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Galaxy INC.

525 School Street, S.W., Washington, D. C. 20024

"ADDITIONAL RESEARCH ON ADVANCED R&D IN JAPAN"

TO:

THE U.S. DEPARTMENT OF ENERGY
IN ACCORDANCE WITH CONTRACT
NO. DE-AC03-79SF10538

August 1979

DISCLAIMER

ACO3-79SF10538

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"ADDITIONAL RESEARCH ON ADVANCED R&D IN JAPAN"

TO:
THE U. S. DEPARTMENT OF ENERGY
IN ACCORDANCE WITH CONTRACT #DE-AC03-79SF10538

BY

R.W. Straus, R.S. Thurman, J.N. Carsey, C. Fujishima,
and Staff Assistants

Galaxy Incorporated
525 School Street, S. W.
Washington, D.C. 20024

August 1979

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TELEX: 248461

August 1, 1979

Mr. Michael Perlsweig
Division of Fossil Fuel Utilization
Room E-178
U.S. Department of Energy
Washington, D.C. 20545

Re: Contract #DE-AC-03-79SF10538
Task #002

Dear Mr. Perlsweig;

We have the honor to transmit the topical report, "Additional Research on Advanced R&D in Japan" as required in Task 002 under the above contract.

As specified in Subsection A of this task, a preliminary report on "High Temperature Gas Turbines in Japan" was delivered on May 25, 1979.

On June 15th, a "Report on Foreign Travel" was forwarded in compliance with the travel regulations. An additional copy is attached hereto.

Copies of these reports to you and to the addressees specified in the contract documents, complete the work under Task 002.

Sincerely yours,

Robert Ware Straus
President

RWS:ju
Encls.: As described above. (3 copies)

cc: Conservation Division (1 copy)
San Francisco Operations Office.

Mail & Records Division (1 copy)
San Francisco Operations Office.

Ms. Kathleen Thurston (1 copy)
San Francisco Operations Office.

Ms. Margaret Garcia (1 copy)
San Francisco Operations Office.

Table of Contents

1. Introduction

This task was outlined in a request from DOE dated April 10, 1979. The assignment was confirmed by DOE on April 17, 1979.

Galaxy's senior personnel held extensive discussions with Fossil Fuel Utilization Project Managers immediately thereafter. These conferences defined specific parts of technologies in which there was particular interest.

The request was then transmitted to Galaxy-NJM in Tokyo. A Galaxy senior staff member was sent to Tokyo May 7th-16th for conferences with the Dr. Fujishima staff assigned to this task and led interviews with public officials and corporate officers of companies involved in the work under study.

The report was prepared by Dr. Fujishima and his staff in Tokyo and translated into English in Japan.

The report was reviewed and edited by the Galaxy staff in Washington. Where the translated usage is perfectly clear, but not in English vernacular, no attempts have been made to change it. However, in cases where it might be unclear to those unused to translations, it has been changed.

The word "rationalization" appears repeatedly in the translations. Rationalization, as used by the Japanese Government and industry, is a shorthand, meaning the use of scientific principles for management, planning and manufacturing aimed to obtain maximum production at the lowest possible costs and embraces every step balanced to achieve optimal results. It also involves the Japanese concept of "consensus", meaning that everyone must agree before a project becomes operational.

Also frequently used is the name "MITI", which designates the Ministry of International Trade and Industry. The Agency of Industrial Science and Technology is a division of MITI.

It is obvious that the Japanese high temperature, high pressure turbine program is considerably more ambitious than the program now scheduled in the U.S.A. A preliminary examination of the Japanese high temperature turbine program was carried out by Galaxy. The preliminary report ("Report of Foreign Travel") on this is attached hereto as Appendix A and has proved useful in evaluating that program.

Dr. Fujishima's thoughtful and revealing introduction gives insights into the Japanese approach to technology development and the role of the government in guiding the work.

As usual, Galaxy is prepared to follow-up in depth on the preliminary reports of the Fossil based technologies in this initial sweep, upon request of DOE.

2-1 Scope of Work

The Scope of Work was defined by the Fossil Fuel Utilization Division's memorandum dated April 10th, on Task 002, as follows:

"A. High Temperature Gas Turbines

It is our understanding now that Japan is undertaking a greatly expanded ultra high temperature gas turbine program. This program is designed to provide a technology, causing little environmental effect and very high efficiencies. It is reported they are aiming for inlet temperatures from 2,500 degrees to 3,000 degrees F. We particularly desire to be informed as to the basic concepts of the program with emphasis on the following items:

1. What type of blade cooling, whether water or air transpiration?

2. Type of fuel. Are the designs such that they are to utilize lower grade heavy fuels, the bottom ends, or coal?

"3. What is their approach for controlling NO_x? Is it catalytic combustion, staged rich burning, or exhaust gas cleanup?

4. What are their plans for demonstrating the technology or the complete engine?

5. What are the details on the schedule or the development of materials, cooling methods, prototypes, commercial sized installations?

As this technology is of great interest to this division, we would appreciate preparation of a report in two sections. The preliminary report is to be delivered on or before the 1st of June and will deal with the concepts, the technical problems, and in a preliminary way, with the schedules, the milestones and the funding profile. This should be followed with a more detailed report which should be in our hands by the end of July.

B. <u>Environmental Control</u>

In addition to the above items, we desire details on the state-of-the-art in Japan of cleanup of exhaust gases from turbines, particularly in SO_2, NO_x, and particulates less than 1 micron, instrumentation and control for scrubber.

Japan has very tight environmental standards. We would like to have copies (in English) of their environmental standards, as promulgated by Japanese Environmental Protection Agency. It is known here that Japan pioneered the use of scrubbers. We would like comprehensive report on the state-of-the-art and performances, specifying what fuels are used, the sulfur content, the treatment of the waste stream, the removal of sulfur, NO_x, particulates less than 1 micron, instrumentation and control of scrubber, the problems of maintenance, the onstream availability, and disposal of waste sludges, including the prevention of leaching at disposal. This report should cover the state-of-the-art, both in cleanup of combustion for steam generation, and in gas turbines.

C. Fluidized Bed Combustion

Prepare a preliminary report on the state-of-the-art in fluidized bed combustion, covering the pressurized and atmospheric FBC in Japan. The report should cover the advanced work going on in Japan. Is the work on laboratory scale; are the prototype units being scheduled; is there a schedule for commercial size test?

D. <u>Fuel Cells</u>

The division is not aware of any advanced work in fuel cells, beyond a subcontract by the Japanese firm Toyo Engineering, with UTC here under a subcontract from EPRI. We would appreciate a preliminary report as to any developments in Japan on advanced RD&D fuel cell work.

The main objective of the above tasks is to report Government and private RD&D programs in the areas outlined and identify the technical data and expertise which could benefit our domestic program.

2-2 Methodology

In accordance with Galaxy's standard procedures, the work commenced with a review of Galaxy's extensive files on developments in Japan. This was followed by detailed review of the task with DOE's technical staff.

Thereafter, a Galaxy senior staff member was sent to Japan for discussions with Dr. Fujishima and the staff already assigned to and working on this project. Also, the senior staff member led the necessary high level meetings with officials in the public and private sector, called for by Japanese custom to "open the doors" for the technical staff.

The subsequent face-to-face interviews carried out by the Japanese staff, obviated the necessity for interpreters and completed the niceties and protocol required by Japanese custom.

The interviews covering the items listed in the "Scope of Work", were held with technical and planning personnel of the following governmental organizations, government supported research institutes, universities and private industries.

A. <u>Governmental Organization</u>

1. Agency of Industrial Science and Technology of MITI

   Mr. Hiroshi Takahashi

   Director of Moonlight Projects

   Mr. Tatsumi Ueyama

   in charge of Gas Turbine

   Mr. Seiji Iwata

   in charge of Fuel Cell

2. Agency of Natural Resources and Energy of MITI

   Mr. Hikaru Hayashi

   (Fluidized bed combustion and other items)

3. National Electrotechnical Laboratory

   Dr. Hiroyuki Sato

   (fuel cell)

4. Prof. Kazuo Fueki

   Department of Industrial Chemistry

   Faculty of Engineering

   Tokyo University

   (fuel cell)

5. National Research Institute for Pollution and Resources
   (fluidized bed combustion)

6. National Aerospace Laboratory
   Mr. Masakatsu Matsuki
   (gas turbine)

7. National Research Institute for Metals
   Mr. Michio Yamazaki
   (gas turbine)

8. Governmental Industrial Research Institutes of Tokyo, Osaka, Nagoya, Hokkaido
   (all items)

B. Private Enterprizes

Gas Turbine

1. Central Research Institute of Electric Power Industry
   Dr. Tadashi Hatano
2. Mitsubishi Heavy Industries Ltd.
3. Ishikawajima-Harima Heavy Industries Co., Ltd.
4. Kobe Steel Ltd.
5. Hitachi, Ltd.
6. Kawasaki Heavy Industries, Ltd.

Environmental Control

1. Industrial Pollution Control Association
2. Ishikawajima-Harima Heavy Industries Co., Ltd.
3. Mitsubishi Heavy Industries Ltd.
4. Sumitomo Shipbuilding & Machinery Co., Ltd.

Fluidized Bed Combustion

1. Hitachi, Ltd.
2. Kawasaki Heavy Industries Ltd.
3. Mitsubishi Heavy Industries Ltd.

Fuel Cell

1. Central Research Institute of Electric Power Industry
2. Fuji Heavy Industries Ltd.
3. Hitachi, Ltd.
4. The Tokyo Electric Power Company, Inc.
5. Tokyo Gas Co., Ltd.

3. Summary and Conclusions

Soaring price of petroleum is about to change the conventional values of existing technologies substantially. And the prediction of possible extinction of petroleum resources in future drives mankind to do develop new sources of energy.

Not awaiting the opportunity of the Tokyo Summit, the problem of future energy supply has ever been a serious matter of concern for Japan, and the development of new energies and save-energy technologies is an urgent importance for her, without a moment delay to be allowed to be lost.

The Environmental Control technologies, the main theme of this survey have been achieved by industries through their every investigation and development in order to cope with the government's environmental requirements which are generally recognized as being the severest in the world, as a countermeasure against the environmental devastation which was brought about rapidly during Japan's experience of her high economy growth until the oil crisis of 1973, greatly accelerated by the factor of Japanese territorial or geographical narrowness. Of course, the achievement was attained by introduction of various technologies developed in the Western countries and at the same time, by particular efforts for improvement and development to adapt to the Japanese specific environmental conditions. In fact, Japanese sky and waters have regained old clearness, by virtue of various economical technologies for emission desulfurization, NO_x removal, waste water treatment, harmful heavy metals treatment, etc. These had been adopted by private industries and are being operated with probably most advanced level of technology in the world. This goal has been attained through hard experience and overcoming technical difficulty.

The R&D on the technologies of the advanced gas turbine, fluidized bed combustion system and fuel cells have, as a part of the Sunshine Project and Moonlight Project of the MITI, finished their basic study and are about to enter into a stage of pilot plant for practical purposes. Especially, the Fluidized bed combustion system and Fuel cell developments will hereafter receive increasing attentions of the government who would favor with investment of money for the development, in consideration of their possibility of utilization of coal energy.

The following descriptions are conclusions on the R & D status in Japan.

1) The R & D of High efficiency Gas turbine is one of the Japanese big projects, which started in 1978, with a discussed and then agreed objective for the 1st stage being 55% in the over-all efficiency but does place little emphasis on utilization of coal gas nor heavy residue oil as feeding material. Currently, with a cooperation of an association named "Engineering Research Association for Advanced Gas Turbine" which is constituted of governmental research laboratories and 14 private companies, such basic studies as heat resistant and corrosion resistant material study and structural study are going on stream.

In parallel with the said studies, the studies on various design parameters for a practical plant are also under way. The project is scheduled such that a full-scale system designing will start in 1982 fiscal year (April, 1982 - March, 1983), construction of demonstration plant be commenced in 1983 fiscal year and in 1984 the demonstration plant will be operational.

2) Environmental Controls

It is observed that as a result of the past hard endeavors by industries, Japanese technologies on environment preservation have almost come to stay on certain type industries. However, in future when coal will be used as a substitute for petroleum, it would become a problem how the conventional, established unit technologies could be economically adapted into system operation.

In desulphurization, currently the Lime Process, wet method is considered most optimal. On the other hand, however, the dry method also gets to be thought better of from the save-energy view point. As for denitration, the dry catalytic reduction process to use NH_3 as a reducing agent is currently deemed to be the most pertinent method and for soot and dirt removal, the bag filter and the electric collection systems are commonly employed. Collected pollutants are treated by either being reclaimed(for the unharmful), or cement-solidified(for the harmful metals).

All of the systems of removing sulphur, nitrogen and soots and dirts are operated full automatically.

3) Fluidized bed Combustion System

Three kinds of Project, classified by the objectives, are currently under way. One of them is a High calorie coal gasification being developed by the National Research Institute for Pollution and Resources and Hitachi, Ltd, as a subproject under the MITI's Sunshine Project. Based on the results of a small experimental equipment of 50 m^3/day, a 7000 m^3/day pilot plant is now being constructed. This is a pressurizing fluidized gasification system of 30 kg/cm^2 pressure.

The second project is a multi-purpose fluidized furnace which can treat wastes and regenerate of used activated carbon. This is still on laboratory scale in progress. The third project is a study by the National Research Institute for Coal Technology. This study does not belong to the MITI's Sunshine Project but is administered by MITI's Coal Bureau and is aimed at low calorie gas production, where common grade coal is first pulverized and added with air and steam of 10 atm. into a pressurized fluidized furnace wherein gasification is occurred.

A 40 t/day plant is scheduled to commence construction in fiscal 1979 with cooperation of Mitsubishi Heavy Industries, expecting operation in 1979 fiscal year. After the operation for a year or two, it is planned that a 100 t/ - 200 t/day verification furnace will be constructed.

4) Fuel Cells

Japanese Fuel Cell R & D is, as a part of the MITI's Sunshine Project, being developed for utilizing the hydrogen energy. The focus of development is centered principally on the first generation Alkaline electrolyte Fuel cells and the third generation solid electrolyte Fuel cells. U.S. UTC's technical development in the first generation phosphate electrolyte Fuel Cells is on stream much far ahead of Japanese development and it will be most probable that Japan will be ready to have the technical fruits of the U.S. Target Program and FCG-1 program introduced to Japan.

Among the basic studies of Solid electrolyte Fuel Cell, the promising results of the study by the National Electrotechnical Laboratory are to be remarked for a future possible practical success in application but it appears still it would require a considerable time before realization of the practical applications will be successful.

The R & D on the second generation molten carbonate electrolyte Fuel Cell is not yet conducted in Japan presently. However, it is very probable that this item, as a high efficiency dispersed power generation system technology, would be taken up to be involved into the MITI's Moonlight Project.

As discussed above, much R & D is situated on a transient step shifting from a basic study to a practical application study and it is expected that with a policy of government increasing the amount of investment for R & D, it would take less time than scheduled before the aimed results of the respective developments would be attained successfully.

4. Survey of High Temperature Gas Turbines

4. Survey on High-Temperature Gas Turbine.

4-1 Introduction

The development of high-temperature high-efficiency gas turbine has been being propelled by the nation as part of "Moonlight Project" led by MITI's Agency of Industrial Science and Technology.
Effort to work out a concrete plan to develop the system of this equipment is now being exerted by a group with Mr. Seiji Iwata, R & D official in Moonlight Project Office of the Agency as its leader.

