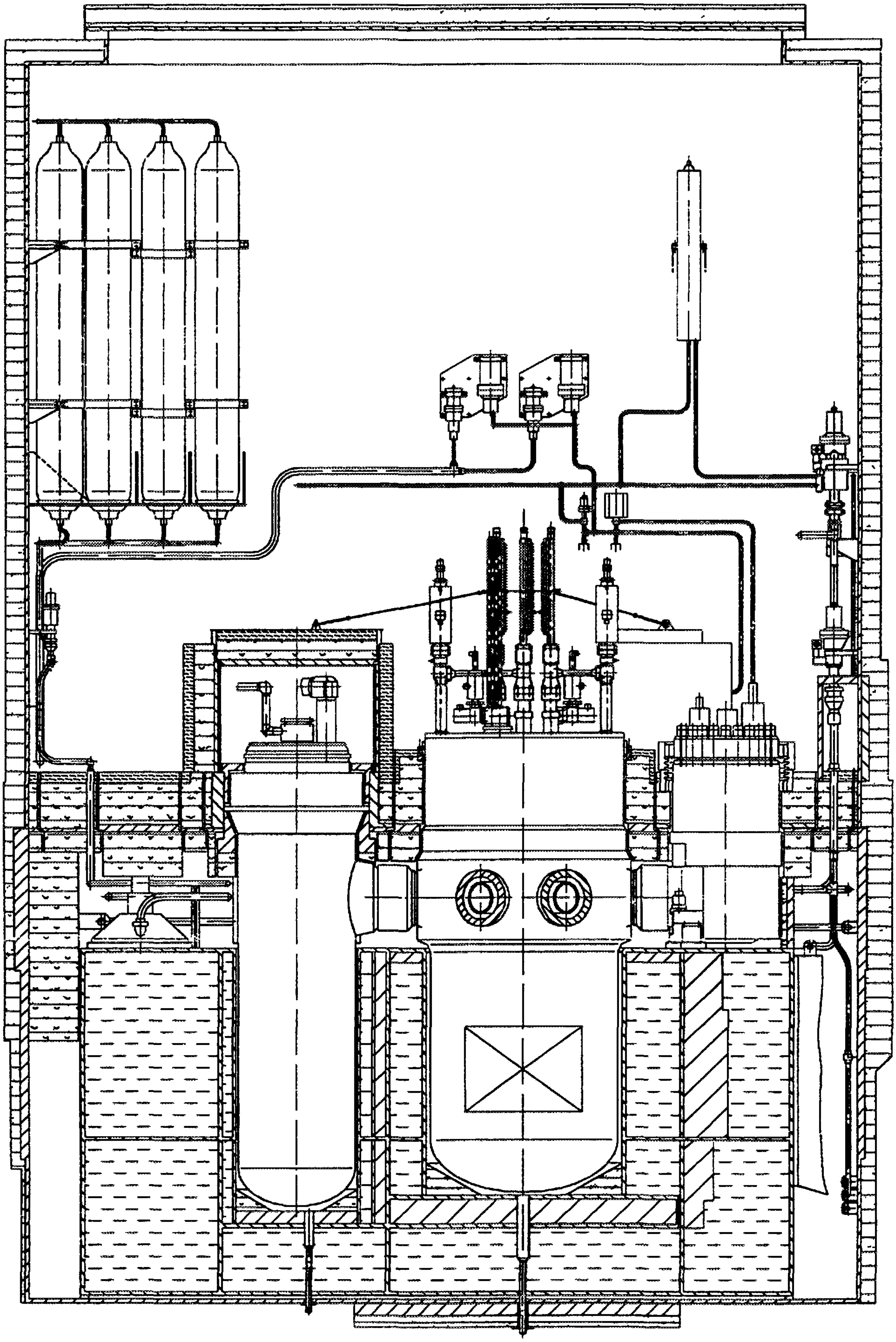


FIG. 2b

Distillation desalination plants (DDP) equipped with horizontal-tube film evaporators are developed by Sverdlovsk Scientific-Research Institute of Chemical Engineering which is leading Designer of stationary DDPs (Fig.3). These are the most up-to-date, compact, economic evaporators respective consumption of thermal and electric power. There is many-years experience of using analogous plants in industrial complex in Aktau (Kazakhstan), Novocherkask, Urengoy. Machinebuilding enterprises are capable to provide for fabrication and delivery of desalination plants for APVS-80.

The principal diagram of combining the reactor and desalination plants is given in Fig. 4.

More than 20 year experience of joint operation of water desalination and RPs in Aktau and in Russia nuclear ships has shown the absence of radioactive contamination of desalinated water.

To preliminary estimate (variant of desalination complex using KLT-40-type RPs and reverse osmosis desalination plant) is more economic but less developed by Russia enterprises in respect to desalinators. In this variant the complex includes two structures: floating nuclear power station (FNPS)(Fig. 5) and reverse osmosis desalination plant. The desalination plant in this case can be both floating one and land-based.

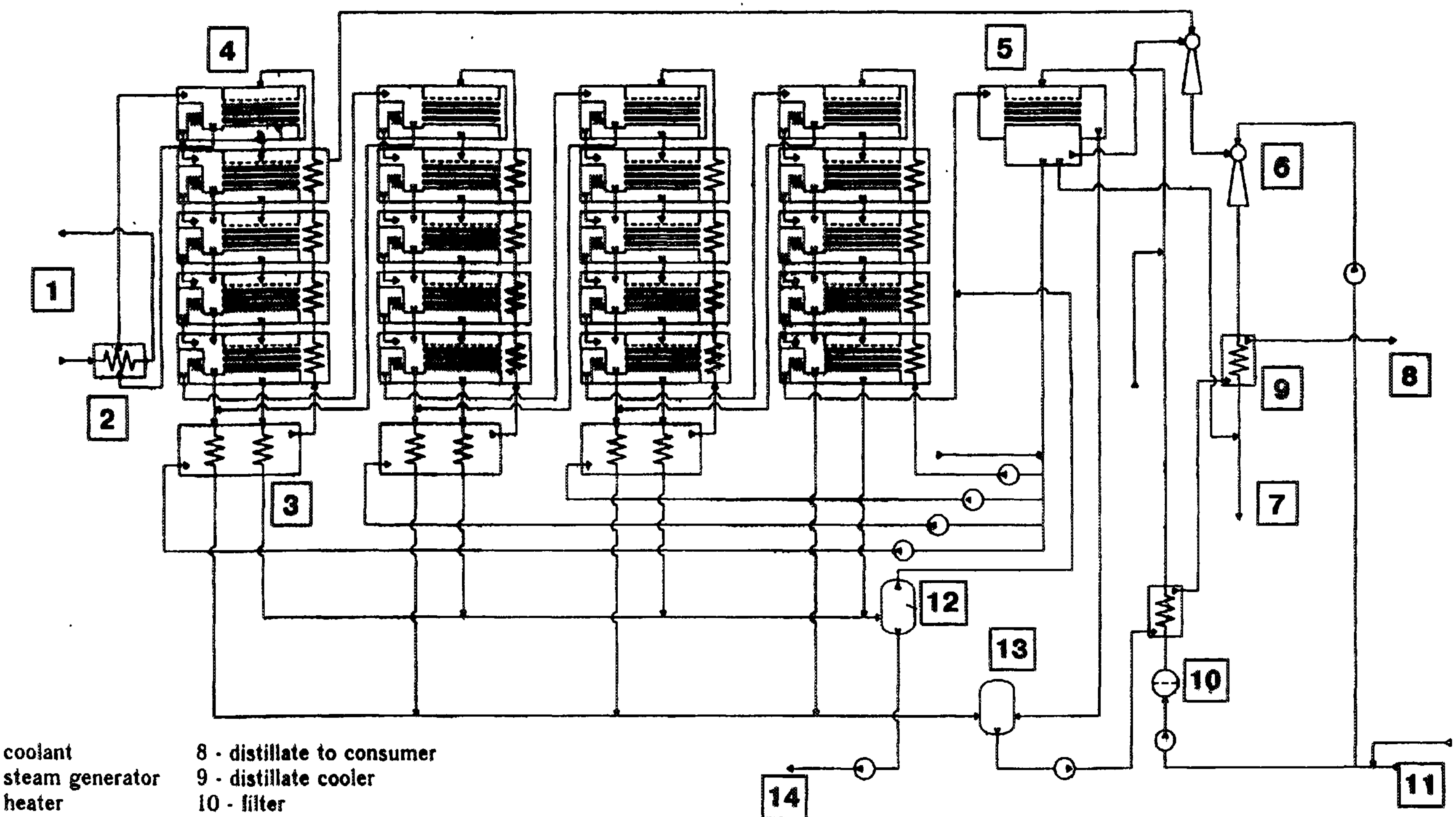
FNPS Main Characteristics

Length, m	- 120
Width, m	- 28
Draught, m	- 3.5 - 4.5
Number of reactor plants	- 2
Power of one-reactor plant, MW(th)	- up to 150
Electric power (gross), MW	- up to 70
Electric power consumed by FNPS, MW	- appr. 5
Heat delivered, Gcal/h	- 50

Now design and industrial enterprises of Russia are working at the creating of floating nuclear co-generation plant for north regions of the country which can be a prototype for FNPS for desalination complex.

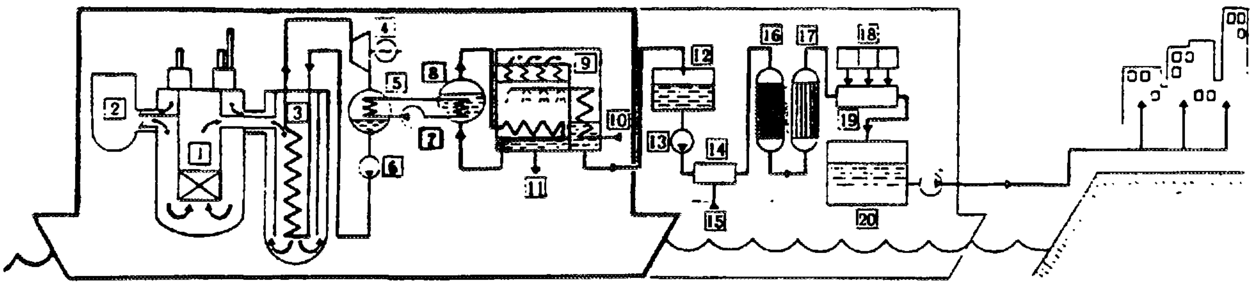
As for reverse osmosis desalination plant Canadian firm "CANDESAL" has reached certain success in their development.

The program of this firm foresees the use of new technologies for sea water desalination using reverse osmosis allowing to considerably reduce the specific consumption of power for desalination and cost of desalinated water. In this connection



1 - coolant
2 - steam generator
3 - heater
4 - evaporation stage
5 - deaerator
6 - water-jet ejector
7 - sea water
8 - distillate to consumer
9 - distillate cooler
10 - filter
11 - source sea water
12 - salf water concentration tank
13 - distillate tank
14 - sea water with high salf concentration

FIG. 3. Distillation desalination plant.



1 - reactor
2 - primary circuit circulator
3 - steam generator
4 - turbo-generator
5 - condenser
6 - secondary circuit electric pump
7 - intermediate circuit electric pump
8 - steam generator
9 - distillation desalinaton plant
10 - sea water
11 - evaporated sea water
12 - intake tank for distillation
13 - electric pump of potable water preparation plant
14 - mixer
15 - H_2CO_3 solution
16 - water enrichment facility
17 - running water ssorbent containing filter
18 - plant for fluorine, chlorine water treatment and stabilization
19 - mixer
20 - potable water tank

FIG. 4. Principal flow diagram of the station.

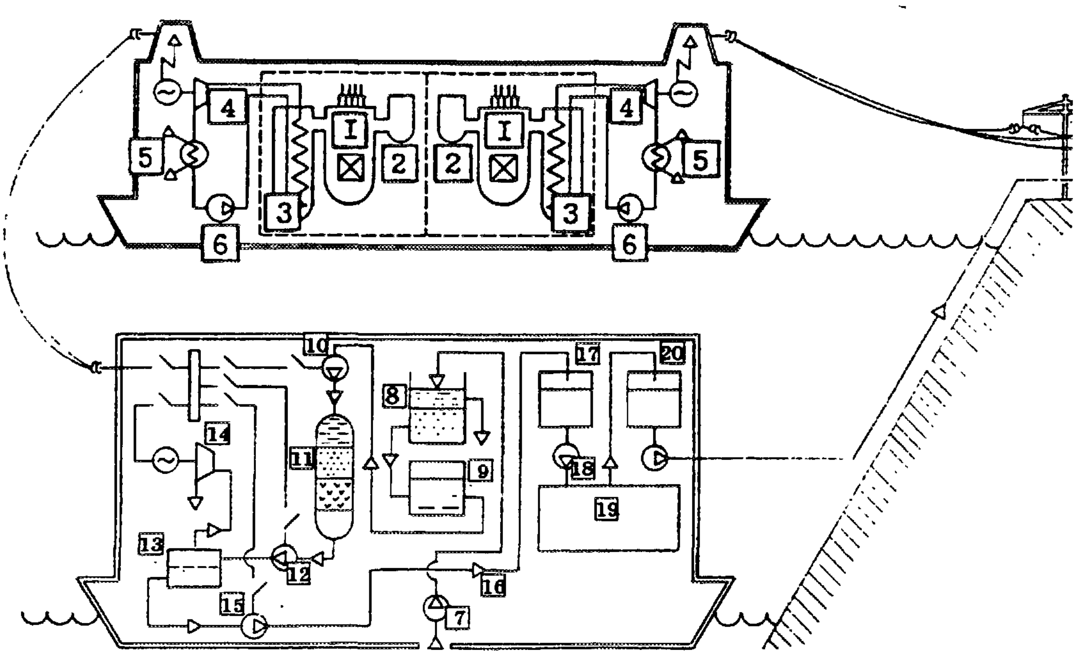
the development of joint Russian-Canadian Project of desalination complex using FNPS on the basis of new technologies of sea water desalination by reverse osmosis seems to be expedient. At specific electric power consumption of appr. 5 KW/m3 the output of such complex for desalinated water can be appr. 300 thousand m3/day.

At present, Russian MINATOM and firm "CANDESAL" have signed Memorandum of Intents on design, marketing and fabrication of APVS using power plant on KLT-40 basis

WATER DESALINATION COMPLEX ON THE BASIS OF ABV REACTOR PLANT

The complex comprises two barges:

- "Volnolc.:"-type floating nuclear power station with ABV reactor plant (Fig.6)
- desalinator for sea water desalination by reverse osmosis(Fig.7).



1 - reactor
2 - primary circuit circulating pump
3 - steam generator
4 - turbogenerator
5 - condenser
6 - secondary circuit electric pump
7 - sea water
8 - gravity filter
9 - clarified water tank
10 - booster pump
11 - twin-layer pressure filter
12 - high pressure filter
13 - reverse osmosis module
14 - hydroturbine
15 - fresh water pump
16 - filtrate
17 - filtrate intake tank
18 - electric pump of potable water preparation system
19 - potable water preparation unit
20 - potable water storage tank

FIG. 5. Principal flow diagram of the complex.

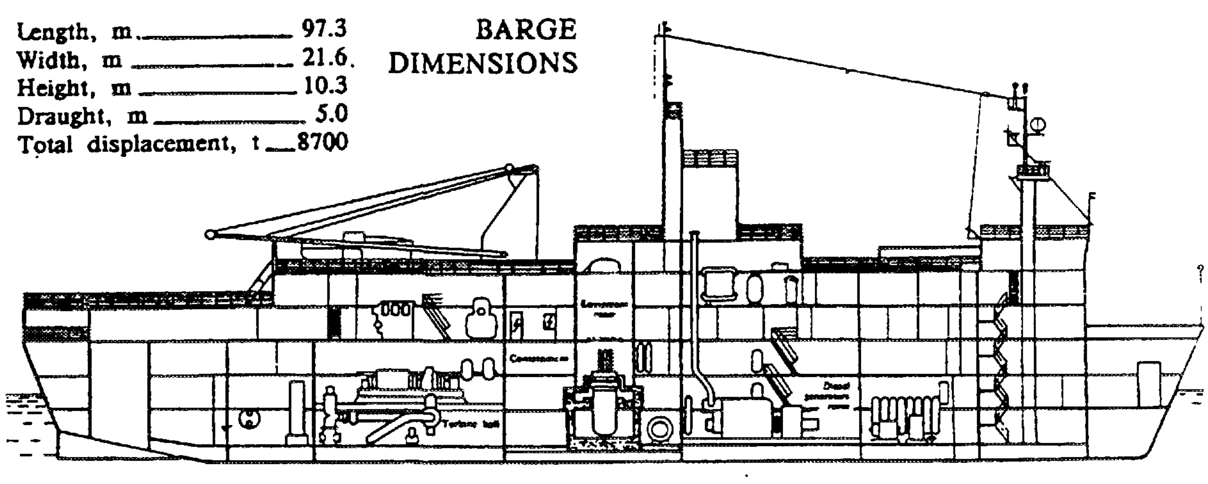
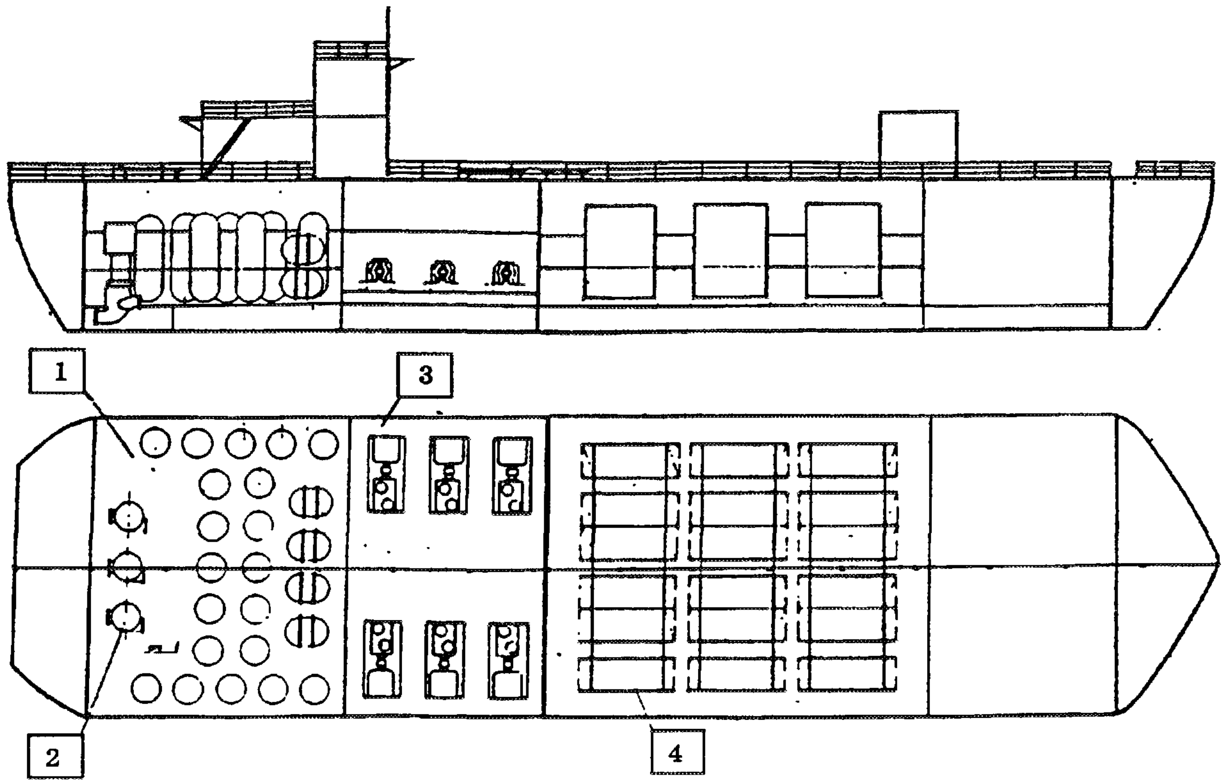


FIG. 6.



1 - room for sea water pre-treatment system

2 - booster pump

3 - desalinating system pump room

4 - desalinating modules

FIG. 7. Desalinating complex layout.

FNPS "Volnolom" Main Technical Data

Length, m	- 97.3
Width, m	- 21.6
Draught, m	- 4.5 - 5
Number of reactor units	- 2
Thermal power of one RP, MW	- 38
Electric power of unit (gross), MW	- 12
Amount of heat delivered, Gcal/h	- 12

The reactor plant is designed using two-circuit scheme with integral type reactor having natural circulation in primary circuit (Fig.8).

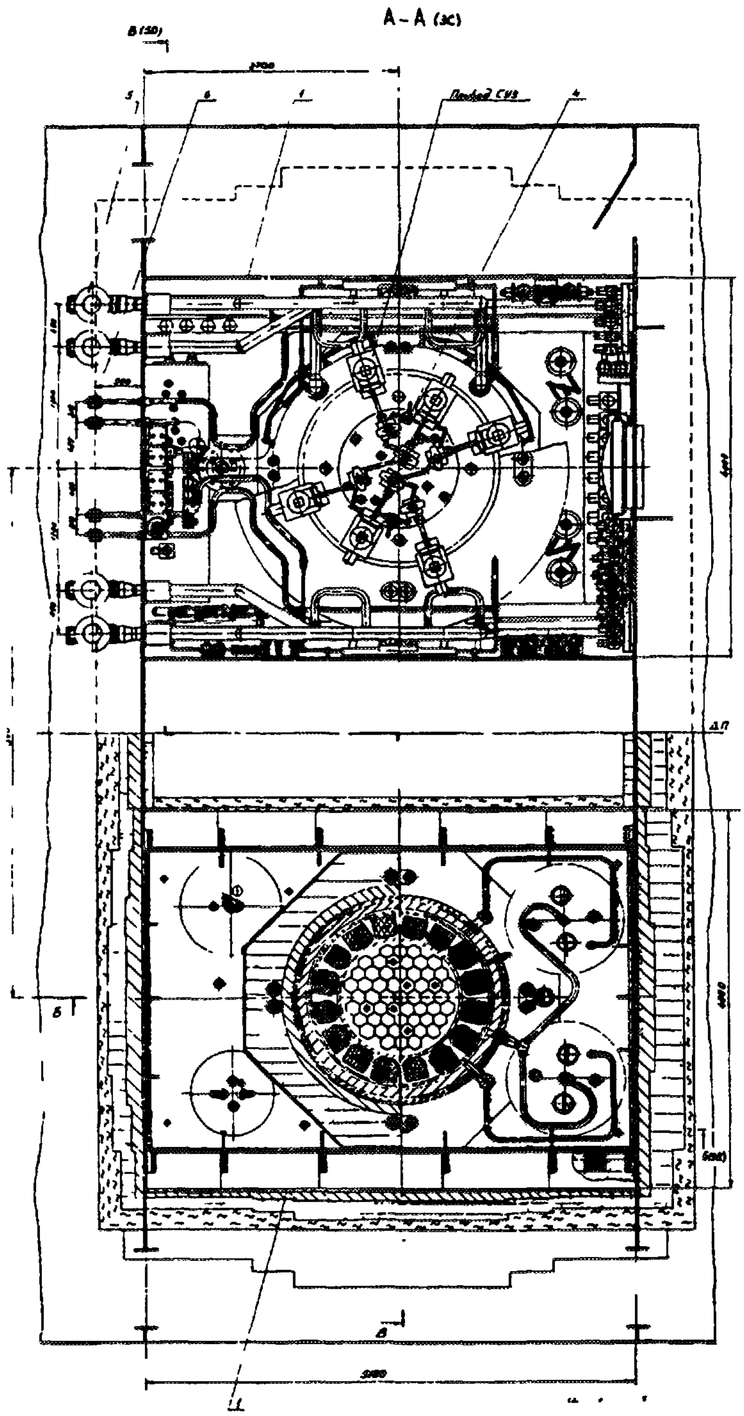


FIG. 8. ABV reactor plant.

The reactor plant was designed in accordance with modern home requirements, IAEA recommendations and with account of advanced NPPs design experience.

KLT-40 and ABV RPs were the winners among the plants of the same power at a competition "Small Nuclear Power Stations-91" held by RF Nuclear Society.

Main Characteristics of Desalinator-Ship

Length, m - 72

Width, m - 24

Draught, m - 3.9

Output of desalinated water, m3/day - 40000

When designing the desalinator-ship the use of fibre modules of "Permasep B-10"-type (Dupont firm) was foreseen.

NUCLEAR CO-GENERATION COMPLEX ATETS-80

ATETS-80 is nuclear two-reactor co-generation complex incorporating integral vessel-type PWR which can be used for production of electricity, steam, hot and desalinated water (Fig.9).

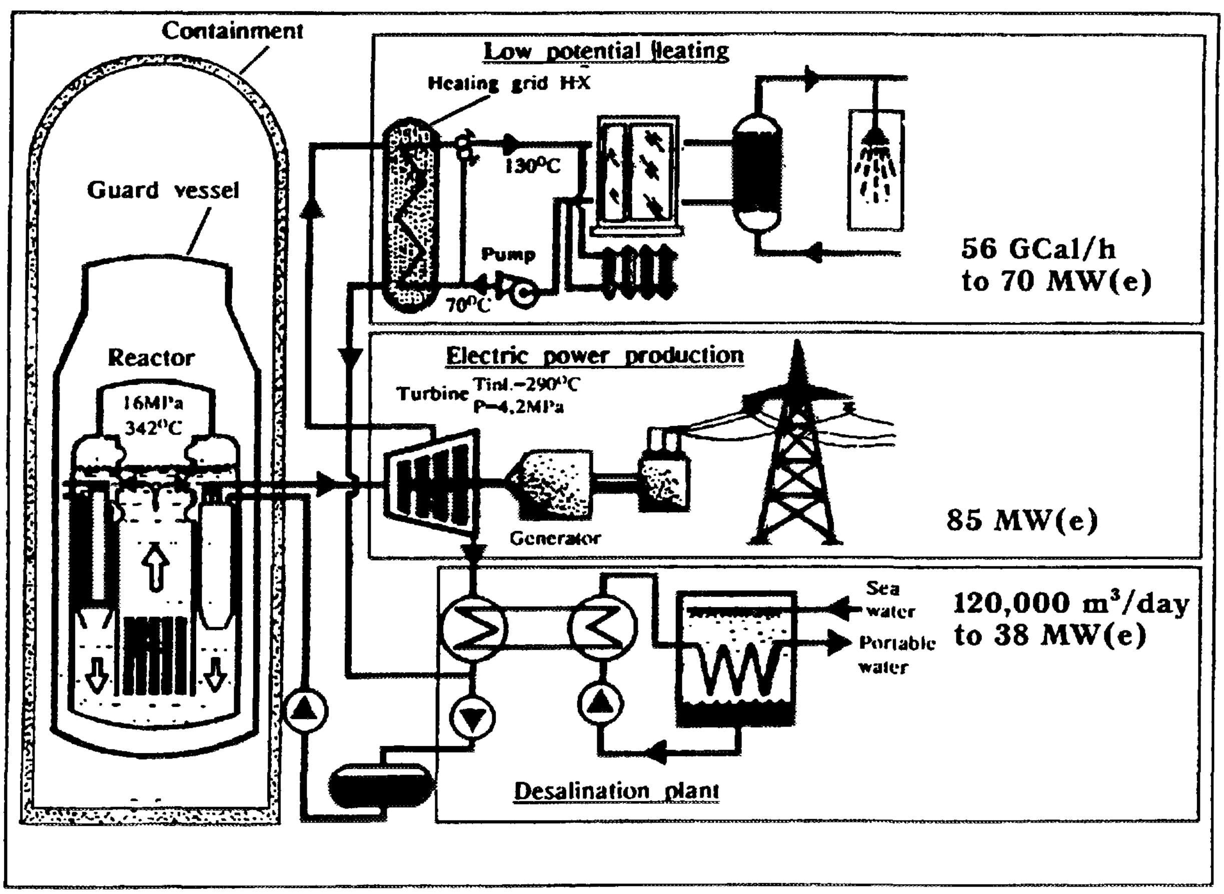


FIG. 9.

ATETS-80 Main Technical Data

Number of RPs	- 2
Reactor thermal power, MW	- 250
Maximum electric power, MW	- 85
Heat capacity (at 70 MW(e)), Gcal/h	- 56

In addition, on the Customer's request ATETS-80 can be used in the following variants:

1) Combined production of electricity, hot water and industrial steam (layout with back-pressure turbine)

Electric power, MW	- 20
Steam (1.2 MPa), Gcal/h	- 40
hot water (150°C), MW	- 160

2) Sea water desalination with the use of distillation plants and autonomous energy supply

Electric power, MW - 60
Output for desalinated water, m3/day-70000

3) Sea water desalination with generation of electric power for desalination complex auxiliary needs

Electric power, MW	- 38 (9 MW of desalination complex auxiliary power)
Output for desalinated water, m3/day	- 120000

When erecting ATETS-80 in shore zone of seas and rivers an effective method of their transportation and construction is floating one.. The floating module (reactor compartment, machine hall) is brought to the Site by water. The scope and cost of construction works is reduced.