The national researching organizations which have taken part in this development work are 5; including Science and Technology Agency's National Aerospace Laboratory (Driving Machinery Department, whose manager is Mr. Masakatsu Matsuki) and National Research Institute for Metals (Steel Materials Researching Department's 3rd Steel Laboratory whose chief is Michio Yamazaki) and MITI's Agency of Industrial Science and Technology's Industrial and Technical Research Institute of Nagoya (5th Division whose manager is Mr. Hiroshi Okuda), Industrial and

Technical Research Institute of Osaka (Heat-Resistant Materials Researching Laboratory which is represented by its chief researcher Mr. Yasuo Hibata) and Industrial and Technical Research Institute of Kyushu (Machinery & Metalic Materials Department which is represented by its 1st section chief Mr. Kazuo Kobayashi. 14 manufacturing firms also have taken part in this development work and organized "Engineering Research Association for Advanced Gas Turbines" on the ground of Paragraph 1 in Article 8, Mining and Manufacturing Technologies Researching Association's Law by MITI. The 14 firms include Asahi Glass Company, Limited, Ishikawajima-Harima Heavy Industries Co., Ltd., Kobe Steel, Ltd., Daido Steel Co., Ltd. Kawasaki Heavy Industries, Ltd., Kyoto Ceramics Co., Ltd., Central Research Institute of Electric Power Industry, Tokyo Shibaura Electric Co., Ltd., NGK Insulators Ltd., Hitachi Metals, Ltd., Hitachi, Ltd., Mitsui Shipbuilding & engineering Co., Ltd., Mitsubishi Metal Co., Ltd. ('s Central Research Laboratory) and Mitsubishi Heavy Industries, Ltd.

Among the above organizations and firms, Central Research Institute of Electric Power Industry represents users;
Science and Technology Agency's National Aerospace

Laboratory, Ishikawajima-Harima Heavy Industries, Kawasaki Heavy Industries, Hitachi, Mitsui Shipbuilding & Engineering and Mitsubishi Heavy Industries are in charge of the field of gas turbine system;
Science and Technology Agency's National Research Institute for Metals, Kobe Steel, Daido Steel Co., Ltd., Hitachi Metals and Mitsubishi Metal's Central Research Laboratory in charge of the field of metallic materials and MITI's Agency of Industrial Science and Technology's Industrial and Technical Research Institute of Nagoya, same of Osaka, same of Kyushu, Asahi Glass, Kyoto Ceramics, Tokyo Shibaura Electric and NGK Insulators in charge of the field of inorganic materials.

The detail of "The Engineering Research Association for Advanced Gas Turbines" is mentioned in the following item.

4-1-1 DESCRIPTION

of

The Engineering Research Association For Advanced Gas Turbines.

[*Association of High Efficiency Gas Turbine Technical Researchers]

A Outline of formation of the Association

1. Name: (Engineering Research Association for Advanced Gas Turbines.)
2. Establishment: Sept. 29, 1978
3. Objective: The association has for its object researches and experiments by cooperative works of the Association members on Advanced Gas Turbines and other operations which may bring about a raise of technical level of the members.
4. Members: (Name, Address and Representative)

   Asahi Glass Company, Ltd.

   2-1-2 Marunouchi Chiyoda-ku, Tokyo

   Hideaki Yamashita, President

Ishikawajima-Harima Heavy Industries Co., Ltd.

2-2-1 Otemachi, Chiyoda-ku, Tokyo

Hisashi Shinto, President

Kawasaki Heavy Industries, Ltd.

14 Higashi Kawasakicho 2-chome, Ikuta-ku, Kobe

Zenji Umeda, President

Kyoto Ceramic Co., Ltd.

52-11 Higashino-Inouyecho, Yamashina-ku, Kyoto

Kazuo Inamori, President

Kobe Steel, Ltd.

1-3-18 Wakihamacho, Fukiai-ku, Kobe

Kokichi Takahashi, President

Daido Steel Co., Ltd.

1-11-18 Nishiki, Naka-ku, Nagoya

Kizo Takeda, President

Central Research Institute of Electric Power Industry

1-6-2 Otemachi, Chiyoda-ku, Tokyo

Michio Yokoyama, Director General

Tokyo Shibaura Electric Co., Ltd.

72 Horikawacho, Saiwaiku, Kawasaki

Kazuo Iwata, President

NGK Insulators, Ltd.

2-56 Sudacho Mizuho-ku, Nagoya

Junichi Takemi, President

Hitachi Metals, Ltd.

2-1-2 Marubouchi, Chiyoda-ku, Tokyo

Sukeo Kono, President

Hitachi, Ltd.

1-5-1 Marunouchi, Chiyoda-ku, Tokyo

Hirokichi Yoshiyama, President

Mitsui Shipbuilding and Engineering Co., Ltd.

5-6-4 Tsukiji, Chuo-ku, Tokyo

Isamu Yamashita, President

Mitsubishi Metal Central Laboratory, Ltd.

1-5-2 Otemachi, Chiyoda-ku, Tokyo

Yoshihiro Inai, President

Mitsubishi Heavy Industries, Ltd.
2-5-1 Marunouchi, Chiyoda-ku, Tokyo
Masao Kanamori, President

5. Directors: (Title in Association, Name, Company and Title in Company)

Director General, Yoshio Shomura
Central Research
Institute of Electric Power Industry
Deputy Director General

Vice Director General, Osamu Nagano
Ishikawajima-Harima Heavy Industries, Ltd.
Counselor

Vice Director General, Concurrently Executive Director
Katsuyoshi Yoshikai (full-timer)

Vice Executive Director, Shoji Hori (full-timer)

Vice Executive Director, Hiroshi Nakata (full-timer)

6. Advisers: (Name, Organization and Title)

Takahiro Ishida
Federation of Electric Utility
Chief of Engineering Department

Hoshi Urata
Japan Gas Turbine Academy, Chairman

Hiroshi Okuda
Agency of Industrial Science and Technology
Industrial Research Institute, Nagoya
Chief of Fifth Department

Tadao Torizaki
Science and Technology Agency
National Aerospace Laboratory
General Researcher

Keizo Hatta
Tokyo University, Honorary Professor

Masaru Hirata
Tokyo University, Professor

Masakatsu Matsuki
Science and Technology Agency
National Aerospace Laboratory, Chief of Engine Department

Michio Yamazaki
Science and Technology Agency
National Research Institute of Metals
Iron and Steel Material Research Department
Chief of Iron and Steel Third Laboratory

7. Location of Office:

1-1-3 Shiba-Daimon, Minato-ku, Tokyo
(Japanese Red Cross Society Building)
Tel.: 03-437-9261 (Key No.)

8. Staff (as of Dec. 1, 1978):

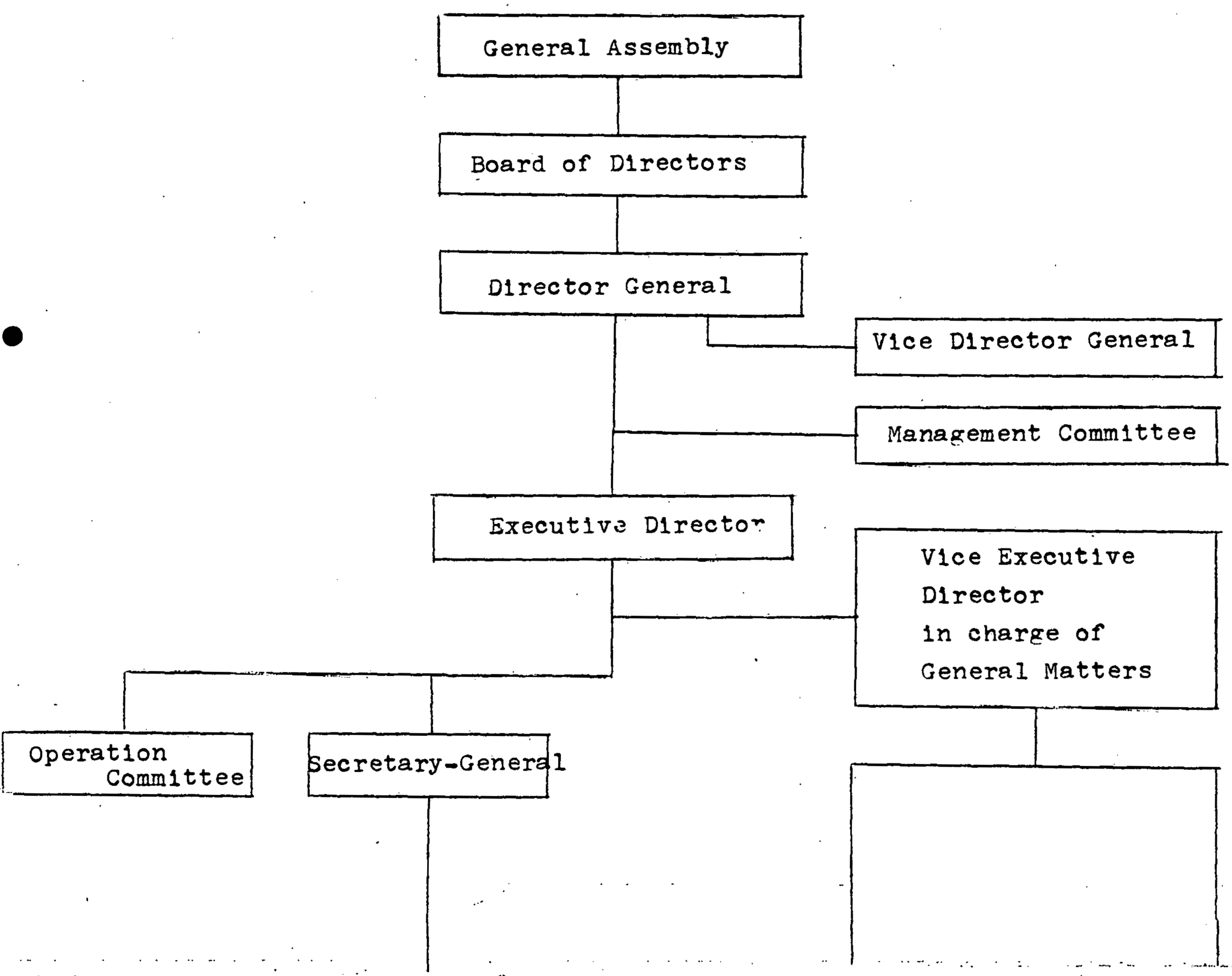
Male: 8 (including personnels on loan from member companies.)
Female: 3
Total: 11

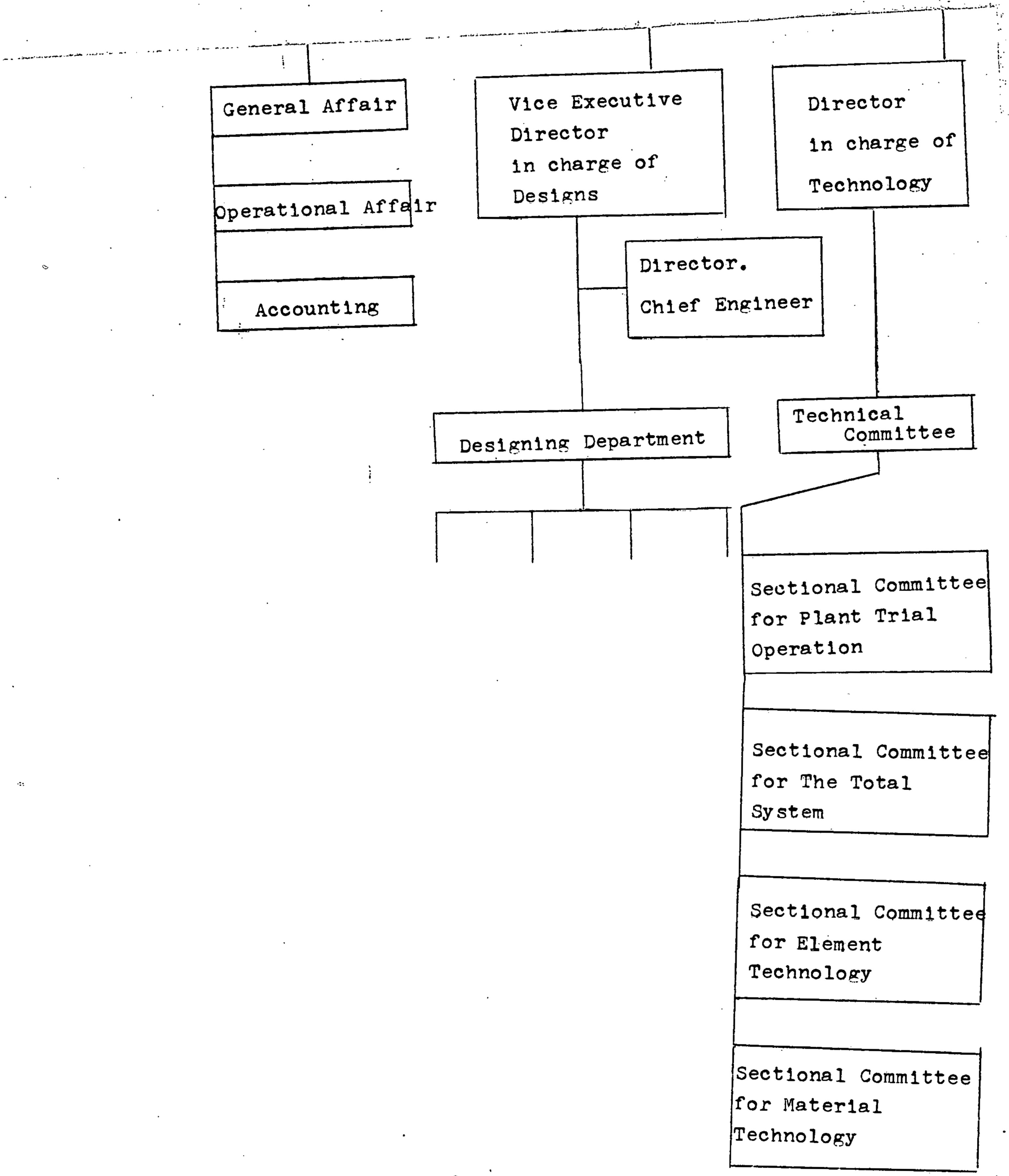
9. Banks: The Daiichi -Kangyo Bank, Ltd., Hamamatsucho Branch

The Mitsui Bank, Ltd., Hibiya Branch

The Mitsubishi Bank, Ltd., Otemachi Branch

10. Organization:




General Affair
Operational Affair
Accounting
Vice Executive Director in charge of Designs
Director. Chief Engineer
Designing Department
Director in charge of Technology
Technical Committee
Sectional Committee for Plant Trial Operation
Sectional Committee for The Total System
Sectional Committee for Element Technology
Sectional Committee for Material Technology

B <u>Outline of workings of the Association</u>

1. Objectives

(1) To undertake researches and experiments on Advanced Gas Turbines for the members.

(2) To administer the fruits of the actions stated in (1) above for the members.

(3) To undertake technical guidance for the members.

(4) To allow the members to use the facilities for the research and experimentation.

(5) To undertake environmental verification survey for combined Gas and Steam power plants and other operations in connection with the operations set forth in the above paragraphs.

2. The objectives of the research and experimentation.

For our nation wherein a great amount of energy is consumed, we are responsible to positively promoting development for save-energy technologies. For this purpose, it is necessary to make long strides in heat efficiency improvement of a heat engine with which energy is to be converted. Considering the fact that the heat efficiency of the current heat engines for power generation has already almost reached to its limit, future heat efficiency improvement should be achieved by gas-steam combined cycle power plants.
In the light of this requirement, the Association, a technical research organization, will conduct research and development of an advanced high efficiency gas turbine which is a nuleus of the high efficency combined cycle system, and other researches in relation to this area as well.