CONCLUSION

1. Russia design organizations and enterprises had been developed and can supply to the Customer multi-purpose nuclear floating (or land-based) complexes of various power for sea water desalination, industrial and district heating.

2. Concerning the level of safety and ecological cleanness the floating nuclear complexes meet modern international regulations and can be recommended for sea water desalination, industrial and district heat supply (cryosupply) for North Africa, Near East, several regions of Indian Ocean including Insular Indonesia.

3. Perfection of main technical solutions for the complex on the basis of KLT-40 plant and their validation during many-year operation allow to have minimal time for its creation (4-5 years) and acceptable cost of desalinated water.

PRELIMINARY DESIGN CONCEPTS OF AN ADVANCED INTEGRAL REACTOR

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Abstract

An integral reactor on the basis of PWR technology is being conceptually developed at KAERI. Advanced technologies such as intrinsic and passive safety features are implemented in establising the design concepts of the reactor to enhance the safety and performance. Research and development including laboratory-scale tests are concurrently underway for confirming the technical adoption of those concepts to the reactor design. The power output of the reactor will be in the range of 100MWe to 600MWe which is relatively small compared to the existing loop type reactors. The detailed analysis to assure the design concepts is in progress.

1. Introduction

The nuclear reactors currently under development in the worldwide nuclear societies are largely categorized into two different concepts with respect to the configurations of major primary components ; namely, loop type and integral type. Most of power reactors that are currently in operation and under development have loop type configurations which enable large-scale power output and thus provide economical power generation. On the other hand, integral reactors receive a wide and strong attention due to its characteristics capable of enhancing the reactor safety and performance through the removal of pipes connecting major primary components, even for a certain power limit due to the limited reactor vessel size which can be manufactured and transportable. The relatively small scale in the power output of integral reactors compared to the loop type reactors, however, draws a special concern for the various utilization of the reactor as an energy source, as well as power generation especially for the small-sized grid system.

Small and medium reactors with integral configurations of major primary components are actively being developed in many countries. The design concepts of those reactor vary with the purposes of application. Since the second half of 1995, Korea Atomic Energy Research Institute (KAERI) has been putting efforts to research and develop new and elemental technologies for the implementation to the advanced reactors. In parallel with those efforts, an advanced integral PWR by implementing those technologies and also passive safety features is under conceptual development. The electrial power output of the reactor will be in the range of 100MWe to 600MWe depending on the purpose of utilization such as power generation, energy supply for the seawater desalination and others. As far as the electricity generation concerned, this range of power output is considered as suitable for energy supply to the industrial complexes, remotely located islands, and specially isolated areas. The reactor core is conceptually designed with no soluble boron and hexagonal fuel assemblies to enhance the operational flexibility and to improve the fuel utilization. The reactor safety systems primarily function in a passive manner when required.

This paper describes the conceptual design features of the advanced integral reactor under development at KAERI, and also important R&D subjects concurrently in progress in order to prove and confirm the technical feasibility of design concepts.

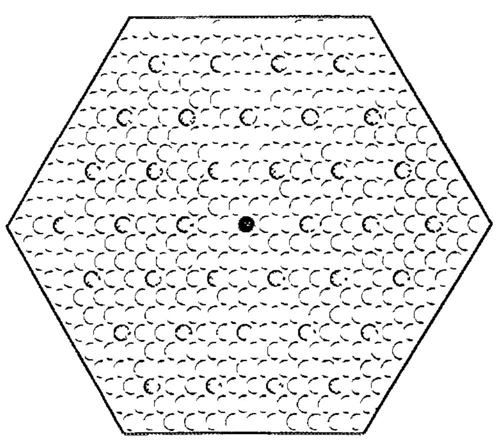
2. Reactor Design Concepts

In general, an integral type of reactor contains all major primary components such as core, steam generator, pressurizer, and reactor coolant pumps in a single pressurized reactor vessel, which mainly differs in concept from the loop type reactor. KAERI's advanced integral reactor also applies the same general definition of integral reactors.

2.1. Reactor Core and Fuel

The achievement of intrinsic safety and operational reliability is a concern of most importance in the core design. To this end, the low core power density and soluble boron free operation are implemented as major design features of the core. The low core power density and thus increased thermal margins with regard to the critical heat flux ensure the core thermal reliability under normal operation and accident conditions. This feature, furthermore, provides passive safety benefits with respect to the enhanced negative feedback for lower operating fuel temperatures and inherent power distribut... stability. The elimination of soluble boron from the primary coolant becomes a major potential simplification for the advanced reactors. From the point of the view of the reactor control and safety, soluble boron free operation offers potential benefits through the presence of a strong negative moderator temperature coefficient over the entire fuel cycle. This design feature thus provides much improved passive response for a variety of performance transients and load changes. As a result of the above two important design features, the core is more stable and resistant to transients, and therefore provides improved operational flexibility. The longer refueling cycle such as 18months or longer is adopted for the purpose of improving the plant availabilty.

Fuel assembly adapts a semi-tight hexagonal geometry to improve the fuel utilization through a relatively high plutonium conversion ratio compared to the conventional LWRs. The fuel design is based on the existing Korean Optimized Fuel Assembly (KOFA) design technology. The hexagonal fuel assembly yields the lower moderator to fuel volume ratio(V_m/V_f) and the hardened neutron spectrum which result in stronger moderator temperature coefficients and higher plutonium conversion ratio. The fuel rods are the same as those of the KOFA except geometrical arrangement which is changed from the square array to the hexagonal array. Fuel utilizes low enrichment, uranium dioxide fuel, which is operated at a low specific power density(19.6kW/kgUO_2). The uranium enrichment of the fuel will be selected to achieve the 18 months(or longer) operating cycle. As shown in Fig.1, the fuel assembly is a hexagon with 22.9cm in lattice pitch and is provided to accommodate the control assembly in each fuel assembly. The fuel assembly consists of 360 fuel rods and 36 guide tubes for control absorbers and/or insertable burnable absorbers and 1 guide



Lattice Pitch 22.9cm
Rod Pitch: 1.142cm
Flow Area 196cm^2
No of Rods: 397
No of Fuel Rod: 360
No of GT for CR: 36
No of GT for Instrument: 1

FIG. 1. Hexagonal fuel assembly.

tube for central in-core instrument. The same fuel assembly is utilized in the core design regardless of the reactor power output.

For 100MWe and 600MWe power output as examples, the reactor core is rated at 300 MWt with 55 fuel assemblies and 1933MWt with 151 fuel assemblies, respectively. The corresponding average linear heat generation rates are 8.4 kW/m and 9.7 KW/m which are much lower that of conventional PWRs. Table 1 shows major design parameters of the conceptual designs for the core and fuel.

TABLE 1. BASIC DESIGN PARAMETERS OF ADVANCED INTEGRAL REACTOR

Reactor Core and Fuel			Steam Generator	
Nominal Core Power, MWt	1933(a)	300(b)	Steam Temperature, °C	290
Power Density, KW/l	77.3(a)	66.7(b)	Steam Pressure, MPa	4.7
Avg. Linear Heat Rate, KW/m	9.7(a)	8.4(b)	Superheat, °C	30
Active Core Height, m	3.66(a)	1.8(b)	Feedwater Temperature, °C	240
Effective Core Diameter, m	3.12(a)	2.0(b)	Tube Material	I690 T T
Number of FAs	151(a)	55(b)	Tube Diameter, mm	19
Fuel Rod Descriptions			**Reactor Coolant Pump**	
Fuel Type	UO_2		Type	Glandless, Wet Winding Canned Motor
Enrichment(Equil.), w/o	~ 3.5		Number	4
Clad Material	Zircaloy-4			
Fuel Pellet OD, cm	0.784			
Clad OD, cm	0.91			
Primary Circuit			**Containment Overpressure Protection**	
Design Pressure, MPa	17		Type	Passive, Steam Driven Injector
Operating Pressure, MPa	12.5			
Coolant Inlet Temperature, °C	285		**Reactor Safety Systems**	
Coolant Outlet Temperature, °C	315			
Coolant Flow, Kg/sec	1.2×10^4(a)	1.8×10^3(b)	Decay Heat Removal	Passive, Natural Convection Hydraulic Valve/Heat Pipe
Pressurizer			Reactor Shutdown	Control Rods/Boron Injection
Type	Gas/Steam Self-Pressurizer		Emergency Core Cooling	Not required

Note : (a) for 600MWe, and (b) for 100MWe Power Output

2.2. Primary Circuit

Fig. 2 shows the general arrangement of the primary components and internal structures of the reactor pressure vessel. Above the reactor core, helically coiled once-through steam generator is located between the core support barrel and reactor vessel. Thermal shields are provided around the core to reduce

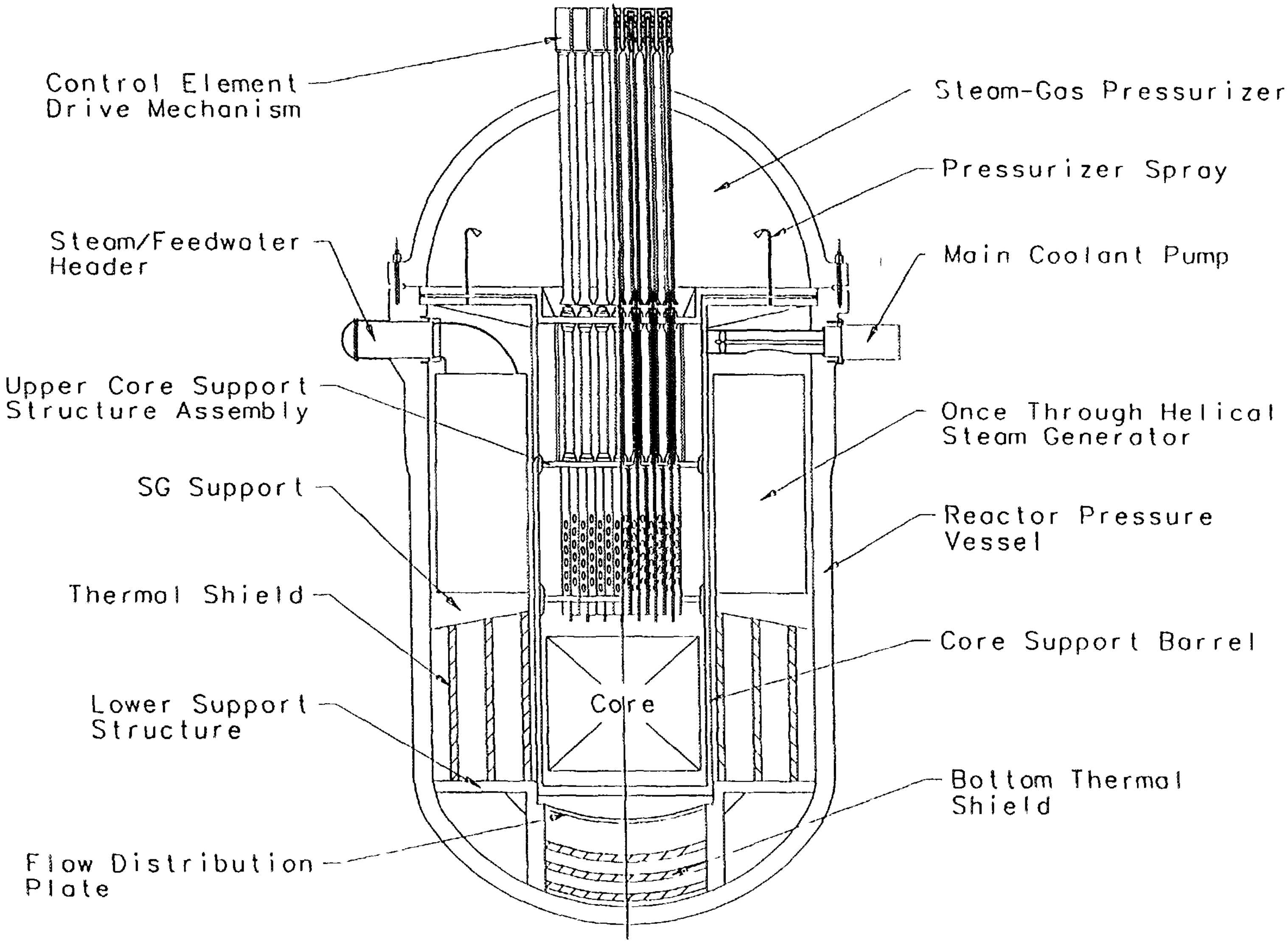


FIG. 2. General arrangement of primary components and reactor internals.

the neutron fluences on the reactor vessel. The canned motor pumps are horizontally installed on the reactor vessel above the steam generators. The upper plenum of the vessel forms a pressurizer to maintain the operating pressure of the reactor. Since all the primary system components are installed in a single pressure vessel, there is no primary pipings between major primary components and thus it completely eliminates the large break LOCA. The primary circuit is designed to provide the enhanced natural circulation capability through the sufficient temperature difference between cold and hot water along with the sufficient difference in height between the core and steam generator to produce the driving force to circulate the primary coolant. The reactor vessel is surrounded, as shown in Fig. 3, with another vessel called as safe guard vessel which contains water up to the level of the top of steam generator. The water in the safe guard vessel is pressurized with the nitrogen gas at approximately the atomospheric pressure, and is served as an interim heat sink for the emergency decay heat removal system that will be described in the next section. This section describes the design concepts of major primary components, and Table 1 summarizes some of basic design parameters of the reactor systems.

▮ Steam Generator : The helically coiled once-through steam generator(SG) is located within the reactor vessel in the annular space between the core support barrel and the reactor vessel inner wall. The SG is designed to completely evaporate the secondary coolant in a single pass through the S/G tube side. Since the current design concept adopts primary circuit natural circulation operation to produce approximately 50% of full power for a relatively small power output reactor design, the SG will be located high above the core considering the current manufacturing capability of a single pressure vessel. The SG consists of groups of tube bundles, downcomer, feed water and steam headers, shrouds to guide the primary flow, and tube supporting structures. The design utilizes Inconel 690 tubing and the tube bundles are supported by perforated radial support plates so that the load can be transferred to the bottom support structure located on the supporting lug. The size of the SG will be selected depending on the sclae of power output with consideration of simplifying many of operational concerns including the access for in-service inspection and maintenance.