3. Itemized objectives of the research and development.

(1) R & D on super high-temperature resistive material.

(2) R & D on element technology of Gas Turbines.

(3) Test making, verification and operation study of Advanced high efficiency Gas Turbines.

(4) R & D on optimal total energy supplying system.

(5) General experiments and researches.

4. Practical research scheme

Item \ Fiscal year	1978	1979	1980	1981	1982	1983	1984
(1) R & D on super high temperature resistant material:				Interim evaluation			
R & D on heat resistant alloy components	●———	———	———→		———	———	———→
R & D on heat risistant ceramic components	●———	———	———→		———	———	———→
(2) R & D on Gas Turbine element technology:							
Compressor technology		●———	———→		———	———	———→
Combustor technology		●———	———→		———	———	———→
Heat exchanger technology		●———	———→		———	———	———→
Turbine cooling technology	●———	———	———→		———	———	———→
Turbine airodynamics technology		●———	———→		———	———	———→
Control technology		●———	———→		———	———	———→
Reliability, Maintenance technology		●———	———→		———	———	———→
(3) Advanced Gas Turbine Trial manufacture, Verification test, Operation study:							
Pilot plant		●———	———→		———	———	———→
Prototype plant					●———	———	———→
(4) Study on optimal total energy supplying system:							
Study on combined power generation system	●———	———	———→		———	———	———→
Study on total energy supplying system		●———	———→		———	———	———→
(5) General Study and experiments:	●———	———	———	———	———	———	———→

4-2 What type of blade cooling system is planned ? Water cooling or air cooling ?

Both metallic and ceramic materials are now in parallel under research and development to use them for the turbine blade which is the heart of a gas turbine. It is aimed as the final concept that ceramic materials would be used in the hot sections which need high heat-resistance and heat-resistant alloys would be used in the sections which need breaking strength more than high heat-resistance. In such a concept, cooling is to be applied to the sections made of metallic materials and not to be applied to the ceramic sections.

This hybrid blade system as above described is one of the new trials which have been proposed in "Moonlight Project". Ceramic materials are excellent in heat-resistance but poor in both breaking strength and toughness. Such metallic materials as used in conventional gas turbines have problems related to heat resistance which should be solved in future. However, thanks to their good toughness, use of such metallic materials for moving blade would allow the structure where the opening between the moving blade's edge and the casing's inside surface is minimized. Even if contact should occur between the moving blade and the casing, satisfactory operation would be secured by the good flexibility of metallic materials. If ceramic material were used for a moving blade, there would be a fear that damage may occur in some part of the blade when it contacts the casing, because of insufficient flexibility of such material. If the opening between the ceramic moving blade's edge and the casing's inside surface is set wider than in the case of using metallic material for the moving blade, it would eliminate such a fear of damage but result in more pressure loss which would reduce the efficiency. It is therefore planned that metallic material would be used for the most outside layer of the section of the moving blade which may come into contact with the casing and that ceramic material would be used for the inner core section which requires heat-resistant property most. Besides for the moving blade, ceramic material is planned to be used for the stationary blade (mainly at the inlet side of the turbine) also.

4-2-1 Concerning Blade Cooling

To attain a high turbine inlet temperature, the metallic material used in the turbine blade is required to have enough heat-resistance. In addition, the heat-resistant alloy material for a gas turbine is needed to be improved about the creep rupture strength against high temperature of combustion gas and tensile stress by centrifugal force, the resistance to high-temperature sulfurizing corrosion possibly caused by combustion gas and the strength against thermal cycle fatigue resulting from repetition of start-up and stoppage. It is also required to have enough performance in such other properties as thermal expansion coefficient and weldability.

These alloys also require application of such treating technologies as directional solidification and HIP (Hot Isostatic Press) to make improvement and reduce variation in their performances. (Directional Solidification Method is a process where metal is crystallized with its crystals oriented in one direction. This method has recently

been considered promising in particular as a useful method for manufacturing high-temperature heat-resistant materials.)
Depending on the sections where these alloys are used, they sometimes need also application of such coating processes as packing, (which is a process where a layer of heat-resistant material is applied onto the surface, plasma arc, CVD, (Chemical Vaporized Deposit), PVD, (Physical Vaporized Deposit), etc. and are very difficult to incorporate into a cooling device.

In principle, a water cooling method is scheduled to be adopted because the gas turbine is installed at a fixed place on the ground and can be much larger in size and weight than that used in an airplane.
This cooling method is composed of letting pressurized water added with rust preventive, etc, pass through the inside of the blade to cool it, then recooling the water by removing heat through a heat exchanger and then sending the cooled water back into the blade's inside. However, development has not so far been attained on the technology to provide a cavity for water passage to the inside of the metal blade which has undergone various kinds of surface treatments and composition modifications. It is necessary to establish

a material which would have no remaining strain inside it even if it undergoes such treatments as HIP after having been fabricated to the shape of blade with a cooling water passage inside. It is attempted to establish an outlook for such a technical feasibility. Currently, development is under way on the melting stock to attain control of alloy composition as well as on the precise casting technology for large-sized blades.

In every effort above, it can be considered that focus has been placed on the research aimed for "water cooling method".

Besides the water cooling method, there are some other cooling methods including air cooling and steam cooling. However, these other methods are still only at a stage where ideas for them are discussed. Though it has been planned that research works centering on simulation study are conducted also concerning air cooling and steam cool . methods, the favorite has been the water cooling method. It is because there are such merits that the water used for cooling can be reused to preheat water for a steam turbine.

The reason why the idea of air cooling has been discussed is that a good result was obtained on the fanjet engine for aircraft which was developed as a large-scale project. However, there is no need to use air for the high-temperature gas turbine which is installed on the ground. Though researches including trial production are performed also on air cooling and steam cooling, they should be considered to be done just to know the possibility of those methods. The Outline Report previously submitted stated that the researches for air cooling and steam cooling would proceed in Fiscal 1978 and 1979. However, as mentioned above, the biggest emphasis in research for practical application has been placed on the water cooling.

4-3 What kind of fuel is planned to be used ? Low-grade heavier oil, residual oil or coal ?

The development project for the high-temperature high-efficiency gas turbine has been offered with the aim at elevating the fuel efficiency of existing electric power generating systems . It is characterized by a desire to increase the fuel efficiency from a little below 40% in a most up-to-data thermal power generation plant and 20-30% in a simple power generater to more than 50% with same fuel. Thus, the target by the combined cycle power generation has been set at 55% on the condition of using heavy oil as the fuel.

When fund is spent with a target set in a national project, the primary object is exclusively to attain the target. If it should turn out impossible to accomplish the aimed efficiency by using low-grade oil as the fuel, it would affect the prestige of Agency of Industrial Science and Technology*. Therefore, in the initial plan, the research work has been designed to be concentrated only on utilizing distillates oil as the fuel and on developing the know-how for such utilization. However, in view of the anxiety about securing energy in

* This is important in Japan.

the future, it obviously can not be permitted to rely only on heavy oil for the fuel. The most important feature for a gas turbine should be that it can use whatever kind of fuel. Thus, it would be natural to consider developing such a feature.

As to residual oil, the prevailing opinion is that, since the demand for this material is expected to remain large also from now on in application as asphalt which has so far been mainly used to pave most roads in the nation, there would be little room for this oil to be utilized as fuel. On the other hand, use of low-grade heavier oil involves the problem of the damage to the turbine blade, casing, etc. which may possibly be caused by corrosive substances contained in the combustion exhaust gas since this kind of oil contains a large content of such corrosive sources as sulfides. As to such technologies as improvement of structural materials, since they are not of the nature which can be developed in a short period, the schedule for them has been designed on a long-term basis. Development works for such technologies are planned to be materialized after having accomplished (1) efficiency of 55% and (2) use of other alternative fuels.

The most promising alternative energy resourse is coal. As a project using coal, a high-calorie gasification (pilot) plant with a capacity of 7000 m^3/day has been put into construction in the city of Iwaki, Fukushima Prefecture in northeastern Japan since fiscal 1979*, under the "Sunshine Project". MITI's Agency of Industrial Science and Technology has planned to use the gas from this pilot plant as the fuel for the composite cycle power generation and to adopt the high-temperature gas turbine as the generator. It is planned in this power generation system that, with the configuration of connecting the high-temperature gas turbine directly to the coal gasification plant, the produced gas would, while being kept hot, be put into combustion, the gas turbine would be run by the combustion gas and a steam turbine would be run by the steam obtained through heat exchange to utilize the waste heat borne by the exhaust gas from the gas turbine. This design is expected to reduce harmful substances in the exhaust gas and to facilitate pollution control and system maintenance.

Besides the above, the plan for the high-temperature high-efficient gas turbine also includes using kerosine and gas oil, natural gas, blast furnace gas

*April 1979 to March 1980.

and coke oven gas. However, there has not yet been any concrete move taken about these alternative fuel sources.

4-4

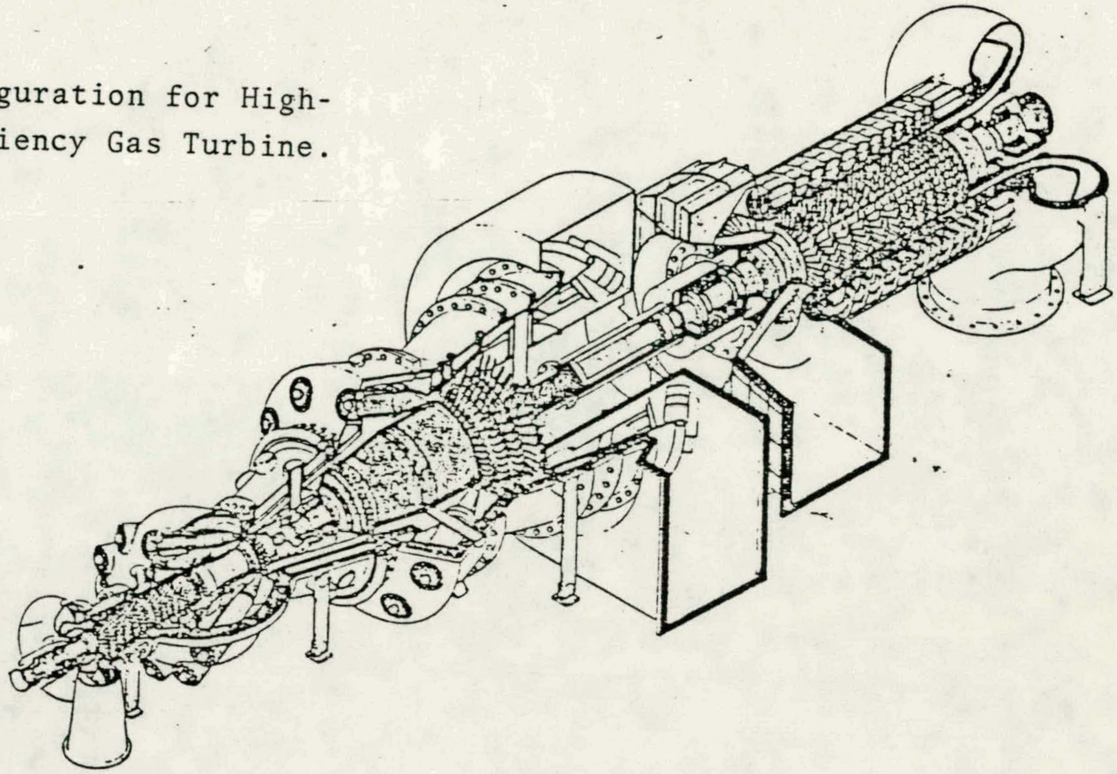
<u>What measures have been planned to control NOx in exhaust gas ?</u>

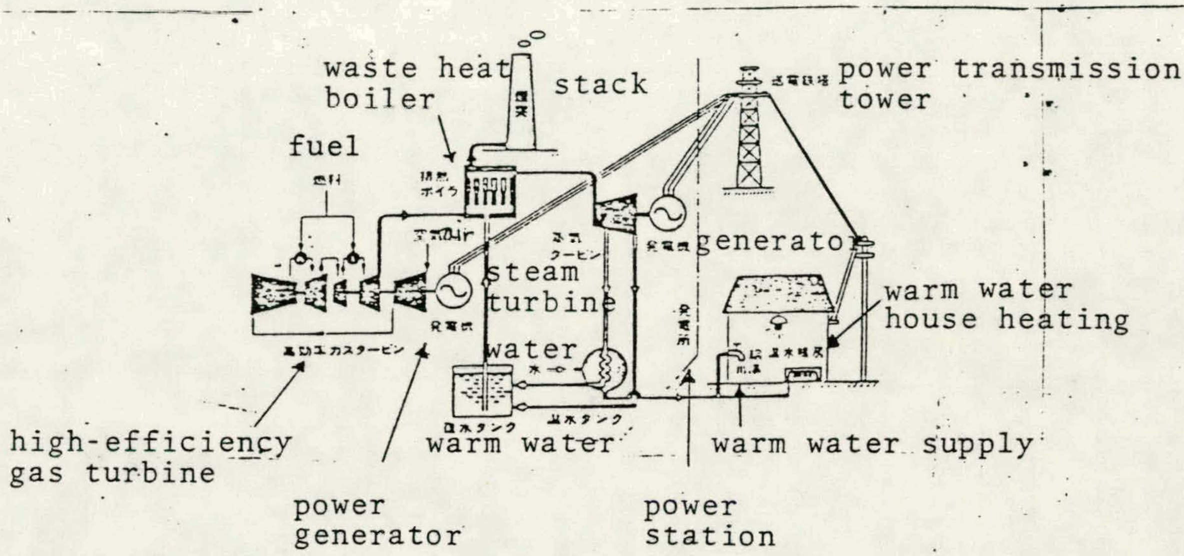
<u>Such as contact combustion, stepwise pollution-eliminating combustion and exhaust gas clarification</u>.

Production of NOx is unavoidable as long as heavy oil, kerosine, gas oil or natural gas is used as fuel. It is expected that such fuel as gas from coal gasification which is small in nitrogen (fuel N) content will be used in the future. However, even in such a case, high-temperature combustion with the turbine inlet temperature of 1500°C would involve the problem of thermal N producing.

The configuration as shown in the sketches attached, has been planned for the high-efficiency gas turbine by MITI's Agency of Industrial Science and Technology. In the system by this configuration, hot gas at a little over 1500°C is generated by combustion of fuel and air pressurized by a compressor and is jetted to the turbine blades.