▮ Pressurizer : *The large free volume above the primary coolant level is* designed as a self-pressurizing pressurizer This upper part of the reactor

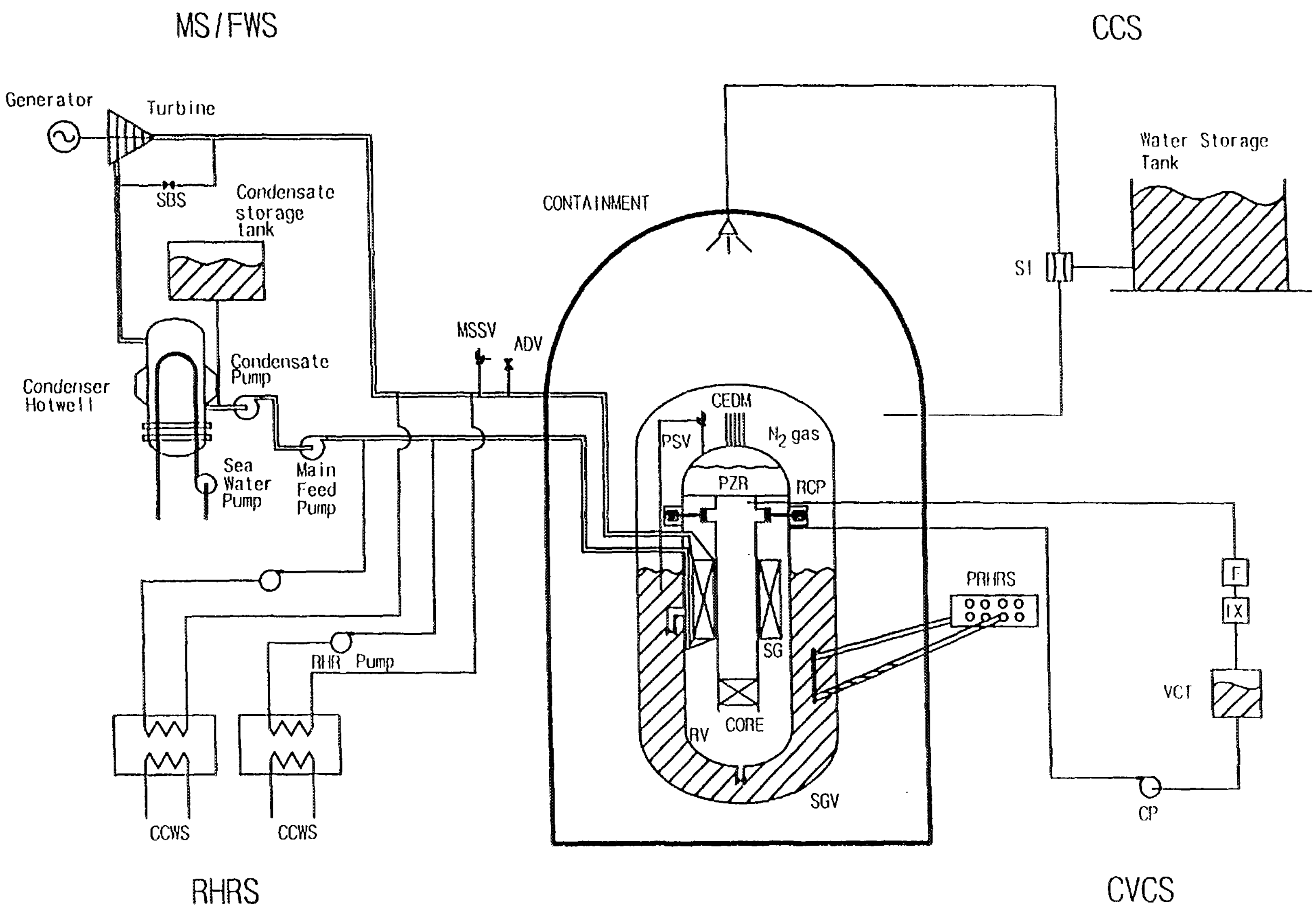


FIG. 3. Schematic diagram of advanced integral reactor systems.

vessel is thus filled with the mixture of nitrogen gas and steam providing a surface in the primary circuit where liquid and vapor are maintained in equilibrium at saturated condition. The pressure of the primary system is equal to the gas partial pressure plus the saturated steam pressure corresponding to the core outlet temperature. The reactor therefore operates at its own operating pressure matched with the system status. The nitrogen gas partial pressure is chosen to maintain subcooling at the core exit to avoid boiling in the hot channel during transients. The volume of gas space is large enough to prevent the safety valves from opening during the most severe design basis transients.

▮ Reactor Coolant Pump : The reactor coolant pumps are sealed type canned rotor pumps with added inertia to increase the pump rundown time. With no shaft seals in the pump, the small LOCA associated with seal failure of the pump as in the conventional standard design is eliminated. The required number of pumps and pump capacity to circulate the primary coolant can be reduced by the design characteristics of the primary circuit natural circulation capability.

▮ Control Element Drive Mechanism(CEDM) : The design of soluble boron free core results in the only use of control rods for the reactivity control and load change operation and thus requires a fine positioning control capability of the control rod. In addition, the adoption of a self-pressurizer in the upper plenum of the reactor vessel introduces difficulties in lubricating the moving parts with the primary coolant since the latch mechanism of control rods will be located in the steam-gas region of the pressurizer. These reasons yield the useless of the existing magnetic jack type CEDM. Consequently, a new concept of CEDM is developed and adopted. The design of CEDM consists of position encoder, brushless DC servo motor, lift magnet coil, rare earth permanent magnet_rotor, driving tube, and split ball nut assembly. The fine control capability of CEDM is assured by the use of ball nut-lead screw mechanism. When the scram of the reactor is required, the current supply to the lift magnet coil is cut off once the signal is issued , and then the split ball nut releases the lead screw to drop down the control rods by gravity and spring forces. The worth of control rods provides sufficient shutdown margin at any conditions of reactor operation.

2.3. Engineered Safety Features

The safety concepts of the advanced integral reactor under currently conceptual development are basically taking advantages from the characteristics of intrinsic and passive safety principles on which most of small and medium reactors rely. The passive safety concept applies to the major engineered safety features as shown in Fig. 3 and described below.

▮ <u>Passive Decay Heat Removal System</u> : When the normal decay heat removal is required, the steam generators with turbine bypass system are used to reject the heat to the condenser. This can be achieved by natural circulation on the primary side but requires feed pumps and other equipments on the secondary system. If the secondary system is not available, active decay heat removal systems with steam generators are used and the heat is removed through the component cooling system. Should there be no ac power available, the core decay heat is removed to the water contained in the safe guard vessel through the natural convection system, as shown in Fig. 3, with passive actuation of initiation valves installed on the side and bottom of the reactor vessel. The heat is then passively removed through the heat pipes to the outside of the containment. Therefore, there provides theoretically infinite time of heat removal without any intervention by operator. One of the advantages of the passive decay heat removal system usinh heat pipes is that the system can be continuously operating during normal operation to remove the heat transferred from the reactor vessel to the water in the safe guard vessel through the wet thermal insulation.

▮ <u>Passive Emergency Core Cooling System</u> : Since all large primary circuit pipes are eliminated, the large LOCA is intrinsically not considered and thus no conventional emergency core cooling system is required. However, the break in the connection pipe from the chemical and volume control system(CVCS) may cause the loss of the primary inventory through the siphoning effect. To prevent the siphoning loss of the reactor water inventory in the hypothetical event of a CVCS line break, the installation of a siphon breaker is conceptually considered. Since the reactor vessel is always externally flooded with the water in the safe guard vessel, there is no need for the external emergency core make-up. The safe guard vessel is sized to provide a minimum of 72 hours heat removal without the operator intervention.

■ Reactor Shut-Down System : The reactor shut-down system is consisted of the control rods and the emergency boron injection system. The reactor trip at emergency is accomplished by simutaneous insertion of control rods into the reactor core by gravity following the control element drive mechanism de-energization which is actuated by trip signals from the automatic control system. In case of failure to actuate the eletromechanical protection system, the borated water from the emergency boron injection system shutdowns the reactor. The individual system is fully capable of shutdowning the reactor and provides sufficient shutdown margin to keep the reactor in a subcritical condition.

■ Passive Containment Cooling System : The containment overpressure protection is provided by a passive containment spray system. Since the hypothetical pipe break is small-sized, the pressurization rate of the containment is much slow compared to that of the conventional loop type reactors. When the energy removal from the containment is required to prevent the containment pressure from exceeding the design pressure, the steam injector driven containment spray system passively actuates as the containment energy released from the break is supplied to the system. The steam injector is a simple and compact passive pump that is driven by supersonic steam jet condition. The steam injector pumps up the water from a water storage tank to the spray nozzles located at the top of the containment.

3. Research and Development Activities

In parallel with preliminarily constructing the design concepts of an advanced integral reactor, various R&D subjects are concurrently under study. The purposes of those R&D activities are two folds : to provide the proper technical data for the design features, and to evaluate the technical feasibility and characteristics of those design concepts. Major R&D activities are as follows :

■ Hexagonal Semi-Tight Lattice Fuel Assemby : Neutronic Design and analysis methodology is under development for analyzing the reactor core with hehxagonal semi-tight lattice fuel assmblies. Thermal-hydraulic tests such as critical heat flux and pressure drop tests will be conducted to evaluate the

T/H phenomena and behavior of the fuel assembly. The suitable T/H analytical models including T/H correlations will also be developed.

■ <u>No Soluble Boron Core Concept</u> : The use of no soluble boron in the core design causes to utilize large amount of lumped burnable absorbers to properly hold down the excess reactivity at the beginning of cycle and to install considerable number of control rods for the reactor control and operation. The optimization in the number of burnable absorbers and control rods is required with respect to the reactivity compensation with fuel burnup and reactor control through the cycle, and this study in conjunction with the core design with hexagonal fuel assemblies are thus investigated in this R&D subject.

■ <u>Natural Circulation for Integral Reactor</u> : The natural circulation is an important design feature of the reactor. The thermal-hydraulic characteristics of the primary circuit is thus being investigated to prove and confirm the design concept through experimental tests and the analysis using computer codes.

■ <u>Helically Coiled Once-Through Steam Generator</u> : A thermal-hydraulic design and performance anlaysis code - ONCESG for a once-through SG has been developed and tested against available design data of similar types of SG which are designed for other integral reactors. Further improvements of the code are under progress for the application to more complicated geometrical design and analysis. Experimental investigations are also being performed to generate the proper heat transfer and pressure drop correlation applicalble to the current design concept.

■ <u>Passive Equipments for Residual Heat Removal System</u> : The characteristics of the two important passive installations, hydraulic valve and heat pipe, is currently investigated regarding their performance and reliability. A small scale of those equipments will be experimentally tested. Analytical models of those installations are also being developed for the use in the analysis of the thermal-hydraulic behaviors.

■ <u>Steam Injector Application to Passive Containment Cooling System</u> : In order to investigate the performance and technical application of a steam injector concept, theoretical and experimental study is being conducted through this R&D acticity. A computer code is also under development for the analysis of thermal-hydraulic behaviors of the steam injector.

■ <u>Wet Thermal Insulation</u> : This concept is implemented to properly protect the unnecssary heat transfer from the reactor vessel to the water contained in the safe guard vessel. An experimenatal investigation is underway for the proper material selection and performance tests for the wet thermal insulation concept.

■ <u>Fluidic Diode Application to Passive Pressurizer Spray System</u> : A study on the fluidic diode device is experimentally being conducted for it's use in the passive pressurizer spray system. The study also includes the development of analytical models and computer codes for the analysis of the thermal-hydraulic behavior of the device.

■ <u>Other R&D Activities</u> : Besides the above major R&D activities, several elemental technologies are currently being studied at KAERI to seek for their possible application to the advanced reactor design.

4. Summary and Remarks

A small and medium advanced integral reactor under currently conceptual development at KAERI based on PWR technology fundamentally utilizes the intrinsic and passive safety features to enhance the safety and reliability of the reactor. The fundamental safety charateristics of the reactor are summarized as follow :

- Low core power density that results in the increase in thermal margins provides much improved passive response for a variety of performance transients.
- Subtantially large negative MTC resulting from no use of soluble boron offers potential benefits on the inherent power stability and resistance to transients.
- Integral configuration of primary components in a single pressure vessel basically eliminates the large-size pipings and thus large break of loss of coolant accident.
- Large volume of primary coolant provides more thermal inertia and thus much enhanced resistance to transients.
- Large passive pressurizer significantly reduces the pressure increase for the decreased heat removal events.

- No reactor coolant pump seals eliminates a potential of small LOCA associated with the seal failure.
- Adoption of various passive safety systems enhances the reactor safety and reliability which are the key concerns in advanced reactor development.

The preliminarily established design concepts of the reactor require more detailed evaluation and analysis for both the integrated concept and individual design features to technically prove and confirm its concepts. The overall evaluation and analysis is now in progress. Advanced technologies adopted in constructing the design concepts are also independently being studied to assure its technical feasibility and to generate necessary basic data for the analysis and evaluation of integrated reactor design concepts. The further evaluation and analysis may possibly result in some changes and modifications in design concepts.

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SURVEY ON ALTERNATIVE ENERGY FOR INDUSTRIAL PROCESSES IN INDONESIA

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Abstract

SURVEY ON ALTERNATIVE ENERGY FOR INDUSTRIAL PROCESS IN INDONESIA. In consequence of the national industrial development, it is necessary to supply a lot of energy. This paper presented a discussion about the option of supplying nuclear processed heat as alternative energy sources for industry especially in Java island. The electrical energy requirement can be estimated rising. The stock and the requirement of energy in Indonesia is unbalance. If the oil production rate is constant, such as that of to day, it can be estimated that the oil stock would be over in 20 years. The country is trying to difertify its source of energy and reduce its dependence on oil. High Temperature Reactor (HTR) produces electric and also heat at various temperature in the form of steam and gas. Heat processes from a high temperature reactor, could be used in industry for supplying heat for coal hidroforming , gasification of coal, metal annealing, petrochemical hydrogenation, distillation, purification of petrochemicals, evaporation, water heat etc.

I. INTRODUCTION

In conformity with the Main Features of the National Course 1993 ("GBHN 1993") the energy development program for the long term development program II ("PJP II") is awarded to improve the development activity, prosperity and the quality of services. The energy development program must take into account the energy resources for a long term, the national energy requirement, chance for export, human safety and safe environment[1].