Configuration for High-efficiency Gas Turbine.




waste heat boiler
stack
power transmission tower
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water
high-efficiency gas turbine
warm water
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power generator
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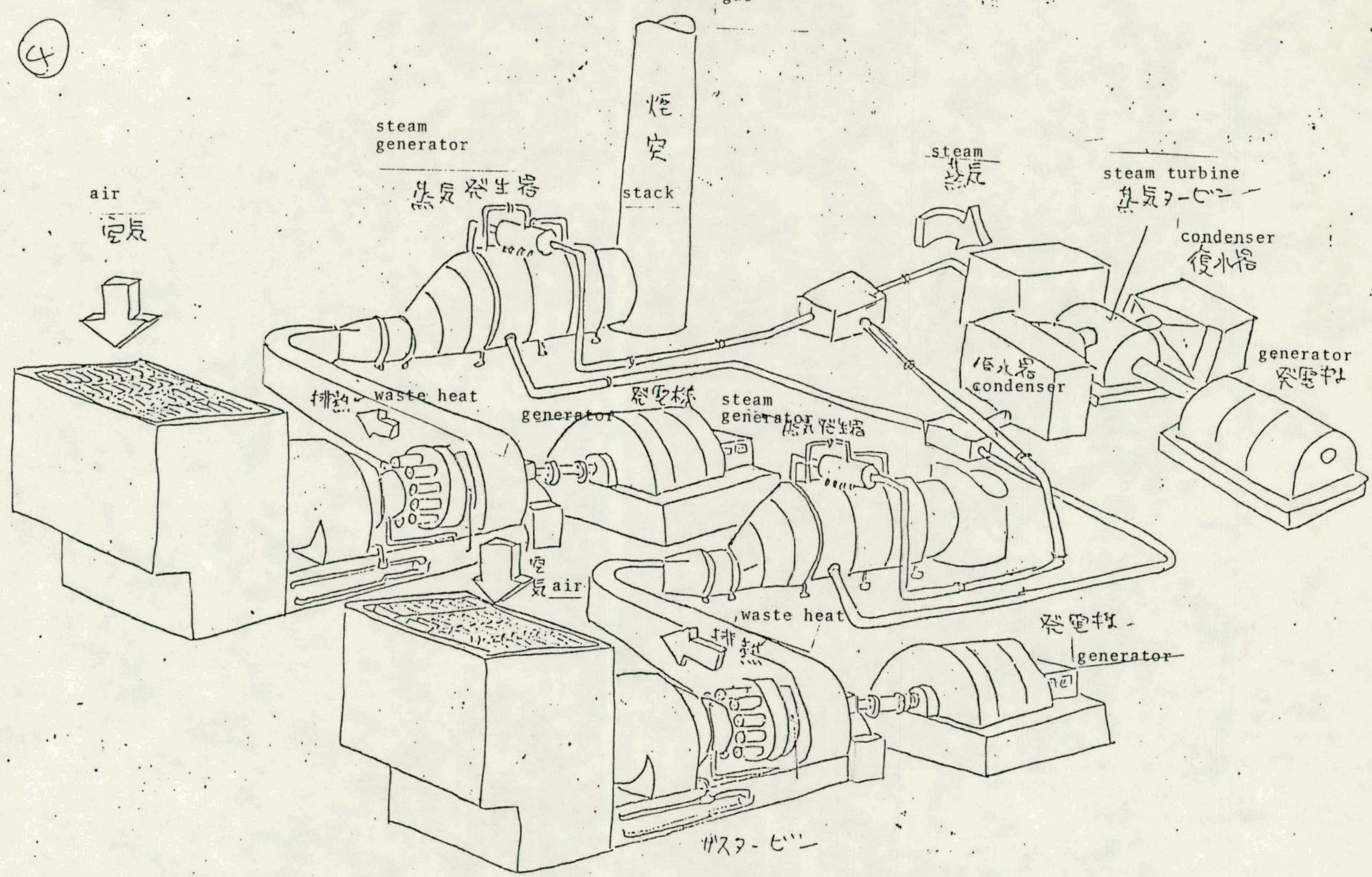
Schema of Gas Turbine-Steam Composite Power Plant



high-efficiency gas turbine

This combustion manner is nearly same as that in the aircraft jet engine. When any of other heavier oils than kerosine and gas oil is used as fuel in this combustion system, fuel is fed into the combustion chamber after having been preheated in an annexed chamber which is equipped with fuel nozzles. Thus, the entire quantity of NOx produced in the gas turbine is discharged from its outlet. The exhaust gas is likely to have the temperature of 550°C and the NOx level of 3.0-5.0 kgs per hour. Through the loop as shown in the diagram below, this exhaust gas is fed to the waste-heat boiler (which is a heat exchanger) to produce steam from water by heat exchange there. This steam is used to run the steam turbine for additional power generation.

None of the above diagrams shows an NOx controlling system. However, in the current program, it is planned to provide a denitration equipment between the waste heat boiler and the stack. This means adoption of the exhaust gas clarification method.

The reason why the exhaust gas denitration method is to be adopted is that this manner enables the exhaust gas from combustion to go exclusively to the stack and eliminates a fear that any part of the exhaust gas may be discharged to the atmosphere from any other exit. Since the current denitration processes usually use the wet method, installation of such a process prior to the waste heat boiler would cause heat loss which should be avoided to as much an extent as possible in this entire treatment system. There is a method of eliminating pollution stepwisely. However such a method still now involves a lot of problems in the aspect of heat efficiency. Thus, it has been belived most effective to remove NOx from the exhaust gas whose temperature is below 100°C where it would no longer be able to be utilized in any way.

4-5. What plan is there to demonstrate this technology or the completed engine ?

It is scheduled that the high-efficiency gas turbine will be put under system engineering work from the beginning of fiscal 1982 (1982.4-1983.3) and into construction in fiscal 1983. Then, the demonstrating operation for it is scheduled to start around June, 1984.

In terms of structure, this turbine is of the same kind as the aircraft-use fan jet engine which is now under development as one of the large-scaled projects by MITI's Agency of Industrial Science and Technology. This aircraft engine is higher in grade and smaller in size than the high-efficiency gas turbine. However, the mechanism for the high-efficiency gas turbine will be modeled after the fan jet engine. As to this fan jet engine, one of commercial size is planned to be displayed by Ishikawajima-Harima Heavy Industries Co., Ltd. (more specifically, its Tanashi Factory) in fiscal 1982. This means that the display indicating the mechanism of the gas turbine is to be disclosed to the public within fiscal 1982 (1982.4-1983.3). As to the gas turbine itself, it is scheduled

that three will be completed late in fiscal 1983*
(by Mitsubishi Heavy Industries, Ltd., Kawasaki Heavy Industries, Ltd. and Ishikawajima-Harima Heavy Industries Co., Ltd). Display to the public is planned to be held in a factory of theirs for the best one among three gas turbines.

4-6, What are the current status and future schedule on the development works for materials, cooling system, prototype plant and commercial-scaled plant ?

For this R & D program for the high-efficiency gas turbine which was started just in fiscal 1978, the work is currently under way to determine detailed specifications and what functions should be allotted respectively to the firms taking part in the program. The amount budgeted for this program is $450,000.00 for fiscal 1978 (1978.4-1979.3) and $1,900,000. for fiscal 1979. About $2,325,000. is planned to be demanded for fiscal 1980 as the necessary cost to develop heat-resistant materials and components. It is projected to invest $69,000,000.00 for the 7

*First part of calendar 1984.

years including and until fiscal 1984.

As to the budget for fiscal 1978 and 1979, which has been allotted for R & D cost and Researching Association's research propelling cost, it is to specifically cover the fundamental research aimed at attaining the following targets:

Overall efficiency ..... 55%.

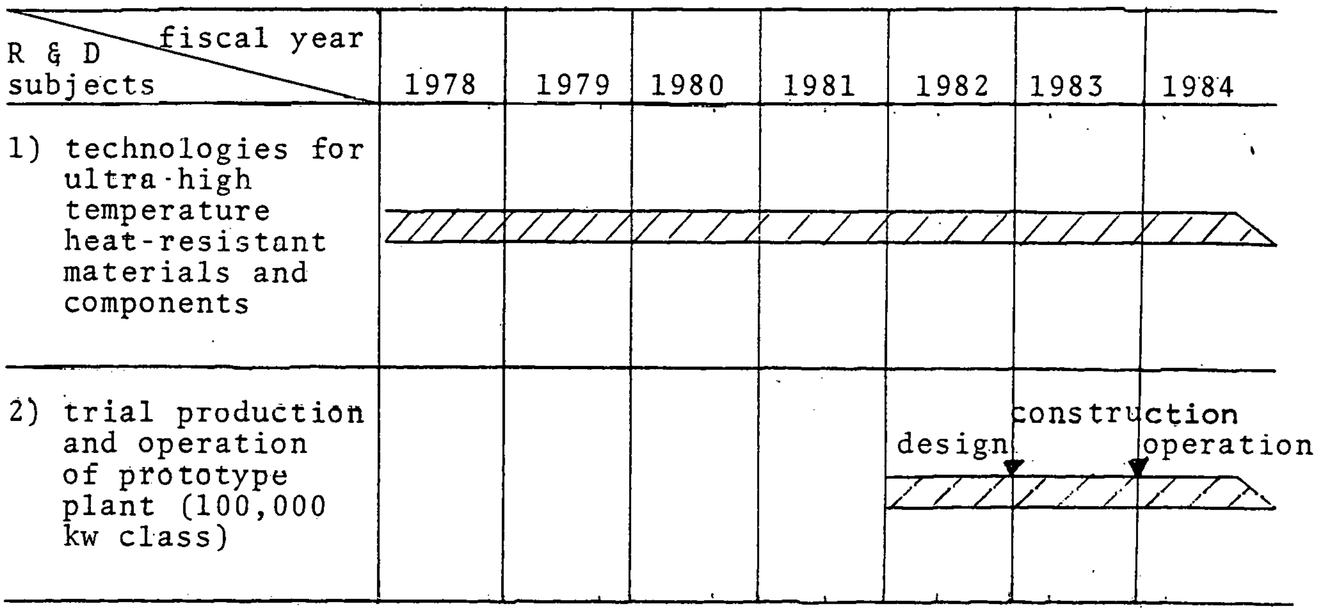
Composite power generating cycle ..... turbine inlet temperature 1500°C and gas turbine output 100 MW level.

Ultra-high temperature heat-resistant alloy ..creep rupture strengths of min. 3, min. 5, min. 11 and min. 26 kg/mm^2 respectively in case of loading for 55 hours at 1000, 900 and 800°C; high-temperature fixed-strain fatigue strength of max 0.5% of entire strain width (2500 or more cycles); and high-temperature sulfurizing-corrosion resistance of 200 or more hours in time required for 0.1 mm thickness of material to be corroded under the immersion test in hot molten salt (25% Nacl + 75% Na_2SO_4, at 900°C)

Ultra-high temperature heat-resistant ceramics (silicon, silicon nitride and silicon carbide).

...flexural strength by 3-point bending test of min. 100 kgs/mm^2 at normal temperature and min. 60 kgs/mm^2 at 1500°C; high-temperature corrosion resistance represented by normal temperature flexural strength by 3-point bending test of min. 50 kgs/mm^2 after having undergone air-oxidation for 1000 hours at 1500 °C; and creep rupture strength of min. 25 kgs/mm^2 under loading for 1000 hours at 1500°C.

The following diagram shows the time schedule for this entire R & D program :



In the present plan, there is no more detailed contents that have been determined other than the above. Further detailed data are scheduled to be formed after this fall. NJM-Galaxy will report on this if requested.

5. Environmental Control

5. Environmental Controls

5-1 Introduction

Stringency of requirements of the Japanese environmental standards is proverbial in the world. This is due to the fact that during the Japan's high economic growth period which was ended by the first Oil Crisis (1973), industries were accused of increasing pollution in atmosphere and waters and damages of living environments which went rapidly for the worse, and so, industries' technical R & D on waste gas/water treatment advanced at a rapid pace within a short time, although the investment was disadvantageous for the industries.

The basic technologies which were covered by the said development works ranged over a great variety and actually, throughout Japan, currently many types of treatment method are conducted by numerous enterprises in removal of SOx, NOx and dust and dirt.

Among the most advanced and also economical technologies, the following patterns have settled as for removing methods of pollutants. Such common patterns are: for SOx removal, Lime process, wet method technology; for NOx removal, dry process for reduction with NH3 and for dust less than 1μ, electric dust collectors.

Collected dust will be processed to eliminate harmful heavy metals and undergo regulated respective treatments. The details of these treatments, however, is beyond the scope of this survey and thus mention is omitted.

A sentence in the Scope of work of the Contract acting upon this survey, which says "It is known here that Japan pioneered the use of scrubbers" may lead one to understand that a most advanced technology on Scrubber is required to be reported. However, the writer interprets the matter in a broad sense, so that the survey will cover general removal technologies of SOx, NOx, SS and the like. (This interpretation is derived from the fact that Dry reduction by NH3, the most advanced NOx treatment process now, is not called a scrubbing technology in Japan.)

Air pollutants include sulphur oxides, dust and dirt, Nitrogen Oxides, etc. emitted from industrial fixed sources as well as Carbon monoxide, dust and dirt, Nitrogen Oxides, etc. exhausted from automobiles. In the treatment of waste gas from large size boilers in power plants and chemical plants and waste gas from gas turbines, it is important to consider that the fuel should be utilized at its best capacity (that is to obtain the best heat efficiency of boilers or gas turbines), and then the harmful pollutants should be removed of the exhausts.

In view of this point, conventional methods of burning fuels have prefered to use low sulphur heavy oil, Kerosine, gas oil or natural gas which all contain lower sulphur. In future when fuels of low quality, containing high sulphurs have to be used, desulphurization prior to combustion should be required, especially for Gas turbine use wherein high temperature burning will subject turbine combustion parts to suffer corrosion.

Current processes can afford to reduce NOx in waste gas down to 200 ppm: However, taking the matter of economy into account, to conform to furthermore severe regulatory requirements would be difficult and it is apparent that more in-depth studies will be required.

The most updated environmental standards regulated by the Japanese Environmental Protection Agency are shown in Appendix 1.

There is a variety of treating process and systems in order to be able to conform to these standard requirements.

Taking an example of the desulphurizing technology, it may well exceed 50 kinds of art, each having respective features. A summary of desulphurizing technology is discussed in Appendix 2 in detail which please refer to.

Appendix 3 and Appendix 4 show Japanese instances of desulphurization and denitration of coal fuel burning, which would safely represent the present Japan's state-of-the-art of R & D in the field concerned.

5-2 Fuel Gas Desulphurization (FGD)

To desulphurize fuels, petroleum companies have hitherto installed themselves desulphurizing equipment for supplying users with low-sulphur heavy oil. The desulphurizing equipment so far installed before 1977 by the oil companies amounts to 1,380,500 BPSD.

On the other hand, flue gas desulphurization apparatus installed in industrial areas by 1976, big or small in scale, so far registered 1,134 units in all, capable of 106,141,550 Nm^3/h. The installation of these equipment was affected by the time during which the fuel situation was changed, i.e. increase of use of low-sulphur oil, use of natural gas, etc. and thus it retrogressed, resulting in quitting of the manufacturers who have otherwise engaged in development of desulphurizing technology. Currently, limited number of companies who are all heavy industrial machinery manufacturers work in this area. The companies' names are: Mitsubishi Heavy Industries, Hitachi Corporation, Hitachi Shipbuilding, Kawasaki Heavy Industries, Ishikawajima-Harima Heavy Industries, Chiyoda Chemical Engineering & Construction and etc.

Many types of desulphurizing technology are on stream in current Japan as shown in Appendices but actually the wet method is generally considered to be most economical. The above stated manufacturers prepare respectively 2 - 3 systems of wet method so that they could select and offer to potential users a system most suitable to the user, based on the user's location conditions and required capacity for treatment.

Taking an example of a specialized manufacturer, IHI, they have 3 systems as follows:

System	Absorbent	Material Recovered
(1) Calcium Process	$CaCo_3$ $Ca(OH)_2$	(Gypsum ((Calcium Sulfite
(2) Sodium Process	NaOH	(Sodium Sulfite Solution (and powder ((Mirabilite solution* (and powder ((Mirabilite solution effluent
(3) Ammonia Process	NH_4OH	(Ammonium Sulfite solution ((Ammonium Sulfate

Depending on marketability of the by-products; Gypsum, Sodium Sulphate and Ammonium Sulphate, IHI recommends the users Calcium Process for larger projects and Sodium Process for smaller systems, and so on. As for Ammonia Process, due to its by-product or Ammonium

*Glauber's salt.

Sulphate being low in value as well as some difficulty in technical phases, this process is not prevailing.

As above-reported, wet method of desulphurization is dominant in use and settled in Japan, but recently needs for dry method have arisen and thus re-examination of dry method for development of economical technique is under way.

The requirement involves desulphurization of waste gas exhausted from coal burning boilers of thermal power plants. In conventional process, waste gas lowered to a temperature of about 350°C is sent through a high temperature electric dust collector where dust is removed, then sent to a dry method denitration device at the temperature of about 350°C, where Nox is removed, and next, sent to a wet desulphurization system. However, the current wet desulphurization requires the gas to be lowered to a temperature of about 60°C. From the save-energy view point, this process is quite a heat-looser, justifying to adopt a dry desulphurization system, and dry denitration as well all together.

Based on the afore-said concept, Electric Power Development Co., as a core, IHI and Sumitomo Shipbuilding & Machinery Co. are cooperating in R & D which is said to be including a study of direct removal of sulphur content out of waste gas of coal burning by a dry method, though its actual detail is not allowed to be publicized, according to the staff in charge, owing to a confidential agreement among Electric Power Development Co. and relevant manufacturers.*

Among the themes of the coal exhausts treatment, there is a study on treatment of particulates smaller than 1 μ, which is one of the principle subjects of this Survey. In the afore-said systems, removal of particulates less than 1 μ, cannot be achieved with the conventional electric dust collectors. These particulates under 1 μ are presumed to generate when, in dry method denitration apparatus, reducing ammonia and SO_3, has resulted from oxidation of SO_2 in the

*NJM-Galaxy has been asked by DOE not to include sensitive proprietary information in this preliminary survey.

exhausted gas, reacting together to form these particulates.

Because the removal technology of these particulates is a must in order to comply with the emission requirements, it is expected that during this fiscal year, the solution of problems would be certainly completed, though no information is available at present.

5-3 Flue Gas Denitration

Japanese environmental standard of NO_x emission has been relaxed to 0.04 ppm - 0.06 ppm, a day average of hour values, since July, 1978. However, during the period from 1973 to June, 1978, Japanese industry had invested a lot of money in development of flue Gas Denitration technologies under a severe standard of 0.02 ppm. Appendix 1 detailedly describes the Japan Environmental Protection Agency's reasoning of this revision of standards.

Appendix 1 shows Japanese emission standards of Nitrogen oxides, but there is no regulation for gas turbine emissions. As for boilers, the regulation prescribes 60 - 150 ppm for gas combustion, 400 ppm for solid fuel combustion and 130 - 180 ppm for other kinds of fuel. In this case, solid fuel implies coal, and the regulation makes conditions according to various burning systems.

Nitrogen oxides are produced in a form of NO in the course of High temperature combustion, and, after discharged and oxidized in the open air, they will change into NO_2. In the course of this reaction, participation of ultraviolet rays and some sorts of hydrocarbon is considered to give a secondary creation of peroxides such as ozone, which, under some weather conditions, will form photochemical smog, and thus NOx will give impacts complicatedly and diversely to human body.

In parallel with the development of denitration technology, the development of the suppressing technology to reduce NOx also have been undertaken with its principal-objects as follows:

(1) To use fuels not containing organic nitrogen compounds,

(2) To reduce Oxygen density in combustion zone,

(3) To shorten residence time of burning gas in the high temperature zone,

(4) To lower combustion temperature, especially eliminating local high temperature zones, and etc.

According to the above concepts, fairly many NOx suppressing technologies have been made practical. However, it should be noted that trying too much to reduce NOx will bring about possibility of adverse increase of dust, soot, CO and other pollutants, and cares have been taken of this matter.

Hereunder is a list of denitration proceseess so far developed in Japan. As a matter of fact, majority of NOx to be produced by fuel combustion is consisted of NO which has low reacting potentiality, causing the removal of NOx technically difficult. A technology already settled and prevailed in Japan is the Catalytic reduction process to use NH_3, which is one of the dry methods.

Classification of Flue Gas Denitration

Dry method	Catalytic Reduction process	Preferential Catalytic Reduction Process
		Non-Preferential Catalytic Reduction Process
	Non-catalytic Reduction Process	
	Catalytic Decomposition Process	
	Absorption Process	
	Adsorption Process	
	Electron Beam Radiation Process	

Wet Method	Alkali Absorption Process		
	Acid Absorption Process		
	Complex Absorption Process		
	Oxidation Absorption Process	-	Ozone Oxidation Process
			Permanganate Oxidation Process
	Liquid Phase Reduction Process		

Major manufacturers of Flue Gas Denitration apparatus, at the same time manufacturers of Flue Gas Desulphurizers, include Mitsubishi Heavy Industries, IHI, Hitachi, Ltd., Hitachi Shipbuilding, Kawasaki Heavy Industries, etc. who all concentrate to the Dry method of Denitration. Hereunder is discussed an outline of Dry method Denitration:

(1) Catalytic reduction process

This process reduces NO_x by adding a reducing agent to the flue gas under the presence of a proper catalyst. Reducing agents used include ammonia, hydrocarbon, hydrogen and carbon monoxide. When oxygen coexists, ammonia will react with NO_x selectively but hydrocarbon, hydrogen and carbon monoxide will react with oxygen preferentially.

1) Preferential catalytic reduction process

NO_x is reduced by NH_3 following the undermentioned equations:

$$4NO + 4NH_3 + O_2 \longrightarrow 4N_2 + 6H_2O \qquad (a)$$

$$6NO + 4NH_3 \longrightarrow 5N_2 + 6H_2O \qquad (b)$$

$$6NO_2 + 8NH_3 \longrightarrow 7N_2 + 12H_2O \qquad (c)$$

At a temperature range of 350-400^{o}C, the reaction in accordance with the equation (a) progresses preferentially.

The catalysts used include precious metals such as Pt; Al_2O_3 supported on sulfates of Cu, Fe, etc.; iron sulfate - Fe_2O_3; iron sulfate - Fe_2O_3 - TiO_2; V_2O_5-TiO_2 and so on. Catalysts are used in granular, cylindrical, spherical, ringed or honeycomb form.

The Pt-based catalyst shows a high activity even at a relatively low temperature. With this type of catalyst, denitration efficiency of 90% or more can be attained at a temperature of 200-300°C and even a space velocity (SV, ratio of hourly flue gas flow volume to catalyst volume) of tens of thousands h^{-1}. However, it is not actually used because of its vulnerability to SO_x, etc and its high cost.

In general, among Al_2O_3-, Fe_2O_3- and TiO_2-based catalysts, the Al_2O_3 type is most apt to react with SO_2, SO_3 and O_2 to produce sulfate, resulting in lowered catalytic activity.

The TiO_2 type is less apt to produce sulfate and shows good activity even at a relatively low temperature.

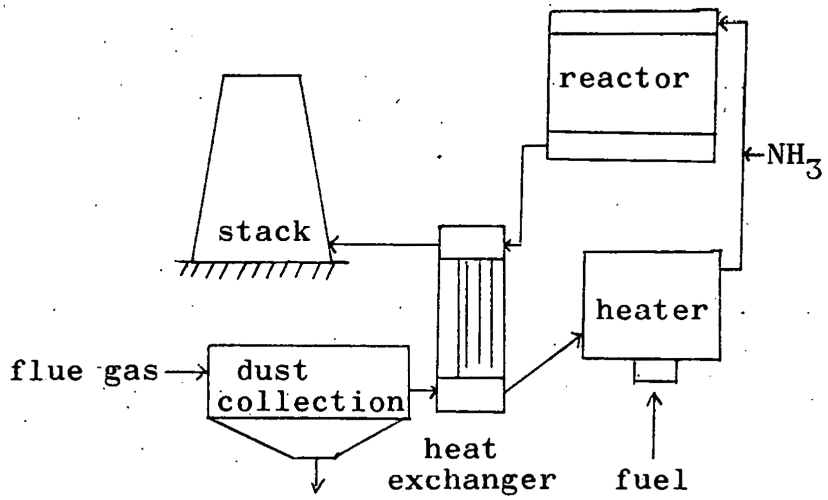
In addition to the degradation due to its reaction with the ingredients of the flue gas as described above, catalyst degrades in its activity with time, due to deposition of dust on it. Deposition of dust on catalyst will also enlarge the flow resistance in the reactor.

The flue gas is usually made free from dust with an electrostatic precipitator before entering into the reactor. However, it is difficult to perfectly remove such matters as fine alkaline fume which may be contained in some dirty flue gases.

The catalysts are, in general, used in a form of fixed bed. However, there is another way where catalyst is used in a form of moving bed and the degraded one, after having been freed, with sieve, of dust deposited on it, undergoes the regeneration and then the regenerated one is recycled for reuse. There is further another manner that catalyst is charged in thin-plate-shaped containers made of wire sheet and these containers are placed at a certain interval in the reactor. In again another manner, catalyst in ringed shape is used so that dust can be prevented from accumulating on it.

The denitration efficiency varies depending on such parameters as kind of catalyst, temperature, SV and quantity of added NH_3. When base metal catalysts are used, an initial denitration efficiency of about 90% is obtained at a temperature of 300-400°C, SV of 3000-10000 h^{-1} and NH_3 addition of 1.0-1.2 (in terms of NH_3/NO molar ratio).

An outlined flow sheet for this process is shown under.



Flow sheet for preferential catalytic reduction process.

This process is the most advanced one among various denitration processes for flue gas. However, it involves the following problems:

a) SO_x and dust contained in flue gas tend to cause degradation of catalyst's activity or clogging in catalyst bed.
b) If the quantity of added ammonia exceeds 1.0 (in terms of molar ratio), part of ammonia would leak out into the exhaust gas coming from the denitration reactor and, when the temperature

becomes below about 250°C, react with SO_3 to produce ammonium acid sulfate (NH_4HSO_4), which would deposit in the heat exchanger, thus causing corrosion and increasing flow resistance. The content of the leaked ammonia is 10-20 ppm in general.

To prevent such an ill effect, there are countermeasures such as of lowering the ratio of NO_3/NO to less than 1.0 to decrease leak of ammonia (though it will result in a lower denitration efficiency) and of using ammonia decomposing catalyst.

There are also such other ways as of applying enamel coatings onto the heat exchanger elements to prevent corrosion and of removing the deposit by soot-blowing or water scrubbing.

c) When this process is applied to such lower-temperature flue gas as that from a boiler, the higher reaction temperature in this process will make it necessary to heat the gas and, in this case, energy consumption will be large even if partial heat recovery may be possible with a heat exchanger.

In order to settle these problems, developments have been under way to establish a catalyst which have higher activity at a relatively low temperature and hard to be poisoned by SO_x, dust, etc, a reactor with such a structure as to cause no clogging in the catalyst due to dust and a method to prevent trouble caused by ammonium acid sulfate.

There is also a method where H_2S is used as a reducing agent as follows:

$$2NO + 2H_2S \longrightarrow 2S + N_2 + 2H_2O$$

This method is lower in reaction temperature but involves such problems as poisoning of catalyst due to sulfur, thus having poor possibility of practical use.

2) <u>Non-preferential catalytic reduction process</u>

The following equations show the reduction reactions using CH_4 as the reducing agent:

$$4NO + CH_4 \longrightarrow 2N_2 + CO_2 + 2H_2O \qquad (a)$$

$$4NO_2 + CH_4 \longrightarrow 4NO + CO_2 + 2H_2O \qquad (b)$$

$$CH_4 + 2O_2 \longrightarrow CO_2 + 2H_2O \qquad (c)$$

The reaction velocity is slowest in the equation (a), with its order of (b) > (c) > (a).
Thus, reduction of NO will begin after O_2 has been consumed.
This process has been used for the purpose of treating the flue gas from nitric acid manufacturing plants. There have been some cases where only the reaction (b) (a decoloring reaction from brown to colorless) is performed.
Materials based on precious metals such as Pt are used as catalyst in most cases. Oxides of base metals such as Co, Ni, Cu and Cr can be used in some cases.

In the reaction by the equation (c), which is a greatly exothermic one, the controlling of temperature in the catalyst bed is a critical matter, for the case of using Pt as catalyst, because of the upper limit of operation temperature being about 800°C in the case, even if the reaction starts at about 400°C.

It will be difficult to apply this process to general combustion flue gases which are high in their oxygen content.

The following equations show the reduction reactions using CO and H_2 as the reducing agent:

$$2NO + CO \longrightarrow N_2O + CO_2 \quad (d)$$

$$N_2O + CO \longrightarrow N_2 + CO_2 \quad (e)$$

$$NO_2 + CO \longrightarrow NO + CO_2 \quad (f)$$

$$2CO + O_2 \longrightarrow 2CO_2 \quad (g)$$

$$2NO + 2H_2 \longrightarrow N_2 + 2H_2O \quad (h)$$

$$2NO_2 + 4H_2 \longrightarrow N_2 + 4H_2O \quad (i)$$

$$2H_2 + O_2 \longrightarrow 2H_2O \quad (j)$$

In all of the above cases (d) - (j), like the case of using CH_4 as the reducing agent, the reducing agent will be oxidized before reduction of NO occurs. Thus, all of them are unlikely to have a feasibility of practical application.

(2) Non-catalytic reduction process

This is a process where NO is reduced by ammonia, without using any catalyst. The reduction of NO by ammonia required coexistence of O_2 and, in appearance, progresses in accordance with the equation (a) in (1), 1). Elevating the denitration efficiency requires a longer retention time, a high temperature of about 1000°C and addition of NH_3 at a NH_3/NO ratio of 2 or more.

Addition of H_2, CO and hydrocarbon along with NH_3 can accelerate reduction reaction and thereby decrease reaction temperature to about 700°C. This process, which requires no catalyst, can eliminate some equipment related to the reactor, thus resulting in a lower capital cost and suits in particular to denitration of dirty gas. However, it gives a relatively low denitration efficiency which seems to be about 50-60 percent. If the amount of added ammonia is increased to elevate the denitration efficiency, there will be a fear that leakage of NH_3 may increase and that the aforementioned problem of ammonium acid sulfate may occur.

(3) Catalytic decomposition process

This is a process of decomposing NO into N_2 and O_2 catalytically.

$$2NO \rightleftarrows N_2 + O_2 \qquad (a)$$

The velocity of the decomposing reaction is very low. Various studies have long been done to increase the reaction velocity. However, this process still remains low in NO decomposition efficiency even at a considerably high temperature, unlikely to be put into practical use.

(4) Absorption process

This is a process where flue gas is made to contact with molten carbonate of alkali metal at a temperature of 400-450^{o}C and NO_x in the gas is caused to react with the carbonate.

This process, originally proposed in the U.S., however involves a lot of problems in the aspect of its feasibility of practical use.

(5) Adsorption process

Activated carbon, alumina, silica gel, molecular sieve, etc. are used as adsorbent.

Though NO_2 is adsorbed, NO is hardly adsorbed. This process requires cooling of the flue gas and removal of such obstructive ingredients as water vapor and is little likely to be put in practical use.

(6) Electron Beam Irradiation

This is a process of irradiating flue gas with electron rays and thereby converting NO_x and SO_x into fine solid particles, which are removed in an electrostatic precipitator.