The national industrial development program for " Pelita IV" (5 years Development Programme IV) was making by features of basic development. It was continued at "Pelita V" by stabilizing the features of basic development, and at "Pelita VI", beginning

"PJP II" the growth and development of industries upon the own ability . A strong industrial structure is characterized by a relatively small import of raw material and intermediate product, development of mechanical and electronic industries, development of home industries. The export of industrial product take relatively high part on national export of non oil and gas[2].

In consequence of the national industrial development, it is necessary to supply a lot of energy. On the other hand we must save the energy resources by mean of using it efficiently, it is necessarv to make energy diversification , to use highly efficient equipments.

This paper presented a discussion about option of supplying nuclear processed heat as alternative energy sources for industry especially in Java island in terms of it's prospect, potent and aspect.

II. ENERGY AND INDUSTRIAL DEVELOPMENT

Together with the development progress in all sectors, the electrical energy requirement can be estimated rising, the total energy requirement will also rise. The rise of energy requirement is shown at table 1.

At table 1 it is shown that the energy resources at the end of "Pelita VI" rise 53,34 % from that of "Pelita V". This energy stock is used as stimulant for economic growth and improvement of spread development.

Considering the efficiency of the energy usage, the total energy stock is not all consumed, but only 63,30 % at the end of "Pelita V" and 73,26 % at the end of "Pelita VI", it increase 77,47 %. The rise is stocked for domestic consumption and stocked as stock for domestic and export.

Industrial sector consume greatest amount of energy namely 38,0 % at the end of "Pelita V" and 48,6 % at the end of "Pelita VI", it increases 126,94 %.

Household sector consume smallest amount of energy namely 24,9 % at the end of "Pelita V" and 19,6 % at the end of "Pelita VI" it increases 39,85 %. The total e ectrical energy consumption was 32,04 % of total energy stock at the end of "Pelita V", and 35,16 % at the end of "Pelita VI", it increases 68,13 %. It

Table 1: Primary energy stock, total energy requirement and the use of electrical energy (estimated realization at the end of "Pelita V", Development programme and target at the end of "Pelita VI")

ESTIMATION	END of "PELITA V" (10^6 barrel)	END of "PELITA VI" (10^6 BARREL)	RISE (%)
Total primary Energy resource: - Oil - Gas - Coal - Geothermal - Hydro power	449.11	688.62	53.54
Total energy Requirement: - Oil - Gas - Coal - Geothermal - Hydro power	284.30 (63.30%)	504.54 (73.26%)	77.47
1. Industrial sector	108.06 (38.0%)	245.23 (48.60%)	126.94
2. Transportation sector	105.48 (37.10%)	160.35 (31.80%)	52.02
3. Household sector	70.76 (24.90%)	98.96 (19.60%)	39.85
Electrical energy : - Oil - Gas - Coal - Geothermal - Hydro power	284.30 (63.30%)	504.54 (73.26%)	77.47

proved that the energy stock is stocked for electrical energy and for an other sector like transportation.

III. ENERGY PROBLEM

Stock and requirement of energy.

From the above data and discussion is proves that the policy of energy consumption specialized industrial sector. The change of Indonesia economic structure from agriculture to industry, which estimated go in a long term, cause the commercial energy requirement goes with high acceleration. The accelerated energy requirement is fulfilled by using the primary energy, such as : Oil, Gas, coal, geothermal and water power, see table 1.

The primary energy resources is met in Indonesia, spread in several islands with various intensity. Table 2 shows the energy resources and table 3 shows the energy requirement in 1984. Table 2 and table 3 shows that the stock and the requirement of energy are unbalance. The oil stock/ resources, which is estimated 50 billion, is really less than 10 billion . If the production rate is constant the stock/resources will be over in 20 years. In recent time the use of oil is 70 % of the total energy requirement in Indonesia, see table 3.

Table 2 : Potent and production of energy of Indonesia
(Umar Said, 1986)

Energy	Resources	Production rate (1984)
Oil (barrel)	9.5 (50) billion	550.0 million
Gas (cubic feet)	80 billion	1.5 million
Coal (ton)	23 billion	1.6 million
Geothermal (MW)	10,000	0.4
Water power (MW)	78 000	9,000

Table 3 : Primary energy requirement (1984)
(x 10 TBM barrel equivalent oil) (Johannes, 1987)

Energy	Resources	Production rate (1984)
Oil	164,114	72.4
Gas	45,672	20.1
Coal	1,816	0.6
Geothermal	447	0.2
Water power	14,712	6.5

Because of the above problem, the national energy policy to anticipates the rise of energy requirement from industrial sector in "PJP II" by energy diversification and by the reductionof oil with the following considerations : [4]

Oil will be used as export commodity to devise, as raw material for petrochemical industries and for transportation. By high scenario, (GDP rise 4,5 %/ Year), the oil will finish in 1997-1998 . By low scenario it will finish in 2002-2007.

Gas is Used as fuel in industries, household and transportation, as export commodity with long term contract.

Coal is used as fuel for an electric generating system, converted into liquid or gas for household needs.

Geothermal is used for a small scale electric generating system and agroindustries .

Hydro Power is used for electric generator and mechanical energy.

The national energy policy is supported by the data of energy balance at figure 1, for 10 years 1982/1983-1992/1993, which shows the decrease in the use of primary energy of oil and gas, and the increasing the use of coal and geothermal. The use of water power s relatively constant because almost all the big river in Java have been damed up.

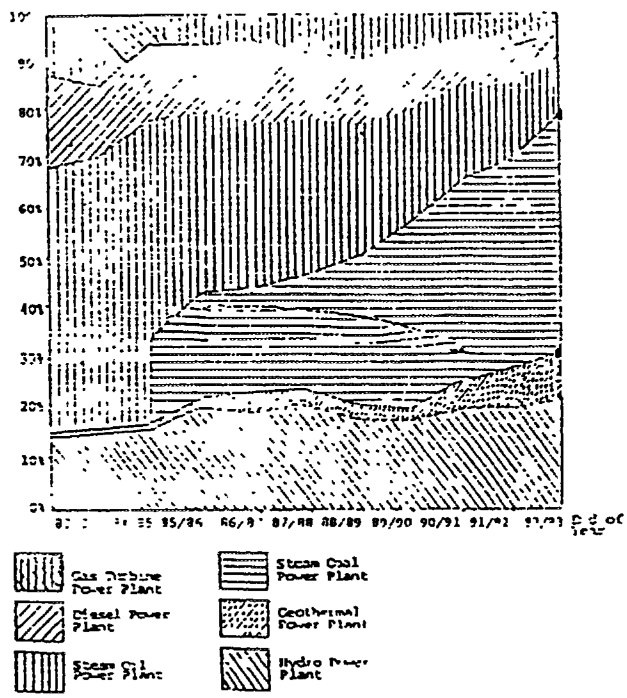

Figure 1 : Energy balance 1982/1983-1992/1993

HTR - coal generating system partnership.

Because of the small use of geothermal the use of coal as energy source increases. Match with the diversification concept the coal energy sources is necessary to border by available energy sources and technology which have big scale. The option for diversification of energy sources for industrial processes is nuclear energy. The nuclear processed heat most flexible for industries is from a HTR. A HTR can produce heat at various temperature in form of steam and gas. The various temperature can be used for industries, mechanical, electronic, chemical and household industries.

In addition to the heat and steam for industrial process, the electric co-generated by a HTR can reduce the thortage electrical energy before the year 2000. Before "Pelita V" it was estimated that electrical energy requirement in the year 2005 for Java-Bali was at least 27,000 MWe. By counting the available non nuclear energy, there will be a deficit of electrical energy of 7,000 MWe. The deficit will be overcome by nuclear energy. Recent study said that the estimation of electrical energy requirement for Java-Bali in the year 2015 was 32,710 MWe, and the deficit was 7,625 MWe. Based on the study it is important to introduce nuclear power plants for Java-Bali electrical system. The cost of electricity generated from coal is almost equal to that from nuclear namely 46-48 Mill/kWH (data US-CEA). Because of the development of nuclear power plant, we hope the fixed cost and fuel cost decrease by 25-30 %.

From environmental aspect, partnership of a HTR and coal-electrical generating system decrease the environment destroying, which is caused by using fossil fuel. Today 63 % of power plants in the world use fossil fuel, this cause the emission of SO_2, CO_2 and NO which causes acid rain and destroction of forest. In addition to that CO_2 causes the green house effect in the atmosphere which increases the global heating and change of climate.

The main problem always encountered by a developing country is expertise in technology. Indonesia does not hand energy technology yet, therefor Indonesian people must work hard to master every energy technology and to improve the national energy.

IV. HTR AS PROCESS HEAT SUPPLIER

HTR option

There are some reactor options as supplier process heat in the form of steam and gas at various levels of temperature as shown at table 4.

Table 4: Temperature level of process heat usage from nuclear reactor (6)

Technology	Temperature (^{o}C)	System
Steam	300	LWR, AGR, HTR, FBR
Steam	500	AGR, HTR, FBR
Helium	950	HTR

The ninimum power, which is economical, to be converted from nuclear fission into secondary energy is 3,000-4,000 MWth. The optimistic assumption that nuclear power can supply 50 % of electric requirement in the world, is proved wrong, really it contri- butes only 10 % of world energy requirement. To increase the nuclear energy consumption it is necessary to spread the usage. At table 4 it seems that HTR is the most flexible. It can coge- nerate electricity and heat (steam and gas) at various temperature (low-medium-high). Even HTR can handle almost 1/3 of the total world energy requirement in 50 years.

Table 5 shows the use of various temperature in some indus- tries.

Table 5: The use of process heat.

Temperature level	The use in process
1. low temperature 80 - 200 ^{o}C :	Household : water heater
100 - 250 ^{o}C : (steam 1-10 atm.)	boiling, evaporation distilla tion, organic and petrochemi- cal, hot molding of plastic, food chemical
2. medium temperature 250 - 400 ^{o}C : heat transfer equipment steam 30 atm.	distillation of petrochemical purification of petrochemical organic chemical
350 - 550 ^{o}C :	catalytic methane forming Petrochemical hydrogenation Organic chemical forming Process steam.
3. high temperature 750 - 950 ^{o}C :	thermally petrochemical form- ing hot molding of metal metal annealing gasification of coal hydrogenation of coal hydroforming of coal

Table 5 shows that heat of various temperature produced by HTR can supply process heat requirement of some industries.

Safety aspect of HTR

HTR is a nuclear power plant, using passive safety concept, especially to avoid core melting. The passive safety concept is an action to save naturally if the power increase is uncontroled. It uses three concepts : the fuel particle coat, SiC, work well as barrier of fission product at 1600 °C, low power density and bounding naturally the maximum temperature of core 1600 °C through optimization of heat transfer in the reactor core.

An other advantage of a HTR is the negative reactivity versus temperature, whereas the efficiency is better than that of other kind of reactor.

V. CONCLUSION

1. Divertified energy supply for industrial purpose using coal as energy source, the increase of energy requirement is anticipated by using nuclear energy.

2. Nuclear reactor increasable as energy source by improving the contribution of the use of electrical energy, sources heat and steam at various temperature.

3. The use of process heat of HTR as an options of diversifed energy source is caused of the most flexibility of HTR to produce heat at low, medium and high temperature. Whereas the cogenerated electricity can support the electricity deficit before 2000th year. The safety aspect is excellent, the energy efficiency is relative high and the energy generating cost is competitive with it of coal.

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RECENT PROGRESS IN THE FEASIBILITY STUDY FOR THE FIRST NUCLEAR POWER PLANT IN INDONESIA

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Abstract

The energy consumption in Indonesia has been continually increasing since 1970 at an average rate of ~10.6%/year. Specifically, for the island of Java, which consumes ~80% of Indonesia's electricity, the installed capacity by PLN was 6363MW in 1990/91. This has increased by ~17%/year during the past three years. Additional increase in electrical consumption of the Java-Bali system projects the need for the installed capacity to reach 31,845 MW in 2003/04. In anticipation of this major addition of installed capacity, the government of Indonesia is conducting feasibility studies of the nuclear option as a means of filling the projected deficit or gap where other fuel options are likely to reach their limits. This paper describes the scope of the present feasibility study including energy economics and financing, technical and safety aspects, the fuel cycle and waste management, general management, and site and environmental studies.

I. INTRODUCTION

In consideration of supplying energy for national development, many come to realize that an increasing demand and supply of energy is a necessity to support development. Conservation efforts also contributes, by the use of energy more efficiently and avoiding its unnecessary use. However, some are of the opinion that conservation would be able to add to the supply of energy, but this still has much to be considered.

In Indonesia, the energy consumption since 1970 has been continually increasing with an average rate of 10.6%/year in support of the development in all sectors. In the case of electric energy for the whole of Indonesia, in the year 1990-91 the installed capacity was 9275 MW in the State Electricity Company (PLN) network with an electrical consumption during that year amounting to 34.0 TWh. The increase of consumption during the last two years amounts to 17.5% and 17.9%/year. In this case the share of supply of electricity has consistently increased.

Specifically for the island of Java, which accounts for 80 % of all of the Indonesian electricity consumption, the installed capacity by PLN in the year 1990-91 was 6363 MW (the same amount of capacity also exists outside PLN), and increased by 17%/year during the last three years. The actual and projected figures are given in Table-1. It is worth noting that, for example, the projected installed capacity for 2003-04 is now 31.8 GW, which is far higher than the previous projection for 2010-11 of only 25.5 GW. In view of this the government has decided to conduct feasibility studies of the nuclear option, in the goal to fulfil the deficit or gap in supply where other options are likely to reach their limitations.

The energy diversification policy adopted by the government has the objective of reducing domestic oil consumption and promoting other energy sources. The importance of oil exports for government earnings, and the fact that oil reserves are finite, has made the diversification policy (using hydro, geothermal, gas and coal) essential.

TABLE 1. ELECTRIC POWER DEVELOPMENT PROJECTION OF THE JAVA-BALI SYSTEM [1]

		1990-91	1993-94	1998-99	2003-04
Consumption	(TWh)	22.4	33.2	75.1	128.1
Average Growth	(%/a)	-	15.5	17.7	14.1
Peak Load	(MW)	4565	6821	15061	24849
Production	(TWh)	27.78	41.35	92.23	156.21
Installed Cap.	(MW)	6363	8937	18765	31845

Note : 1993-94, 1998-99, 2003-04 are respectively the end of the fifth, sixth, and seventh Five-Year Development Plan

With such high growth, a non-nuclear scenario for the Java-Bali region would require as much as 20,880 MW of coal-fired capacity by 2003-04. This figure would exceed the presumed 15 GW limit (equivalent to 40 million tons/a of coal burning limit for Java) unofficially set by the Ministry of Population and Environment. Environmental considerations as well as technological advances, therefore, are making the introduction of the nuclear option for the Java-Bali system more and more attractive.