In this process, the flue gas, after being cooled to a temperature of $100^{o}C$ or less, is added with ammonia gas and then fed into a reactor, where it is irradiated with electron rays.

Irradiation lasting for one to several seconds produces reactive radicals, which convert NO_x and SO_x into fine particles of ammonium nitrosulfate and ammonium sulfate. The reaction mechanism has not yet been made enough clear, but it has turned out that the OH radicals play an important role.

A pilot plant test indicates that both denitration and desulfurization yields increase with the increase in the dose of electron rays, reaching about 90% with a dose of 6 Mrad.

This process has merits that denitration and desulfurization are attained concurrently in a short period at a lower temperature and that the reaction products are recovered in a powder form. However, it is said the process still requires scaling-up on a larger testing plant and cost reduction as well as establishment of a method to treat reaction products.

5-4. Flue Dust Removal

Environmental standards that the Environmental Agency regulates on suspended particulate matter provide that "A day average of hour values should be less than 0.01 mg/m^3 and maximum hour value is 0.20 mg/m^3". The environmental standards on maximum boiler emission provide that 0.2 g/Nm^3 for coal burning emission, 0.8 g/Nm^3 for Coal (less than 5,000 kcal) burning and 0.4 g/Nm^3 for Coal (more than 5,000 kcal) burning. No provision is made on Gas Turbine exhausts now, because kerosine, gas oil or superior grade Heavy oils are used currently as fuel, so that the exhausts are not needed to be subjected to any regulations.

5-4-1. Soot and dust treatment systems

Currently prevailing treating systems in Japan for boilers of pulverized coal combustion and Heavy oil combustion are as follows:

a) Pulverized coal Boilers

In case apparent electrical resistance of the dust stays within ordinary range, a system in which an Electric dust precipitator (EP) or dust collector is placed in the rear of a Multicyclone(MC) is generally used. This is an MC-EP type dust collecting system. If the apparent electrical resistance of the dust is in the sparking range, single EP type or EP-MC type collecting system is commonly used in order to help the dust to be caught at collecting poles peel off easily, and so the rate of collection will not deteriorate.

b) Heavy oil burning large size Boilers

Ammonia is injected to a point where the temperature of flue gas is less than 147°C, permitting contained SO_3 and H_2SO_4 to develop into Ammonium Sulphate and then the gas is subjected to an EP system. The purpose of this Ammonia injection is to prevent corrosion that is to occur at the lower temperature part of the apparatus and also to prevent Acid smuts from forming. Acid smut--(A snowflake-like growth of combustion soot, as a core, by absorbing sulphuric acid which was formed from sulphur contained in fuel, conglomerated at the acid dew point temperature). Besides the above pollution prevention, the Ammonia injection has a secondary merit of increasing the dust electrical resistance, bringing it to the ordinary range and thus making dust-seizing better and easier.

The characteristics of flue gas exhausted from a pulverized coal burning boiler of a) above, vary substantially depending on configuration and construction of the boilers and pulverizers, quality of coal and conditions of combustion and operation, etc., but among others ash content in coal will give a greatest impact on the character.

20 to 25% of total dust produced in a furnace will fall down on the space between the furnace and the air pre-heater, usually in such a concentration, at the outlet gate of the pre-heater, as of about 20 g/Nm^3 for high grade coal and about 35-45 g/Nm^3 for low grade coal. The particle size of the dust is, in the cases in Japan, rather very much varying; between 15 μm and 35 μm. Spherically shaped dust less than 44 μm which are to be used as fly ash as one of the cement

ingredients, makes up 70% of the total dust found at the air pre-heater's outlet.

The characteristics of flue gas exhausted from the Heavy oil burning large size boilers of b) above, will vary depending on structure of the boilers and burners, types of Heavy oil and combustion conditions but due to recent uses of low-sulphur oils, general emission of dust amounts about several tens mg/Nm^3. (Earlier, it was 0.1-0.2 g/Nm^3) Compared with the particle size of dust from pulverized coal boilers, there is a much less variation of particle size distribution which may depend on the difference of construction of the boiler or types of fuel. And the particulates mainly comprise of relatively big (more or less 20 μm), ash-coke like porous particulates and very fine (about 0.02 μm) carbon black.

c) <u>Range of practicality of various dust collectors</u>

Depending on usages, various collecting systems of various manufacturers are being used. General characteristics of the collecting systems are as follows.

Classification and (type)	Particle size treatable (μm)	Pressure loss (mm H_2O)	Rate of collection (%)	Equipment capital required	Operation cost required
Gravitational collection system (Precipitation chamber)	1000-50	10-15	40-60	small	small
Inertia force collection system (Louver configuration)	100-10	30-70	50-70	small	small
Centrifugal force collection system (Cyclone configuration)	100-3	50-150	85-95	medium	medium
Washing collection system (Venturi Scrubber)	100-0.1	300-900	80-95	medium	big
Sound wave collection system	100-0.1	60-100	80-95	medium & up	medium
Filtering collection system (Bag Filter)	20-0.1	100-200	90-99	medium & up	medium & up
Electric collection system	20-0.05	10-20	90-99.9	big	small-medium

Also listed below are characteristics of major system of dust washing collection which is discussed in 5-5 in this report.

System	basic flow rate (m/s)	Liquid/gas ratio (l/m^3)	Pump pressure	Pressure Loss (mm H_2O)	50% separation particle diameter limit (μm)
Spray tower	1-2	2-3	medium	10-50	3.0
Packed column	0.5-1	2-3	low	100-250	1.0
Cyclone Scrubber	1-2	0.5-1.5	medium	120-150	1.0
Taizen Washer	(300-700 rpm)	0.7-2	low	-50 - -150	0.2
Jet Scrubber	10-20	10-50	high	0 - -150	0.2
Venturi Scrubber	60-90	0.3-1.5	low	300 - 800	0.1

5-4-2. <u>Removal of particulates less than 1 μ</u>

Number of coal burning boilers in Japan is much less than that of the U.S. and future direction of Japanese development may be given to how economically the coal combustion exhaust treatment could be systemized, based on the conventional unit technologies on respective treatments.

Removal of particulates less than 1 μ is mostly performed in Japan either by Bag filters or Electric dust collection system (EP), whose characteristics are shown below:

System	Particle diameter	Removal rate
Bag Filter	1 μ	99.8%
	0.5 μ	99.0%
	0.1 μ	99.7%
EP High Temperature (350°C)	1 μ	97.0%
	0.5 μ	96.0%
	0.1 μ	99.3%
EP Low Temperature (150°C)	1 μ	94.5%
	0.5 μ	92.0%
	0.1 μ	98.0%

The removal technologies of submicron particulates in both high temperature and low temperature exhausts will probably be developed in future by solving each case to occur. At this time, no definite method to remove completely these sub-micron particulates has been developed.

5-5. Dust Washing Collectors.

5-5-1. Summary.

The Scrubber system is a branch of applications of dust collection technology and its principle of operation can be roughly devided into the following actions:

(1) Dust particulates will impact liquid drops and adhere to the drops,

(2) diffusion of the particulates accelerates their contact with liquid drops,

(3) moistening of gas assists each particulate to conglomerate together,

(4) Agglomeration is enhanced by condensation of vapor into a drop with particulates as a core.

(5) The particulates will contact and adhere to liquid film or air-bubbles during diffusion.

Embodiment of these principles is made by such methods as pressure water system, still water system or rotation system. Scrubbers are usually operated under the pressure water system and is sub-classified into the Venturi Scrubber, Jet Scrubber and Cyclone Scrubber.

(1) Venturi Scrubber

This is provided with a throat which helps the dust containing gas run rapidly through, where water is injected misty and the particulates impact the mist and conglomerate themselves. This system provides high rate of dust collection.

Capability of dust collection compares with that of Bag Filters, allowing less floor area of equipment. With water drops only, SOx like as SO_2, SO_3, etc. can be removed by adsorption action, but the Pressure loss is great, and further, a series of waste water treatment must be conducted.

Minimum graspable size of particulate 0.2 μ in diameter; basic rate of flow 60-120m/s; Pressure loss 300-800mm Ag; required power 0.14-0.35kg/m^3/min.; Capital investment $281.00-$296.00 per m^3/min. of treated gas.

(2) Jet Scrubber

This type produces a jet stream of waste gas in which water drops are floated. Adhesion between dust particulates and water drops together is more excellent, and dust removal rate is better than the Venturi Scrubber. Also it acts, at the same time, as a gas booster. However, water is used more than 10 l/m^3 and the Jet Scrubber is not suitable for a system that requires treatment of large amount of gas.

Minimum removable size of particulate 2 μ ; basic rate of flow, 20-50 m/s ; Pressure loss 0-200 Ag ; required power 0.07-0.35 $kg/m^3/min.$; Capital investment ¥6,000-¥50,000 per $M^3/min.$ of gas treated.

(3) Cyclon Scrubber

This utilizes the so-called Centrifugal force of cyclone in addition to diffusion and adhesion action and is effective for collecting not only mists but water-soluble dust. At the Pressure loss 100-200 mmAg, 0.5-1.5 l/m^3 of water will be used, so this system is suitable for a big quantity treatment.

Minimum removable size of particulate 5 μ ; Basic rate of flow 10-20 m/s ; Pressure Loss 50-200 mmAg ; required power 0.03-0.07 kg/m^3/min. ; Capital investment ¥12,000-¥50,000 per M^3/min. of gas treatment.

5-5-2, Examples of Dust removal with Dust Washing Colletors.

Scrubbers are, as discussed above, devices for collecting dust. The most desirable density of contained dust in exhausts will be less than 10 g/Nm^3 and dust in such range would be removed 80-90 °/o of total dust contained.

Water soluble gases such as SOx can be all treated by this moistening system. Also effective in treatment are phosphoric acid mist, Sulphuric acid mist and other mists, water absorbing metals such as Sodium and Potassium, fly ash, corrosive substances, malodorous substances, particles, and etc.

In treatment of blast furnace gas of 14 18 m^3/min. in Ohgishima Works of Nippon Kokan K.K., 99 °/o removal of dust was attained from the exhaust which contained 0.0882 g of particulates per 1 ℓ, using a steel Cyclone Scrubber of 366 cm in diameter and 1,830 cm in height. Pressure loss at the operation was 229 mm (Water column), rate of injection of water being 2.28 l/m^3, sprayed through 534 nozzles with pressure of 5.25-5.6 kg/cm^2. The blast furnace gas contained, besides dust, SOx, vapored metals and corrosive compounds. The above system could remove about 10 °/o of SOx which was about 20 ppm density.

Fundamentally, as for dust and water soluble gas, the system is considered to be able to dispose them with a fairly good efficiency and is applicable to exhausted gas from Cupolas.

It is preferred that sulphur content would be as low as possible in the Scrubber dust-removing process, because, if too high, gas flowing rate should be reduced and sprayed water must be increased. As afore-mentioned, rate of flow for Venturi Scrubber is 60-120 m/s, for Jet Scrubber 20-50 m/s and Cyclone Scrubber 10-20 m/s. Venturi Scrubbers provide best SOx removal rate, while the slow-flowing Cyclone Scrubbers are most advantageous in treatment of big quantity of gas.

Another example was reported that SOx of more than 500ppm was successfully treated by a Scrubber system. However, it should be understood that actual capacity of a Scrubber is to remove SOx of 20 ppm density by about 20-30 °/o.

In the above case of Ogishima Works of Nippon Kokan, 20 ppm SOx was reported to have almost 100 °/₀ been removed, but in reality, the Dust collector firstly removed 20-30 °/₀ of SOx from exhaust gas, then a flue gas desulphurizer installed behind further removed so that the removal rate was enhanced upto 95-98 °/₀.

The basic principle of the Scrubber is that a Venturi tube or suction duct through which exhaust gas is drawn in, intersects with a separator which directs the entered gas downward perpendicularly, and at the same time diffuses the gas within the separator, and at the same time water drops are showered over the gas at an appropriate turning place of gas flow. Scrubbers are currently used very commonly in such plants as metal mining, refining, manufacturing aluminum, cement lime, phosphate fertilizer, carbon, chemicals, ceramics, drying and heat-treating, cupola, blast furnace, converter, etc. For smelting furnaces, generated waste gas (at the pressure of 2-3 atm.) is directly drawn in the Scrubber where gas is treated by water showers and further drawn in another scrubber. Multi-stage Scrubber system of 1-4 stages is generally used.

Although the rate of removal of NOx is as low as 10 °/₀, all gas including SOx, NOx, malodorants and particulates less than 1 μ are treated by water shawers and so in the waste water are naturally contained a lot of S and N content besides dust, so needing a waste water treatment.

Because the waste water is acidic, PH adjustment to around 7 is first made, precipitating various metals, again adding some neutralizer,then removing S content with calcium compound and then, content is decomposed with anaerobic bacteria,releasing N2 gas in the open air. Sludge, after precipitation, is dewatered and solidified by means of filter pressing.

5-5-3. Important points for maintenance.

Proper water feeding into Scrubber has a direct effect on the dust collecting rate and performance. So, routine inspection on proper liquid-Gas ratio is required. If water is drained too much from the drain valve at the bottom of the hopper, water level is lowered and waste gas would pass through the Scrubber without undergoing washing.

In the case of Venturi Scrubber, the nozzle (Venturi tube) may be clogged with dust, permitting no start-up. During the machines rest, cleaning should be routinely and well performed. To high acidity of the waste water may corrode the apparatus.

Since scrubbers cannot make adjustment of the size of its section area of contacts, maintenence and control should be given in a manner that if dust collecting rate is lowered, washing water amount is increased.

5-5-4. Scrubbers in operation.

Currently about 50 apparatus are in operation and about 10-20 new apparatus are yearly required. Representative installations are:

1. Smelting furnace of Asahi Glass Co.

2. Sludge incinerator of raw sewage of Kawachi-Nagano town (Yao city) (dust)

3. COKE Oven of Hibino Industries Co. (limestone dust)

4. Blast furnace of Nippon Kokan, Ogishima Works.

In consideration of heat loss by water-washing, those energy saving minded industries such as gas turbines, combined cycle generation, etc. do not use the Scrubber system. A drye type of dust collectors (mainly electric dust collectors) is generally used.

5-5-5. How to dispose of waste sludge.

Dust caught in the water is collected by precipitation and then rid of water (down to a water content of 50-60 °/₀) through such a measure as a filter press. The resultant dust cake is disposed in those ways that harmful one is sealed in concrete and harmless one is used intact for land reclamation.

Recently, there are cases that such waste sludge is mixed in the reclamation of waste plastics.

5-6. Sludge Treatment.

Burning of either kerosene gas,oil or low sulplur-contained Heavy oil emits less solids such as fly ash than coal burning. In the case of coal burning, on the contrary, in addition to the process of collecting solids, when the wet method is employed for removal of Sox, it will become necessary to perform complete treatment of waste water and disposal of remaining sludge. According to the Japanese standards on solid wastes disposal, the resultant sludge generally contains less amount of harmful metals than regulated and thus requires no such strict disposals as by cement solidification.

However, it is difficult for the industries to find land for reclamation of the wastes in such a narrow country as Japan. Although there are many studies concerning how to dispose wastes, yet they are not fundamentally enough to solve the matter, thus the industries are tortured with difficulty of obtaining the place for reclamation of the waste.

Only a way of useful disposal of Fly ash which is produced when coal is used as an energy source, is to sell it to cement companies for their use as a cement additive.

However, since the quantity to be used inthis area is limited, it will become a problem to find out another usage in future.