II. THE FEASIBILITY STUDY

2.1 The Previous Feasibility Studies

The first pre-feasibility study for the introduction of a nuclear power plant was conducted in 1978 - 1979 with the assistance of the government of Italy. However, following this study the Indonesian government deferred the decision until the nuclear research facilities in Serpong became fully operational.

In 1985 work began on updating the studies with the assistance of the International Atomic Energy Agency (IAEA), the US government (through the services of Bechtel International), the French government (through the services of Sofratome), and the Italian government (through the services of CESEN).

These updated reports, and the analytical capabilities developed by the Indonesian partners during the process of this cooperation, have become the foundation for the present planning activities. Recent projections using WASP (computer software for planning electricity expansion) have shown that introducing nuclear power by 2000 would be an attractive option.

Another study (Markal Study) coordinated by the Agency of Assessment and Application of Technology (BPPT) has clearly shown that, if discount rates of 4% to 8% were used, nuclear would become the best option starting from the eighth Five-Year Development Plan (2004-09). This means that the decision to embark on a nuclear power programme should be made imminent, considering that it would require a ten-year lead time.

This Markal Study also reached an important conclusion for the development of Sumatera island. The study examined options for providing the power needed for oil recovery in the Duri oil field; in line with the policy to reduce domestic consumption, high temperature nuclear reactors and natural gas plants were considered as replacements for the present oil-burning plants. The study concluded that the nuclear option should commence as soon as the sixth Five-Year Plan (1994 - 1999).

The site for the first Nuclear Power Plant (NPP) has long been studied since 1975. In conclusion, the Muria peninsula region has been selected to be the most suitable area in Java, where Ujung Watu is considered as a candidate site. The plan for a final site investigation has long been prepared. It consists of a selection and evaluation of the preferred site. A set of site data report, a site selection report, a preliminary safety analysis report, and an environmental impact analysis report will be made available at the completion of this investigation. It is intended also to prepare the domestic participation even at this early stage of activity.

On the financing side, studies of the Build-Operate-Transfer (BOT) scheme were conducted by three consortia of nuclear vendors in 1986. The BOO/BOT scheme are also being studied and considered in the present feasibility study of the first Indonesian NPP.

2.2 The Present Feasibility Study Project

In September 1989 the Indonesian Government through the National Energy Co-ordination Board (BAKOREN) decided to perform anew the NPP feasibility study including a comprehensive investigation of the Muria site. The study itself should be carried out by the National Atomic Energy Agency (BATAN), under the directives of the Energy Technical Committee (PTE) of the Department of Mines and Energy.

On August 23, 1991, an agreement was signed in Jakarta between the Indonesian Ministry of Finance and BATAN on behalf of Indonesia, and the consultancy company NEWJEC Inc. This agreement contracts NEWJEC for a four and a half year period to perform a site selection and evaluation, as well as a comprehensive nuclear power plant feasibility study. The principal part of the contract's value will be spent on studies related to the site, which is to be sought in the northern coast of the Muria Peninsula in Central Java.

The scope of the feasibility study includes two main components :

1. The non-site studies, covering energy economics and financing, technical and safety aspects, the fuel cycle and waste management, and general management aspects, among other things.

2. Site and environmental studies, covering field investigations and assessment of site selection, site qualification/evaluation, and environmental, socio-economic and socio-cultural impacts.

Each part of the study includes a technical transfer and training for the Indonesian counterpart. The whole feasibility study is carried out under a comprehensive quality assurance programme developed by NEWJEC, which complies with IAEA recommendations, and approved by BATAN.

On December 30 1993, two years after the starting date (22 November 1991), NEWJEC submitted the feasibility study report (FSR) and preliminary site data report

(PSDR) to BATAN. At the end of the four and half year contract, a final report will be provided, including a site and environmental report, and preliminary safety analysis report. These documents will provide the information necessary for site permit application, for the design engineering basis and other industrial infrastructure preparations. The attached Figure-1 shows the overall schedule of the feasibility study.

Safety aspects are of the utmost concern of the studies, which will assess not only the proven designs available in the market at present but also advanced and passive systems expected to enter the market in the near future.

The official starting date of the project was announced as 22 November 1991. The quality assurance programme, a prerequisite for beginning the work, was duly submitted by NEWJEC and approved by BATAN. Subcontracts for the site works have already been awarded to Indonesian contractors. A site survey to set up an additional micro-seismic telemetering system had been undertaken.

2.2.1 Non-Site Studies

ENERGY ECONOMICS AND FINANCING

The work on energy economics and financing was completed at the end of 1993. The assessment covered the following items :

• National Energy Market Analysis

The objectives of the National Energy Market Analysis are to conduct a study of the national energy development to support the long term energy demand, and to conduct analysis of the energy system, specifically the electrical energy sector by the use of the ENPEP (Energy aNd Power Evaluation Program).

This report includes an analysis of the evolution of the energy market, evaluation of energy resources, forecast of energy demand, analysis of energy demand management options, and the formulation of an energy supply planning.

Following are some tables showing results of the Macro Economic, Energy Demand and Energy Supply projections.

1. Macro Economic Projection

	GDP GROWTH TOTAL (%/year)	POPULATION GROWTH (%/year)
1990 - 2000	6.50	1.87
2000 - 2010	6.00	1.35
2010 - 2019	5.00	0.85

2. Energy Demand

The energy demand has increased 6 - 7% per year during the study period of 30 years (1990 - 2019).

	GROWTH OF TOTAL ENERGY DEMAND (%/year)	ELECTRICITY DEMAND GROWTH (%/year)
1990 - 2000	6.27	10.30
2000 - 2010	7.20	9.64
2010 - 2019	7.09	8.27
AVERAGE GROWTH	7.18	9.41

3. Energy Supply

- Share of Primary Energy Supply during the Study Period (%)

PRIMARY ENERGY	1990	2000	2010	2019
OIL	60.21	60.79	51.14	34.34
GAS	32.52	18.60	7.01	3.41
COAL	5.72	18.21	35.55	54.29
NUCLEAR	0.00	0.00	3.92	6.18
OTHERS (hydro, geothermal)	1.55	2.40	2.38	1.79

- Electricity Supply

Coal fired plants will dominate the electricity generation system. Nuclear power plants will be feasible to be in operation in the early 2000s (based on current projection studies). Nuclear power plants will increase in accordance with the demand while the result of the analysis of this scope of work is used as reference for optimization studies in the development of the Java-Bali electric system.

In the year 2019 the share of nuclear power plants will give a contribution of 10% to the electricity supply, an amount equal to about 12600 MW.

- Nuclear Cost Estimate

This study covers an analysis of capital cost (based on vendor's overnight cost, in April 1992 US dollars) for each type of nuclear power plant, as offered by various vendors : Mitsubishi Heavy Industries (Japan), Atomic Energy of Canada Limited, Nuclear Power International (German - French Consortium), Westinghouse Electric Company (USA), General Electric Company (USA). Comparisons of maintenance and decommissioning costs of the various designs, based on NEWJEC's method and experience are given.

The results of the analysis and information acquired are as follows :

1. The capital costs (vendors budgetary estimate) of various types and capacities of conventional NPP (600 - 1000 MW) is around 1530 - 2200 US$/kWe and 1530 - 2020 US$/kWe for advanced designs.
2. The operation and maintenance cost of various types and power of NPP averages about US$ 70/kWa.
3. The estimated decommissioning cost is around 10% of the capital cost.
4. The data and information from points 1, 2 dan 3 have been used as a basis for Generation Cost calculation of nuclear power plant.

• Electric System Analysis and Choice of Unit Size

Electric System Analysis

The objective of the Electric System Analysis, is to determine an optimum configuration for the Java-Bali electric generation system with the introduction of Nuclear Power Plants including the size and its main features.

The Electric System Analysis report covers :

1. Load demand forecast and load curve of the Java-Bali system.
2. Generation Expansion Programme : System operating conditions, Formation of optimal generation expansion plans, Recommended Power Development Programme, Public safety and environmental protection.

The results obtained through the optimization study in the development of the Java-Bali electric generation system with the use of the ELECTRIC module (WASP III) of the ENPEP program, shows that the introduction of nuclear power plants in the early 2000s to the Java-Bali electric system represents a very good solution.

Choice of Unit Size

The objective of the Choice of Unit Size study, is to determine the nuclear power plant unit size, taking into consideration the capability and reliability of the electric network system in relation to the load flow, short circuit capacity and the stability of the network.

The results show that commencing in the early 2000s and supported by development of the electrical network, the introduction of the 600 to 900 MWe class of nuclear power plants into the Java-Bali electric system is absolutely possible, furthermore based on economic aspects, the introduction of the 900 MW unit size class is a better option. Meanwhile, to anticipate the increasing demand of electricity in the future, it is very necessary to conduct updating studies of the electric network system.

• Generation Cost

The objective of the Generation Cost study, is to determine the generation cost of various types and sizes of Coal Fired Plants, Combined Cycle Power Plants and Nuclear Power Plants.

The result of this study concludes that the generation cost of the 600 and 900 MW class Nuclear Power Plant units are competitive to the generation cost of 600 MW Coal Fired Plants with DeSOx and DeNOx equipment. In the analysis, the capital cost of nuclear power plant have been based on vendor's budgetary estimates including civil works and IDC.

• **Financial Review**

The objective of the Financial Review Study, is to obtain various options and sources of viable financing for the construction of Nuclear Power Plants in Indonesia.

The scope of the study consists of :

1. Conventional Financing Scheme
2. BOO/BOT Financing Scheme

Following are the results of the study :

1. Conventional Financing

Implementing conventional financing for the construction of 600 or 900 MW units can be done like any other construction of power plants. Feasible or viable sources of financing can be conducted for example : US component 50%-Japanese component 50%, US component 100%, French component 50%-Germany component 50% dan Canadian component 100%.

Project cost for the scope of the Financial Review studies being modelled includes the following assumptions :

1. Base Cost of Nuclear Plants
   Base capital cost (not including financing charges during construction) is based on the Nuclear Cost Estimates study, i.e. vendors budgetary estimate + civil works (10%).

2. Training of Operation/Maintenance Staff is assumed 0.1% of item 1.

3. Consulting Services Cost is assumed 5% of item 1.

4. Owner's Administration Cost is assumed 4% of item 1.

5. The Total Capital Cost is the sum of item 1 until item 4. The Total capital cost is divided into a local portion and a foreign portion, 25% and 75% respectively.

6. Initial Fuel Loading Cost is estimated as follows
   unit 900 MW = US$ 81,0 million/unit
   unit 600 MW = US$ 62,3 million/unit

Note :

1. All costs have been escalated
2. The calculations and modelling have been conducted based on the assumptions of the financial resources which come from each country's export credit agency, and for the commercial bank for the local portion progress payment dan domestic bonds.

As a conclusion for the conventional financing scheme, the construction of the 900 MW and 600 MW nuclear power plant units meet the least cost generation programme; and the cost of electricity generated by nuclear power plant is estimated to be lower than electricity generated from coal-fired plants.

2 BOO/BOT Financing Scheme

The implementation of the BOO/BOT financing scheme for 600 and 900 MW unit nuclear power projects in Indonesia should be supported by the Government in the following cases :

- The need of a bilateral agreement between the Government of Indonesia and the related country concerning the use of nuclear energy for peaceful uses.
- Activities related to the decommissioning and back end of the fuel cycle
- Guarantee of fuel supply
- Third Party Liability insurance from nuclear hazards

Furthermore a power purchase agreement is necessary between PLN with the company, covering the following guarantees and requirements :

a The obligation of PLN to remit payments according to the requirements, using the agreed determined exchange rates.

b A guarantee by the Government to return loans, dividends, and other financial arrangements in the determined exchange rate and currency.

From the BOO/BOT financing scheme studies, the average electricity selling price will be higher compared to the conventional financing method, due to a high rate of investment return (ROI) of about 20% to 30% in order to cover all risks.

As a conclusion for the BOO/BOT financing scheme, there is no such experience in any nuclear power plant project. The overall costs of a BOO project will be more expensive than the conventional scheme, because of private sector loans and equity of higher costs (around a 10% higher energy price, in the case of an ROI = 15%).

SAFETY AND TECHNICAL ASPECTS OF NUCLEAR POWER, FUEL CYCLE AND WASTE MANAGEMENT

• Safety Aspects of Nuclear Power

The Objectives of the study on Safety Aspects of Nuclear Power are

1. To determine the safety criteria to be used.
2. To determine safety characteristics and probabilistic risks.
3. To give recommendations on the type of nuclear power plant to be considered in the offer.

The report consists of six (6) separate studies, which cover

1. Probabilistic Risk Assessment;
2. State of The Art Technology for Instrumentation and Control;
3. Lessons Learnt from TMI and Chernobyl;
4. Requirements for Safety Systems and Equipment;
5. Technical and Safety Aspects of NPP;
6. The Safety Philosophy of IAEA and its major member states.

Results and Conclusion

1. The criteria and standards of all the supplier's countries of nuclear power plant suppliers (United States, Germany, France, Japan and Canada). may be adopted, because they are in line with the international safety philosophy (IAEA).

2. All the reference nuclear power plants, viewed from the safety aspects, can be constructed in Indonesia.

3. The advanced design nuclear power plants have better safety characteristics, but are still pending certification by the supplier's country.

4. The core melt frequency from all nuclear power plants being studied are under 10^{-5}/reactor years, fulfilling the IAEA recommendations.

5. Instrumentation and control designs studied from all nuclear power plants being studied, have considered "human factor engineering".

• Technical Aspects of Nuclear Power

The objective of the Nuclear power plant technology study is to recommended the types of nuclear power plant that can be accepted to be built in Indonesia.

This report which concerns the process of choosing possible vendors and reactor designs, have resulted in the following selection

1. General Electric SBWR;
2. Mitsubishi Heavy Industries/Westinghouse conventional PWR and Advanced AP600 designs;

3. Nuclear Power International/Siemens & Framatome conventional and Advanced PWR designs;
4. Atomic Energy of Canada Limited for Candu PHWR design.

Results and Conclusion

The nuclear power plants that have been offered by AECL (PHWR), Mitsubishi/Westinghouse (PWR), NPI (PWR) dan General Electric/Toshiba/Hitachi (BWR) can be accepted as a basis for nuclear power plant considerations for Indonesia. All offer modem technology, fulfilling construction requirements in their respective countries, fulfilling international safety standards, the IAEA codes and standards, including "human factor engineering" in their designs, showing exceptional operation performance and able to fulfil the first nuclear power plant construction schedule in indonesia.

Presentations have been made by these vendors, and absolute and relative comparisons of the various designs have been carried out.

• Fuel Cycle Technology

The objectives of the Fuel Cycle Technology study are to obtain :
1. An evaluation of the nuclear fuel cycle
2. Economic Calculations
3. A development strategy for the nuclear fuel cycle.

This study consists of an evaluation of the fuel cycle and its economics, as well as the strategies for development of the fuel cycle.

The results of the evaluation are as follows :

1. The selected cycle should be the Open Cycle for a determined length of time.
2. A fuel element factory for power reactors would be feasible to be domestically integrated
3. Uranium domestic production will only be used for supplementary purposes.

• **Waste Management**

The aim of waste management in this case, is to conduct evaluation of radioactive waste management and decommissioning activities in nuclear power plants.

The scope of the study covers the type, amount and process of waste forms, technical aspects, economical aspects and safety in nuclear power plant waste management.

The objectives are to assure safety to the population and environment, draw up sound technical requirements, and define goals, rules and regulations in the management of nuclear power plant wastes.

The results and conclusion of this study are :

1. Identification of the process and origin of the wastes is very necessary in order to:
   a. Minimize the occurrence of wastes
   b. To handle wastes cheaply and safely

2. The volume of nuclear power plant wastes are relatively small and some parts are wastes having low activity which are easily processed.

3. For Indonesia, the open fuel cycle is favoured, as high level activity wastes are not formed which originates from recycling processes.

4. The nuclear power plant shall be equipped with a facility to manage radioactive wastes.

5. A waste storage facility shall be available in a nuclear power plant vicinity.

MANAGEMENT ASPECTS

• Project Development

The objectives of Project Development are among others, to determine the organizational diagram of various participants in nuclear power project, to determine the overall project schedule and to determine the contractual approach to be adopted for the acquisition of the plant including an analysis of the regulatory basis and licensing process for the nuclear power project in well experienced countries and recommend those suitable for Indonesia.

Conclusions and recommendations

From the Project Development study being conducted, some conclusions and recommendations have been developed as follows :

1. It is critical for the successful NPP that all participants in the project are well organised in a manner of achieving the same objectives as a team with clear distribution of functions and responsibilities and through the implementation of a QA programme.

2. The preliminary project schedule for the first NPP project is developed based on international experience and vendor's information. According to the schedule, the first NPP would start its commercial operation in the early 2000s.

3. The single package contract (turnkey contract) is recommended for the first NPP project, because the full responsibility and risks associated with the project are to be borne by the main-contractor.

4. Licensing procedures are recommended to be adopted from procedures of well-experienced countries, which have already been established and practiced in those countries.

5. The owner/utility needs to ensure close cooperation and coordination between the participants in a nuclear power project. Especially for the introduction of the first NPP, the owner/utility should be assisted by a foreign consulting company having enough experience and capability.

6. At a time of formal bidding, the vendors should be requested to develop a detailed project schedule, taking into account the conditions in Indonesia, and also submitting a methodology for the transfer of know-how.

7. In order to avoid difficulty in financing, it is recommended that Indonesia should begin with small size projects.

8. For the first NPP, licensing under the regulations of the country of origin should be accepted. This gives an assurance that the rules and regulations would be complete and consistent. Indonesia, during the construction of the project, must adopt a similar set of regulations, modifying them as necessary, and based on project experience.

9. A minimum legislation necessary to promote and implement the nuclear programme should be established in an earlier stage, before starting the safety assessment of the first project.

10. Licensing procedures should be carefully developed so that it will not induce excessive risks and burdens to an electric utility company, as far as the safety of workers and public are maintained.

- Staffing and Training

The objectives of the study are to develop the following points for the owner (utility) :

- the organization charts for various phases of the nuclear power plant with the listing, qualification and description of the tasks
- the training programme for the personnel involved in the above developed organization charts

Conclusions and recommendations

The study concerning Staffing and Training have concluded the following :

1. The Owner (utility) should establish an organization suitable for ensuring close cooperation and coordination between the project participants.

2. The organization structure should be adapted and expanded efficiently to cover important areas in accordance with the progress of the project.

3. The utility's manpower requirements during the preconstruction stage is relatively low, about 50, but of highly qualified professionals.

   The personnel required start to increase as much as about 330 at the peak of construction and commissioning stage. In the operation stage, about 300 personnel will be necessary for the operation and maintenance of 2 units (about 200 for 1 unit).

4. In order to meet the manpower requirements with appropriate qualification, a training programme must be planned and implemented.

   At the initial stage of NPP, basic training in nuclear power followed by an on the job training (OJT) should be provided to the key utility professionals.
   The training for O&M staff should also be implemented with emphasis on OJT and simulator training.

5. A national organization to be in charge of the planning and coordination of the nuclear power project should be established as soon as possible.

   The distribution of tasks, functions and responsibility between the organizations including the regulatory body and the owner of the plant should follow similar pattern to those for other conventional power projects.

6. A manpower development programme should be planned and implemented among relevant organizations at the earliest stages of the nuclear power project because of the long lead time needed in developing qualified manpower.

7. Care should be taken to the following points for the application of the report to Indonesia.

   - to include an adequate number of reserve and replacement personnel for the assessment of staffing requirements

   - to administer adequate training to the personnel based on their experiences and abilities

8. An employment system of the Indonesian nuclear power plant owner should be established and to be similar to a lifetime employment system especially for operation and maintenance staff, because they must be trained systematically to become highly skilled and to be very familiar to the operation and maintenance of the nuclear power plant in order to keep a reliable and safe operation.

9. The training requirements to vendor should include the consideration of the utilization of domestic available resources.

• National Participation

The principal objective of the current study is, based on the latest information regarding the status of Indonesian industries, to define Indonesia's infrastructure requirements and analyze the national participation possibilities to achieve optimum role of national industries to support the construction of nuclear power plants within the framework of the national program of industrialization.

Conclusions and recommendations

Conclusions

1. Infrastructure requirements for participating in the construction of NPPs should be defined, and a national participation program to be developed.

2. Based on the survey and assessment of the current capability of Indonesian Industries, the development of the national participation has been calculated with the results as follows :

NPP	National participation
NPP # 1	25%
NPP # 2	30%
NPP # 3, 4	35%
NPP # 5, 6	60%
.	
.	
.	
NPP #	optimum

3 The national participation rate can be increased step by step in accordance with development of the national participation program, if successful transfer of nuclear technology and nurturing of nuclear industries in Indonesia are achieved.

For successful transfer of nuclear technology and nurturing of nuclear power industries in Indonesia, the following conditions should be satisfied.

- National consensus on the selection of nuclear power as one of the vital resources to support the welfare and economic growth of Indonesia.

- Commitment by the Government of Indonesia to lead and support nuclear power generation in Indonesia.

- Stability and sound growth of the Indonesian economy.

Recommendations

The following measures and actions are recommended to the Government of Indonesia to transplant and nurture the nuclear industries in Indonesia and fully increase the national participation rate.

1. Study of the economy and technology of the actual status of nuclear power generation, as well as it's introduction into Indonesia
2. Establishment of the Long Term National Energy Policy with clear definition and declaration of the vital role of nuclear power.
3. Initiation of public acceptance programs
4. Amplification of bilateral agreements with foreign countries
5. Legislation for nuclear power development
6. Selection of the reactor type
7. Repeated orders of multiple units of the same standardized design
8. Establishment or selection of key companies for national participation in manufacturing and transfer of technology
9. Incentives for domestic manufacturing
10. Source of Revenue for Nuclear Power promotion by the Government

2.2.2 Site and Environmental Studies

A site and environmental study is presently being conducted in the Muria Peninsula region on the island of Java. The ultimate objective of this site and environmental study is to obtain a preferred candidate site and identify its site-related design basis parameters for the nuclear power plants, through a process of investigations and assessments, based on nuclear safety, population and environment, engineering and economic considerations. The site and environmental study will take about four and a half years to complete, and is divided into three steps which are described as follows :

The Objective Of Step-1

The objective of Step-1 is to obtain two (2) alterative sites. These will be compared and ranked with the reference site, Ujung Watu in Step-2, all on the coastal area of the Muria peninsula. The work of Step-1 was completed at the end of 1992, with the assessment covering the following items :

- Geography and topography
- oceanography and coastal flooding
- Geological and geotechnical studies
- Hydrogeology and hydrology
- Man-induced events
- Demography
- Seismology
- Volcanology
- Meteorology

The result and conclusion of Step-1 have determined two (2) sites called Ujung Lemahabang and Ujung Genggrengan as selected alternative sites.

The Objective Of Step-2

The objective of Step-2 is to compare and rank the three candidates sites (Ujung Lemahabang, Ujung Genggrengan and Ujung Watu) situated in the Muria peninsula in order to select a preferred candidate site (ranked number one).

Studies conducted for the site selection include topical assessment of

- Topography
- Oceanography, off-shore geophysics and coastal flooding

- Geology, geophysics and geotechnical studies
- Hydrogeology/hydrology
- Seismology
- Volcanology
- Man-induced events
- Demography
- Meteorology
- Land and water use
- Endangered species and historical monuments
- Ecology

Comparison and ranking of the three candidate sites were then carried out by considering 20 site characteristics related to the safety, environmental and non-safety aspect of each site, based on results of those topical assessments at the end of 1993. As a result, Ujung Lemahabang has the highest rate in the evaluation and is ranked as the preferred (ranked first) candidate site, while Ujung Genggrengan as second and Ujung Watu as third.

The Objective Of Step-3

The objective of Step-3 is to conduct in-depth investigations and analysis for evaluation of the preferred candidate site (Ujung Lemahabang) in order to confirm the acceptability of the site from the nuclear safety and environmental impact points of view and to obtain the design basis parameters for the nuclear power plant. In accordance with the terms of the agreement, the consultant is presently carrying out Step-3 activities, which are, expectedly, to be completed by May 1996.

The assessment of Step-3 covers the following items :

- Topography
- Oceanography, off-shore geophysics and coastal flooding
- Geological, geophysical and geotechnical investigations
- Hydrogeology and hydrology
- Man-induced events
- Demography
- Seismology
- Volcanology
- Meteorology
- Land and marine use
- Dose assessment
- Emergency planning
- Ecology
- Sosio-economic and sosio-cultural impact
- Comparison study on the environmental impacts of nuclear, coal fired and hydro generating plants during construction, operation and decommissioning phase.
- Other considerations

III. FURTHER CONTINUING ACTIVITIES RELATED TO THE NUCLEAR POWER PLANT

A Workshop on Energy Planning for the sixth Five-Year Development Plan 1994/95 1999/2000) held by the **Department of Mining and Energy** has concluded that due to the increasing demand of electrical energy, nuclear energy needs to be assessed and planned more solidly in achieving an "**Optimal Energy Mix**" in the year 2000.

At the end of the year 1993, a "Feasibility Study Report" of the Non-Site aspect of the First NPP and a "Preliminary Site Data Report" of the Site and Environmental aspect were completed. These reports describe the preferred site (ranked number one) among the three candidate sites in the Muria Peninsula Region. The two other candidate sites (ranked number two and number three) would be considered as candidate sites to assure the availability of NPP sites in the long run.

Based on the result of the Feasibility Study Report and Preliminary Site Data Report, a preliminary technical specification for nuclear power plant has been started in 1994 and will be followed by a more detail technical specification in parallel with the completion of the Final Feasibility Study Report and Site Data Report. Simultaneously other activities such as supporting research activities, regulatory development activities, and human resources development will be executed.

The Manpower Development and the Public Acceptance Programmes, as important parts of the Nuclear Power Programme will be carried out continuously and more intensively.

IV. GENERAL CONCLUSIONS OF THE FEASIBILITY STUDY

A. The introduction of a nuclear power plant with a capacity of 600 MW or 900 MW in the early 2000s to the Java-Bali electric grid system will have no hindrances and would be a sound solution.

B. The construction of nuclear power plant units with a capacity of 600 MW and 900 MW fulfils the least cost criteria for a specific schedule.

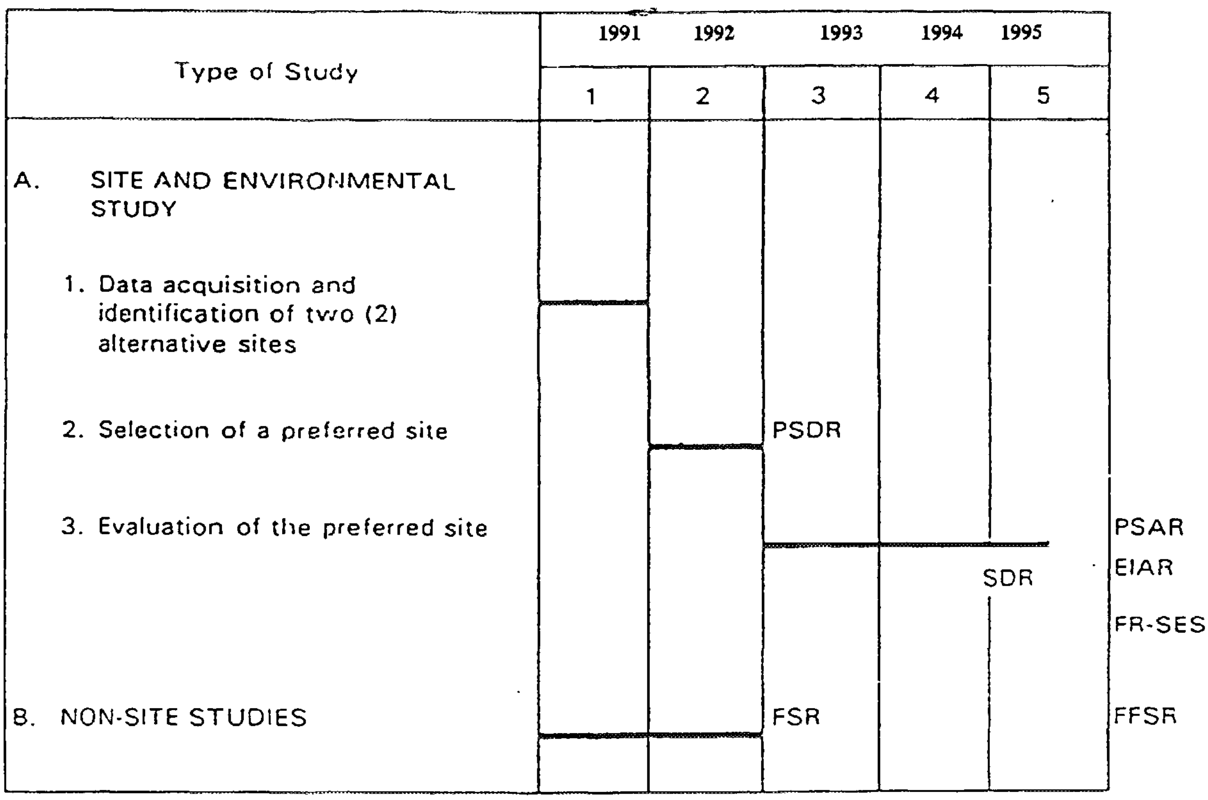
C. The generation cost of electricity generated from nuclear power plants is competitive to electricity generated by coal fired plants of similar size.