R&D on application of Fly ash are currently under way and as in the case of residue sludge from waste water treatment, the use for compost which may be utilized as fertilizer or a soil conditioner, is considered.

Details of the R&D on this theme will be investigated on request.

5-7. Instrumentation and Control.

All of the operation of denitration, desulphurization and dust removal is fully automatized as chemical equipment. Designing consideration is made on respective equipment to deal with any possible problems in advance, and no difficulty may arise inparticular during operation of the respective equipment. However, when new those equipment are integrated into a system, there should be various problems to occur. Appendix 3. indicates an example of occurrence of problems with a boiler of coal burning thermal power plant.

6. Fluidized Bed Combustion

6. Fluidized Bed gasification.

A brief survey on advanced studies of Fluidized bed gasification currently under way in Japan. The survey covers both the pressurizing system and atmospheric pressure system.

6-1. Introdution.

During the period of Japan's high-rate economic growth, the domestic R&D efforts for the technologies to use coal as an energy source were quite stagnant, giving its seat to those for the technologies to use petroleum. However, the first and second oil crises have stimulated domestic energy-related enterprises to become much interested in developing coal utilization technologies. One of these technical approaches is coal liquefaction and another is coal gasification.

As to coal liquefaction, until around the end of World War II, it had been taken up as an important theme for obtaining synthetic oil in the military researching works by such government-run researching organizations as National Industrial & Technical Researching Institutes and Fuel Research Institute which is the precursor of the current National Research Institute for Pollution Control and Resources. And many technical researchers in those organizations had devoted themselves to this theme and continued R&D works in their respective own manners.

However, now that more than 30 years of blank period has elapsed, it has become necessary to map out the R&D plan for this theme quite fundamentally again. Under such circumstances, basic development works have been conducted since 1974 under programs such as Sunshine Project by MITI's Agency of Industrial Science and Technology. Simultaneously, concerning the R&D for coal liquefaction, it has started to take part in respective projects of two U.S. major firms --Exxon and Gulf Oil-- in the hope for international cooperative works.

As to the theme of coal gasification, though enough study has so far been done on the fluidized-bed gasification technologies developed in the U.S. and Europe, there has been no concrete attempt to put this method into practical use because it involves more problems concerning profitability, adaptation to pollution control standards, etc. than the methods based on petroleum and natural gas. However, from the standpoint that the problem of future energy source calls for enlargement of coal utilization, substantial efforts have recently been commenced to develop technologies according to respective purposes, concerning coal liquefaction and gasification.

Thus, at the present stage, coal gasification and coal liquefaction are scheduled to be commercialized by 1990, as national projects.

6-2. Laboratories (address and telephone No.) and staff members in charge.

(1) National Research Institute for pollution and Resources of the Agency of Industrial Science and Technology (MITI)

3-1-1 Kawaguchi, Kawaguchi, Saitama Pref.
(0482) 52-3101
Hideo Kimura, Chief of the 1st Resources Dep't.

(2) Government Industrial Development Laboratory, Hokkaido, of the Agency of Industrial Science and Technology.

41-2 Higashi-Tsukisappu, Toyohira-ku, Sapporo, Hokkaido.
(011) 851-0151
Hiroshi Nishino, Research and design official
Hitoji Ishibashi, Chief research official of the 2nd Dep't.

(3) Research Institute for Coal Technology

2-10 Kanda Jinbocho, Chiyoda-ku, Tokyo
(03) 261-5472
Reijiro Yamamura, Director, Chief of Coal Gasification Dep't.

6-3. The level of R & D of the respective laboratories.

6-3-1. National Research Institute for pollution and Resources.

The study of this Institute represents a high calorie coal gasification project based on the Sunshine Project. Currently, an apparatus capable of high calorie gasification of 50 m^3 per day is undergoing tests for both the apparatus and system performance.

With cooperation of Hitachi, Ltd., the Institute has already established a definite outlook for scale-up, and has started construction of a pilot plant in Iwaki City, which will have a daily high calorie gasification capacity of 7,000 Nm^3. The Institute will conduct their R & D using their laboratory apparatus in parallel with the operation of the 7,000 Nm^3 pilot plant which Hitachi takes care of.

The 7,000 Nm^3 plant is based on a Hybrid itself in construction of a verification and commercial plant (half as a prototype purpose) in 1982 fiscal year or so.

6-3-2. Government Industrial Development Laboratory, Hokkaido.

The fluidized furnace of the Government Industrial Development Laboratory, Hokkaido is a multi-purposed furnace to operate from a waste disposal to regeneration of activated carbon.

At this moment, a test quartz furnace of 10 cm diameter has been barely completed. It is predicted their laboratory study should continue a few years to come. It is said that they plan a

Pressurizing fluidized gasification system of coal and heavy oil, and its gasification reaction pressure is expected to be 30 kgs per cm^2. The coal to be used will be what equals to Taiheiyo brand grade and the heavy oil to be used will be what is equivalent to Gach Saran* based vacuum residue.

Prepared in average grain size of 40-50 mm, the coal will be mixed with the heavy oil (Asphalt) to produce slurry, which will be put into the hybrid gasifying furnace, to produce high calorie gas of total exothermic potency of 5915 kcal/Nm^3 (which contains methane gas occupying 25.87 weight %). This system features the 30 kg/cm^2 pressure which will enhance the pyrolysis of fed material by virtue of the pressure and consequent fluidization. The furnace is composed of a pyrolyizing furnace and a part oxidation farnace, in an up-right 2 stage configuration.

The furnace is expected to be completed during this year and to undergo gasification test running. It is further planned that the Institute will embark

*Middle East grade.

on a schedule, to get their study completed so that a pilot plant could be constructed in fiscal 1985 or so ; however, due to budgetary back-supports unavailable now, much uncertainty is conjectured to be existing in their such long-term plan.

According to the results of experiments made so far, it is observed that an art is being developed, where alumina pellets are charged into a quartz furnace, (which may facilitate men to view reaction in the transparent furnace,) and the alumina pellets, being heated upto the temperature of about 1,200°C and fluidized, will contact with reactants like quartz, organic waste and activated carbon, to effect hydrogenating reaction.

However, it is said there are still problems yet unsolved in the phases of the speed of fluidizing, how to charge the reactant,how to drain, and so on, which suggest further necessity of conducting basic studies. The Institute makes it as a specific item of study to be devoted to.

6-3-3. Research Institute for Coal Technology.

This Institute, under supervision of Coal Mining Administration Department of Coal Mining Bureau of the MITI, not under the Sunshine Project, is studying a pressurizing fluidized bed for the purpose of low calorie coal gasification.

A Gasifier of 5 ton per day capacity is already installed in a branch of the Institute, located in the premises of Yubari Coal mine (in Hokkaido), which has experienced a successful continuous operation for 120 hours with it. With the 1979 fiscal year's starting, the Institute has set out in construction of a 40 ton/day pilot plant (which is engineered by Mitsubishi Heavy Industries Ltd., Nagasaki DOCK), and is expected to complete it in the fall of 1980. After basic experiments and application study for a year or two with this pilot plant, it is planned, a verification furnace (100-200tons) would be built.

The furnace is designed to produce low calorie gas of 1200 KCal from such general grade of coal as Taiheiyo grade, which will be pulverized, and added with pressured air and steam at 10 atmospheric pressure for 80% gasification, (theoretical rate of gasification) in a 2 stage pressurizing fluidized furnace.

The structure of the gasifier includes of three stage lock hoppers through which pre-treated (pulverized and dried) coal is fed to the upper furnace of the set of 2 stage furnace, adding to it 10 atmospheric pressure of air and steam and carbonizes it at the temperature of 600°C-800°C for gasification.

In this gasification reaction, gas and char (carbon) are produced. Take these out from the top of the furnace, remove dirt with a cyclone and separate the char from gas. The gas will be purified in a dry desulfurizer and sent to power generation processes.

The char separated from the gas will be fluidized into the lower stage furnace, with air and steam blown into the furnace at 10 atmospheric pressure. Heated at 900°-1000°C, the char will again be gasified. The feature of this furnace lies in the connecting nozzles located between the upper and lower furnaces. Through these special nozzles the lower furnace communicates with the upper furnace so that all of the created gas in the lower furnace will be drawn up towards the upper furnace by means of these nozzles.

In the steady running of the plant, high pressured air and steam injected into the lower furnace as well as its thermal energy will facilitate gasification in the upper furnace.

6-4. Prototype production plans in the respective research institutes.

There is no prototype machine completed at this moment.

The National Research Institute for Pollution and Resources is, in cooperation with Hitachi,Ltd., constructing a pilot plant of 7000 m^3/day under the Sunshine Project. According to the Sunshine Project, construction of a half prototype and half verification/commercial plant is to be inaugurated in 1982 fiscal year.

The machine in the Government Industrial Development Laboratory, Hokkaido is only a laboratory-based machine. They have set up a schedule to expect, during 1985 fiscal year, a pilot plant and during fiscal 1987-1988 a prototype plant, but presently they are not propped with a budget backing, so the schedule will be very fluid.

The Research Institute for Coal Technology is currently constructing a pilot plant which is expected to go into operation in the fall of 1980. Thoughthere are many uncertain factors for the future outlook, it is planned that in the end of 1982 fiscal year or in 1983 fiscal year a prototype furnace with half purposes of commercial and verification test will be constructed.

6-5. Commercialization plans in the respective research institutes.

As a national project, coal gasification and liquefaction are to be commercialized before 1990's According to this schedule, it would be quite certain that National Research Institute for Pollution and Resources-Hitachi, Ltd., and the Research Institute for Coal Technology would both achieve their commercial stage testings within the above period. However, at present they are still in a primitive stage of development, thus their further technical developments and solutions of problems would require fluctuation of the schedule. It is, however, in the broad sense, the progress will go the pace as set in the above item [6-4].

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7. Fuel Cell

7-1 Introduction

The R & D works for fuel cells in Japan have continued to be conducted since 1974 fiscal year as the "Hydrogen Utilization Project" under Sunshine Program sponsored by MITI's Agency of Industrial Science and Technology.

The purpose of these works is to attain highly efficient power generation using hydrogen as its fuel when an economical hydrogen manufacturing technology has been established in the future. The major themes in the works have been focused on the first-generation fuel cell mainly based on alkaline electrolyte and the third-generation fuel cell using solid electrolyte.

Both of them have been researched on a laboratory scale. The work for the alkali electrolyte fuel cell has been jointly conducted by Fuji Electric Co., Ltd. and Central Research Institute of Electric Power Industry under a budget appropriated by MITI's Agency of Industrial Science and Technology, while the one for the solid fuel cell has been conducted by National Electrotechnical Laboratory under the same budgetary sponsorship.

For the first generation alkali electrolyte cell, study has been completed on a system technology which would even make it possible to construct a power plant with a large capacity if only enough amount of budget can be appropriated.

On the other hand, for the solid fuel cell, progress has been found in the R & D on basic technologies, with successful results steadily being obtained on development of new technologies as mentioned in 7-3. Commercializing the solid fuel cell requires the research work with a large-scale pilot plant and is scheduled to be accomplished around the year of 1995. However, such a time table is expected to be shortened by the acceleration of the R & D works for alternative energy source utilization due to the second oil crisis.

2

Compared with the wide range of R & D works by UTC in the U.S., the works by Japan's MITI's Agency of Industrial Science and Technology have so far consisted mainly of basic researches on the field of hydrogen energy utilization. On the other hand, some domestic power and gas firms have continued the study from the standpoint of plant users. Tokyo Gas Co., Ltd. and Osaka Gas Co., Ltd. have already jointly, under their participation in the UTC's TARGET Program, carried out the study on a 11.5 kw demonstration plant and been proceeding with the preparation for studying a new 40 kw fuel cell.

Tokyo Electric Power Company, Ltd. has decided to purchase at a budget of about ¥5,000 million (or US $ 23 million) one set of the phosphate electrolyte fuel cell power plant already developed by UTC in the U.S. and to adopt it for dispersed power generation.

In Japan, there is no R & D work now under way on the molten carbonate electrolyte fuel cell. (A basic research was conducted on this type of cell at Nagoya University in the past but has been suspended.)

However, in order to meet the demand of switching energy sources from petroleum to natural gas or coal, it is naturally anticipated in general that R & D work will be resumed also on the fuel cell using molten carbonate electrolyte which can use a wide range of hydrocarbon resources as fuel instead of using pure hydrogen and is higher in thermal efficiency.

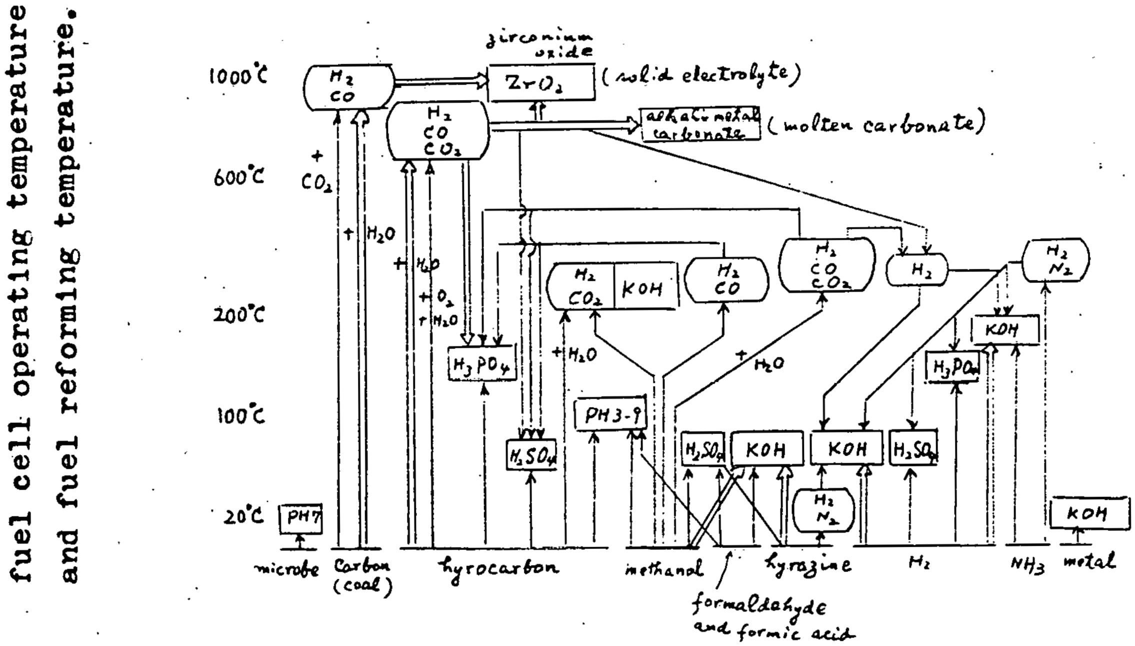
The current status on R & D works in Japan is outlined as follows.

7-2 Status of R & D in Japan

7-2-1 Kinds of Fuel Cell

The fuel cell is a system to generate electric power by burning hydrogen. In general, water and heat are produced when hydrogen is oxidized by oxygen while oxygen is reduced by hydrogen. In the fuel cell, such a reaction is made to progress electrochemically. Namely, the hydrogen-oxygen reaction is the basis for the fuel cell. There are various manners in which this reaction is advanced. Thus, the fuel cell is classified according to such different manners of reaction. The following diagram shows how the fuel cells are classified by several factors:

Classifications of fuel cells by reactant, electrolyte, cell, operating temperature and fuel reforming temperature



note: ▭ represents electrolytes.

⬭ represents fuel ingredients resulting from reforming.

⇒ indicates processes which have been or much likely to be put in practical use.