D. From the results of the BOO/BOT financing scheme studies, the average electricity selling price will be more expensive compared to the conventional financing method due to high rate of investment return (ROI) which is estimated to be around 20% to 30% needed to cover all costs and risks.

E. Type of Nuclear Power Plant : PHWR (AECL); PWR Mitsubishi/Westinghouse), PWR (NPI) and BWR (GE/Toshiba/Hitachi) with "proven" status is recommended to be selected as the basis for nuclear power plants in Indonesia.

F. The fuel cycle selected is the open fuel cycle for a certain period until such time when the closed fuel cycle can one day become competitive.

G. The preferred site among the three candidates sites in the Muria Peninsula is Ujung Lemahabang.



PSDR	-	Preliminary Site Data Report
FSR	-	Feasibility Study Report
SDR	-	Site Data Report
PSAR	-	Preliminary Safety Analysis Report (Site Part)
EIAR	-	Environmental Impact Analysis Report
FR-SES	-	Final Report of Site and Environmental Study
FFSR	-	Final Feasibility Study Report

Figure-1. Time Schedule of the Feasibility Study for a Nuclear Power Plant in the Muria Peninsula Region

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REMARKS TO AND NEW PROPOSALS FOR THE APPLICATION OF VERY CO_2-RICH NATURAL GAS FROM THE NATUNA GAS FIELD IN INDONESIA

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Abstract

As a contribution to the discussion initiated in the HTR team of Indonesia on the application of gas from the NATUNA Gas Field remarks are made and new proposals. The new proposals are derived from variations in products and from additional feed-energy coal, with the result that in principle only heat energy is needed for the conversion processes. A new proposed product is Formic Acid CH_2O_2.

1. Overview on the Remarks and New Proposals

1.1 In summary: For economic reasons it is important that the conversion processes for gas from the NATUNA Gas Field consume only heat energy. This requirement is fulfilled by the new proposals: The new product Formic Acid CH_2O_2, and by the application of coal as additional feed-energy for the production of various products of gaseous and/or liquid physical state.

1.2. In detail on the various conversion processes and the differentiation of feed energy:

1.2.1. Gas from the NATUNA Gas Field in Indonesia has a very high content of carbondioxide CO_2; it is 71 %. The rest is methane CH_4, as well as some higher alcanes, and some nitrogene. For simplicity and convenience it is assumed in the following that such gas can be described by NA = 3 CH_4; 9 CO_2 with the concentration of carbondioxide CO_2 of 75 %, table 1.

1.2.2. For economical reasons it is necessary to differentiate conversion processes into those which need in principle electricity - for example via electrolysis of water -, and those which need in principle heat only. The reason is: electrolytic hydrogene is a by a factor of 3 to 5 more expensive than other fossil fuels. Therefore in table 1 the type of feed-energy is indicated on the left-hand side of each chemical reaction.

1.2.3. The proposals 1, 2, 3, table 1, line 1 to 3, have been discussed before, lit.: RUSLI-1995, and the proposals 4 and 5, table 1, line 4 and 5, are variations of 1, 2, 3. The proposal 2 includes the "reforming of CH_4 with CO_2", equivalent to $CH_4 + CO_2 = 2\ H_2 + 2\ CO$, as described in lit. FEDDERS-RIENSCHE-1985, p. 26, 27 for the calculation and p. 39 to 45 for a semi-technical experiment. The proposals 3 and 5 consume much electricity because they

TABLE 1

Application of very CO_2-rich natural gas
natural gas from the NATUNA Gas Field in Indonesia

N chemical reactions products	n phs	remark
1 NA +s = 3 CH_4 ; $(9CO_2)\downarrow$	1 g	1
2 NA+ h = 6 H_2+6CO+6CO_2	1 g	1 , 2
3 NA+ h +el +18H_2O = 9 CH_3OH+3CH_4+13.5O_2	3 l,g	1
4 NA+ h + 2 H_2O = 4 CH_3OH ; $(8CO_2)\downarrow$	1 l	
5 NA+ h +el +16H_2O = 12CH_3OH+12O_2	2 l,g	
6 NA+ h + 6 H_2O = 12CH_2O_2	1 l	
7 NA+ h +9CH = 3 CH_4+18CO+4.5H_2	1 g	3
8 NA+ h +6CH = 4,5CH_3OH+13.5CO	2 l,g	3
9 NA+ h +6CH+13,5H_2O = 4,5CH_3OH+13.5CH_2O_2	2 l,l	3

Explanation:

NA= ($3CH_4$; $9CO_2$) gas from NATUNA Gas Field, simplified form
CH= coal, simplified form
s = separation energy
h = heat energy
el = electricity
} from exogenous sources, e.g. HTR

n = number of products
phs= physical state of products: g = gasious, l = liquid

Remarks:

1) Lit.: RUSLI - 1995 , p.2 for the principle

2) includes reforming of CH_4 with CO_2
$CH_4+3CO_2+3H_2O = 2H_2+2CO+2CO_2+3H_2O$
Lit.: FEDDERS - RIENSCHE - 1985, p. 26, 27, 39-45

3) includes gasfication of caal with CO_2
$CH+CO_2 = 2CO+0.5H_2$

include the reverse combustion reaction of methanol via electrolysis of water, table 2, lines 4 and 4.1.to 4.3.

TABLE 2

Thermodynamics of „Splitting" for Energy carriers

N	chemical reaction			ΔH kJ/mol (25°C)	ΔG kJ/mol (25°C)	ΔS J/(K mol) (25°C)	$T_{\Delta G=0}$ K
1.1	H_2O_l	=	$H_2+0.5O_2$	285	237	164	1743
1.2	H_2O_g	=	$H_2+0.5O_2$	242	229	45	5438
2.1	CO_2	=	$CO+0.5O_2$	282	257	87	3260
2.2	CO_2	=	$C + O_2$	393	394	-3	∞
3.1	$CO_2+2H_2O_g$	=	$2H_2+CO+1.5O_2$	766	715	176	4365
3.2	$CO_2+2H_2O_l$	=	$2H_2+CO+1.5O_2$	852	731	413	2060
3.3	$CO_2+2H_2O_l$	=	$CH_3OH_l+1.5O_2$	724	702	80	3938
4	$CO_2+2H_2O_l$	=	$CH_3OH_l+1.5O_2$; x1/3	241	234	27	3938
4.1	H_2O_l	=	$H_2+0.5O_2$				
4.2	CO_2+H_2	=	$CO+H_2O$; x1/3				
4.3	$2H_2+CO$	=	CH_3OH ; x1/3				
5	$CO_2+2H_2O_l$	=	$1/6C_6H_{12}O_6+H_2O+O_2$	507	486	174	2913
5.1	$2H_2O_l$ +A	=	$A^* + O_2$				
5.2	CO_2 +A^*	=	A + $1/6C_6H_2O_6+H_2O$				
	$A^* = 2NADP^+ + 3(ADP+P)$						
	A = 2(NADPH+H+)+3ATP						
6	H_2O_l	=	$H_2+0.5O_2$				
6.1	H_2O_l +A	=	B $+H_2$				
6.2	B	=	A $+0.5O_2$				

ΔH, ΔG, ΔS Reaction Values:Enthalpy, Free-Enthalpy, Entropy at 25°C

$T_{\Delta G=0}$ = ΔH/ΔS Minimum T of Heat Source

$NADP^+$ = Nicotin amid-Adenin-Dinucleotid-Phosphat

ADP = Adenosin-Di-Phosphat

ATP = Adenosin-Tri-Phosphat

1.2.4. The new proposals 6 to 9, table 1, line 6 to 9, are in general characterized by the fact, that they in priciple do need only heat energy for the conversion process. This is achieved by the variation in the products for the proposals 6 and 9 and by the edition of coal as feed-energy in the proposals 7 to 9. Proposal 9 is a combination of proposals 6 and 8.

1.2.5. It is impossible to convert all C-atoms of the gas from the NATUNA Gas Field into methanol, even if coal is used as additional feed-energy, if only heat energy - and no electricity - should be used in the conversion process. The maximum production of methanol in a heat conversion process is achieved in proposals 8 and 9, table 1, line 8 and 9, with additional feed-energy coal.

1.2.6. The new proposed product Formic Acid CH_2O_2 is the only product, in which all C-atoms of the gas from the NATUNA Gas Field are converted into a liquid product with the condition that only heat energy is used in the conversion product. Formic Acid CH_2O_2 is an industrial product for chemical industry, it may be of interest in future as a fuel for fuel cells.

1.3. In extension on a hypothesis

1.3.1. The simple stochiometry of the reaction of proposal 6, table 1, line 6, $3\ CH_4 + 9\ CO_2 + 6\ H_2O = 12\ CH_2O_2$ leads to the hypothesis, that the gas of the NATUNA Gas Field might have been formed by a decomposition of Formic Acid or other Organic Acids, which are - of course - natural products in the biosphere.

2. On the Thermodynamics of "Splitting" of H_2O and CO_2

2.1 In summary: In the R & D work on thermo-chemical cycles for the splitting of base materials to produce secondary energy carriers from heat energy of high temperature the "splitting of carbondioxide CO_2" should also be considered in parallel to the "splitting of water H_2O", because it might be easier.

2.2. In detail on the various splitting reactions and thermochemical cycles:

2.2.1. Recently it has been proposed by Dr. A. Rusli, Nuclear Technology Assessment Centre, HTR team, to use the "reverse combustion of methanol", $CO_2 + 2\ H_2O_l = CH_3OH_l + 1.5\ O_2$, here table 2, line 3.3, as a "direct" process for the application of carbondioxide CO_2 from the gas of the NATUNA Gas Field, lit. RUSLI-1995, p. 6, eq. (10). This proposal includes the following question: Would such reaction (as the total reaction) be an "easier" thermo-chemical cycle than the thermo-chemical cycle for the "splitting of water", $H_2O = H_2 + 0.5\ O_2$?

2.2.2. The answer on this question is very interesting (and encouraging): yes, it is an "easier" thermochemical cycle, because the *"chemical equilibrium temperature"* T ($\Delta G = 0$) *for the* formation of synthesis gas, $2\ H_2 + CO$, for the production of methanol CH_3OH, table 2, line

3.1, is by about 1 000 K lower than that one for the splitting of water, table 2, line 1.2 (the difference of the two chemical equilibrium temperatures is 5 438 K - 4 365 K = 1 073 K). The comparative "easier" is ment here in the sense that production of heat-energy from a heat source is less difficult, if the temperature level for the produced heat is lower.

2.2.3. The proof for that conclusion is that the total reaction for the production for synthesis gas for methanol, line 3.1 in table 2, is a linear combination of the two splitting reactions for water H_2O and carbondioxide CO_2, lines 1.2 and 2.1 in table 2, and that the chemical equilibrium temperature $T(\Delta G = 0)$ for the splitting reaction of carbondioxide CO_2 is by about 2 000 K lower than that for water in the gaseous physical state (difference between the two chemical equilibrium temperatures is 5 438 K - 3 260 K = 2 178 K). In short-hand: carbondioxide CO_2 can easier be split into carbonmonoxide CO plus oxygen 0.5 O_2 than water in the gaseous physical state H_2O into hydrogen H_2 plus oxygen 0.5 O_2, because the splitting temperature is much lower.
Remark: For this kind of comparisons the reacting components must be taken in the relevant physical state, that is at higher temperatures - of course - the "gaseous" physical state. The values for the liquid physical state of water respectively of methanol, lines 1.1, 3.2 and 3.3. in table 2, have only been added for completeness, but are not relevant for comparisons of the chemical-equilibrium-temperatures of high temperature reactions.

2.2.4. The conclusion is: In the R & D work on thermo-chemical cycles for the splitting of base materials to produce secondary energy carriers from heat energy of high temperature the "splitting of carbondioxide CO_2" should also be considered in parallel to the "splitting of water H_2O", because its chemical equilibrium temperature is lower and therefore it might be easier.

2.2.5. For a direct comparison of the reaction values of the "reverse combustion reaction of methanol" with the splitting reactions of water and carbonmonoxide the reverse combustion reaction of methanol has been formulated for the "same number of mole of oxygen (1.5 O_2 x 1/3 = 0.5 O_2) in line 4, table 2, with e.g. a reaction enthalpy $\Delta H = 241$ kJ/mol. The practical formation of the overall reverse combustion reaction of methanol could consist of three basic processes: The electrolysis of water, line 4.1, the reverse-shift-reaction, line 4.2 and the methanol synthesis reaction, line 4.3 in table 2. In that case the energetic requirements for the overall reaction of the reverse combustion reaction of methanol, line 4 in table 2, are about the same as for the splitting of liquid water, line 1.1, table 2: much electricity is needed.

2.2.6. In contrary to the above conclusion on the splitting of carbondioxide it can be learnt from nature in the fotosynthesis of biomass (expressed in terms of RUSLI-1995: the reverse combustion reaction of glucose), line 5, table 2, that water is split into hydrogen and oxygen, and carbondioxide is used for the formation of glucose with the result that the oxygen comes from the water and not from the carbondioxide. The difference to the above given argumentation and conclusion is of course that the fotosynthesis of biomass is operated by the light-energy of the sun at about room temperature and not by heat-energy.

2.2.7. A thermochemical cycle for the splitting of carbonioxide CO_2 into carbonmonoxide CO plus oxygen 0.5 O_2 can in prinicple be formulated as given in line 6, and lines 6.1 and 6.2 of table 2 with A and B being reaction partners to be identified by research and development.

2.2.8. The goal of R and D on thermochemical cycles is - at first - to be economically competitive to the thermodynamical cycle (conversion of heat into electricity), that is to electricity and electricity-derived products, and - at second - to be economically competitive to other fossil fuels (which is vey difficult).

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