In the diagram, variations of operating temperature and fuel reforming temperature are shown along the vertical direction and that of fuel material is along the horizontal direction.

In Japan, the common name "first-generation fuel cell" is given to fuel cells using hydrogen as their fuel and phosphates as their assistant medium, the name "second-generation fuel cell" is given to those using hydrogen, carbon monoxide, etc. as their fuel with alkali metal carbonates (molten carbonates) as assistant medium and the name "third-generation fuel cell" is to those fueled by hydrogen and carbon monoxide with zirconium oxide (solid electrolyte) as assistant medium.

In the case of the first-generation cells, reaction is made at a lower temperature of around 150°C but power generating efficiency is as low as 40%. In the second-generation cells, reaction temperature is 650°C and efficiency is 45%. For the third-generation cells, efficency reaches as high as 50 - 55% at 1000°C.

Among them, those coming under the first-generation and the third-generation have been under R & D works in Japan.

First-generation Fuel Cell

The type under development by Power Systems Division of United Technologies Company is predicted to become the first fuel cell power generating system for general civilian use to be put into practical application and is considered to be most advanced in R & D at the present point of time. In this type of fuel cell, concentrated phosphoric acid aqueous solution is used as electrolyte. Concerning this type, an on-site power generating plant (called PC-11) was developed in TARGET program (Team to Advance Ressearch for Gas Energy Transformation). 35U.S. gas and power companies made a joint investment in this program. Tokyo Gas Co., Ltd. and Osaka Gas Co., Ltd. also together made an investment (amounting to $1,390,000) in it and imported 4 sets of PC-11 on-site power plant about 2 years ago. Two of them were installed in Osaka Gas Co.'s club houses and the 2nd two were used for an operating experiment in Tokyo Gas Co., where a field test for 4000 hours was carried out.

Some results have been obtained from those such as a joint research between Fuji Electric Co., Ltd. and Central Research Institute of Electric Power Industry.

Third-generation Fuel Cell

This type of fuel cell is anticipated to be put into practical use after 1990. It uses zirconium oxide as electrolyte to take advantage of this subsance's property of bearing electrical conductivity for oxygen ion when vacancy in crystal shifts.

In overseas, this type has been being researched by Westinghouse Electric Co. in the U.S. and Brown Boveri & Cie A.G. in West Germany. In Japan, it has been under a trial production research by National Electrotechnical Laboratory of MITI's Agency of Industrial Science and Technology. The Japanese cell is same as the two overseas firms' units in the aspect of using zirconium oxide as electrolyte but somewhat differs from them in details.

As to solid electrolyte for third-generation fuel cell, Hitachi, Ltd. has obtained a patent on the one containing cerium oxide as main ingredient. However, the company has "not yet started a study of this type of fuel cell system".

7-2-2 Research laboratories engaged in R & D of Fuel Cells

First-generation hydrogen fuel cell

Fuji Electric Co., Ltd.'s Central Researching Laboratory (Address: 2-2-1, Nagasaka, Yokosuka City, Kanagawa-prefecture. Phone: 0468 (56) 1191). The related research works in this laboratory is superintended by Mr. Ryoji Anahara, Chief Engineer of Technical Planning Department. Central Research Institute of Electric Power Industry's Technical Laboratory (Address: Komae City, Tokyo. Phone: 03 (480) 2111). The related research works in this Laboratory are supervised by Mr. Machida, Manager of Power System Department. (Central Research Institute of Electric Power Industry began a joint research with Fuji Electric Co., Ltd. at the beginning of Fiscal 1978 and completed it in March, 1979. Currently, a smallscale research is being continued by its Power System Department).

Third-generation solid electrolyte fuel cell

National Electrotechnical Laboratory of Agency of Industrial Science and Technology (Address: 5-4-1, Mukaidai-machi, Tanashi City, Tokyo. Phone: 0424 (61) 2141).

The responsible person for this theme is Mr. Takeo Ozawa, Chief of Electronical Chemistry Laboratory of Materials Department.

7-2-3 Scale of R & D works

First-generation cell

(1) Fuji Electric Co., Ltd.

This company started its R & D work for this subject in 1972, with 6 researching persons and a budget of ¥50,000,000.* As a result from this work, they completed a hydrogen-oxygen fuel cell power plant of 10 KW class in late 1973. For the period from Fiscal 1973 to 1976, the work was carried out by 6 persons under a total budget of ¥150,000,000.**

For the period from Fiscal 1977 to 1979, it has been conducted as a joint research work with Central Research Institute of Electric Power Industry, under a total budget consisting of ¥50,000,000 by Fuji Electric Co., Ltd. and ¥50,000,000 by Central Research Institute of Electric Power Industry as well as with 10 researchers composed of 6 in Fuji Electric and 4 in the said Institute.

*$231,500.

**$694,500.

The trial-produced cell of 10 KW class has a conversion efficiency of about 60% and an output of D.C. 11.5V, 900A. The entire fuel cell system is composed of 3 kinds of modules--cell unit; hydrogen & oxygen feeding and circulating unit; and electrolytic solution circulating unit. The cell unit is an array of connecting in series 14 groups each composed of 10 cells connected in parallel. The cell uses metalic plate of 1000 cm^2 as electrode and raney alloy as catalyst. It also uses 30% KOH (potassium hydroxide) as electrolytic solution and operates at 65°C.

(2) Domestic work connected with TARGET program.

Tokyo Gas Co. and Osaka Gas Co. together imported 4 sets of on-site fuel cell power plant under this program. At that time, Tokyo Gas appropriated a budget of ¥15,000,000* with 4 researchers and Osaka Gas did a ¥8,000,000** budget with 3 researchers, where those researchers were devoted to data collection and plant maintenance to study feasibility.

Third-generation cell

(1) National Electrotechnical Laboratory

* - $70,000.
** - $37,000.

This institute commenced its R & D work for this subject in Fiscal 1976. The work was initiated with an annual budget of ¥20,000,000[1] and 3 researchers belonging to its electronical chemistry laboratory. In Fiscal 1977, those were increased to ¥50,000,000[2] and 6 persons respectively, thanks to occurrence of the energy saving boom and increased briskness of the Sunshine Program. Those for Fiscal 1978 were increased to ¥60,000,000[3] and 8 persons (, 2 of whom took charge of third-generation fuel cell and redox cell concurrently), followed by the increase for Fiscal 1979 to ¥100,000,000[4] and 10 persons. For Fiscal 1980, it is planned to demand ¥200,000,000 - 300,000,000[5] and 10 persons.

7-2-4 Applications intended for Fuel Cells Developed

The fuel cell Fuji Electric Co. tentatively manufactured in 1973 was one for demonstration and has been disassembled. The results obtained from the joint research by Fuji Electric Co. and Central Research Institute of Electric Power Industry have not yet been made public. (They are scheduled to be released within 1979.) This will be furnished at the time of release.

1. $ 92,600.
2. 232,000.
3. 278,000.
4. 463,000.
5. 926,000 - $1,390,000

Fuji Electric Co., which is a power generator manufacturer, considers to utilize its first-generation hydrogen-oxygen fuel cell for such uses as auxiliary power generation, viewing that it can be put into practical use earliest in the future among many types of fuel cells. They plan to establish a system where some number of cartridges each containing a unit cell array with respective size of output can be connected together in series to obtain a desired size of total output and such cartridges can be added, removed or exchanged readily according to requirements. It is planned that, when they can attain a scale of 30 - 50 KW per cartridge, they will, through Central Research Institute of Electric Power Industry work on power companies, asking them to adopt this system as a generator for peak load time, at the initial stage. They also plan to market this type of fuel cell system, as a substitute for existent auxiliary generators (such as those using diesel engine and gas turbine), to primary industries demanding a large quantity of electric power, including aluminum smelting industry. It is aimed to be commercialized around 1981 - 1982.

The cell under R & D work by National Electrotechnical Laboratory is currently at the stage of its basic research.

It is planned that this work will be continued till the end of Fiscal 1981 and that, if the result is successful, the work will be scaled up to a large project under Moonlight Program. The staff of this laboratory state "We can plan its applications after taking it up as a national project". However, the cell under their current R & D work is based on an idea of developing the fuel cell power plant to replace the existing thermal power plant, etc. They aim to develop a power plant which does not use fossil fuel such as petroleum, under their forecast that, in the future, power generation will come to the age of coexistence of power plants using various types of energy sources including fossil fuel, nuclear, solar and geothermal energies, MHD and fuel cell. Thus, the longevity and high efficiency have been main targets in the current trial production research for the zirconium oxide-based solid electrolyte which is of the type stabilized by addition of gallcia and yttrium. More specifically, the targets include continuous operation for 100,000 hours.

In view that the fuel cell system is compact and, if the cartridge is applied to it, can be replaced easily, it is planned to put this system in a demonstrating operation in such collective housing as apartment complex, at an initial stage of its commercialization and then to enlarge the scale of application gradually. It is anticipated that the fuel cell system is likely to be put into practical use before 1985.

7-2-5 R & D works in future and commercializing schedule.

Fuji Electric Co., Ltd. started developing the large-size cartridge system in Fiscal 1979. They are scheduled to complete a system of about 20 KW and put it under a demonstrating operation by the end of Fiscal 1980 and to commercialize one of 30 - 50 KW during the period of 1981 to 1982. National Electrotechnical Laboratory plan to continue their in-house R & D work till 1979 - 1980, then to scale up the work to a large-size project under Moonlight Program in 1981 - 1985 and then to develop a demonstration plant in 1985 - 1987.

In Japan, there is no organization known to have been researching the second-generation fuel cell. As to the third-generation fuel cell, it is rumored that Hitachi, Ltd., Matsushita Cell Co., Ltd. and Tokyo Shibaura Electric Co., Ltd. will enter into this field, in addition to National Electrotechnical Laboratory. Hitachi, Ltd. have a patent on solid electrolyte (cerium oxide). However, this patent is just based on a result which was attained by one of the researchers in their Central Research Laboratory, and they are currently performing no research work on the fuel cell itself. They appear to intend to start their research in a more serious manner if they find necessity while watching the movements of other firms.

It appears that a few additional enterprises may announce their R & D project in the field of the third-generation cell, within one or two years.

7-3 Thin Film Solid Electrolyte Fuel Cell Made by High Frequency Sputtering Process

7-3-1 Introduction:

The Solid Electrolyte Fuel Cell represents a high temperature type Fuel Cell in which electrolyte is made of such oxygen ion conductor as zirconia, stabilized with Calcium, Yttrium and the like.

It is generally understood that the operable temperature of the Stabilized Zirconia Solid Electrolyte Fuel Cells is tolerated at about 1,000°C; however in consideration of the life of heat resistant material used, its economical view point and theoretical thermodynamic efficiency of the cells, lower temperatures are more desired.

It is also generally purported that as a target value of a Fuel cell, output density is about several hundred $mWcm^{-2}$. In order to achieve this value, internal resistance per unit area of its electrode should be made less the 1 Ω cm^{-2}.

However, the fact is that in case of CSZ (Calcium stabilized Zirconia), the resistance of the solid electrolyte at the temperature of 1,000°C does register 80 Ω cm and even YSZ (Yttrium stabilized Zirconia) shows more than 10 Ω cm. To reduce the internal resistance to less than 1 Ω cm^{-2}, the thickness of the solid electrolyte is required to be made thinner, possibly 100 μm for CSZ and 1 mm for YSZ or less. Taking further the above desirable lower operation temperature into consideration, the thickness of the solid electrolyte would be more needed to be more thinner.

Since the resistance of the CSZ and YSZ will increase to 10 times when the temperature lowered by 200°C, operation temperature at 800°C requires the thickness of the solid electrolyte be one tenth of the thickness at 1,000°C.

The National Electrotechnical Laboratory, in an effort to develop a fuel cell with thinner solid electrolyte for operating at the temperature at 600 - 800°C as a target, has carried on R & D on how to make the stabilized zirconia solid electrolyte thinner as possible, adopting the High Frequency Sputter system which is an established process for preparing oxides, for a thinning technology. Also several Kinds of Oxide material for electrode have been studied for the purpose of obtaining thin electrode.

7-3-2 Apparatus

In production of the thin films, Dipole High Frequency Sputterer (Nichiden-Varian Co. product, Model FP-46, Frequency 13.56 MHz. Max. High Frequency output 1 KW) was used. Because target material was used in the forms of sintered plates and powder, adopted was the sputter-up system where the target electrode was placed lower, and substrate electrode was set at upper position.

The thickness of the film was measured by both weighing method and interference method using an interference microscope. For determination of the construction and composition of the film, a scanning electron microscope, an X-ray diffraction device and an ion microanalyzer are used. An LCR meter (YHP Co. Model 4261A) was used for conductivity determination.

7-3-3 Economy of the Fuel Cell with Stabilized Zirconia Sputtered Film

The economy of the Fuel Cell with stabilized Ziconia sputtered thin film was examined.

Assuming the thickness of YSZ film being 5 μm and the output density of the cell 0.2 W/cm^2, a comparison of economical characteristics of 3 kinds of apparatus: apparatus used in this study, a High speed sputtering apparatus in general use and a mass production high speed sputterer in general use are shown in Table 2. The Capital recovery was calculated based on the life of equipment for 20 years and the rate of interest 0.08 % per annum. The price of target material is calculated rather low, on the assumption of a mass production system using a small chunk of material. As for labor cost, assuming a man undertakes 5 devices, the value was calculated to obtain one fifth. Annual production was computed by taking into account those factors as film production speed, area, thickness of film and output. If assumed that the high speed sputterer can achieve 3 times higher film-making rate and the mass-production apparatus 10 times wider in the area, the cost comes to ¥20,000/KW.* Reckoning with future reduction of the cost along with improvement of sputtering technique and, considering furthermore, that the current construction cost of thermal power plant is ¥100,000.- ¥150,000/KW,** it is judged that the stabilized ziriconia sputtered film Fuel cell is economically not unfeasible.

* $92.60
** $453.00 - $695.00

	Current Study	High speed sputterer	Mass-production sputterer
Depositing area	100 cm^2	100 cm^2	100 cm^2
Capital recovery	¥500,000 ($2,315.)	¥800,000 ($3,704.)	¥3,000,000 ($13,890.)
O & M	500,000 ($2,315.)	500,000 ($2,315.)	1,000,000 (4,730.)
Target material	200,000 ($926.00)	50,000 ($232.00)	500,000 ($2,315.)
Utilities	90,000 ($417.)	90,000 ($417.)	700,000 ($3,241.)
Labors (1/5)	2,000,000 ($9,259.)	2,000,000 ($9,259.)	2,000,000 ($9,259.)
Total	3,290,000 ($15,231.)	3,440,000 ($15,925.)	7,200,000 ($33,333.)
Annual production	12.3 KW/year	36.9 LW/year	369 KW/year
Unit cost	¥267,000/KW ($1,236.)	¥93,000/KW ($431.)	¥20,000/KW ($92.60)

Based on: Film thickness: 5 μm

Out put density: 0.2 W cm^{-2}

Table 2. Economy comparison of Fuel Cells with sputtered film.

7. Fuel Cell

7-3-4 Conclusion

By using the High frequency Sputtering process it has been found possible to produce stabilized Zirconia solid electrolyte thin film which has essentially same structure and composition as starting substance (target material) originally has. Also it has been made possible to compose a fuel cell, using this thin film, in a structure of 3 layers of electrode-solid electrolyte-electrode.

However, the common problem found in the thin film-making for solid electrolytes and oxides electrodes is that if allowed to thicken the film, the film is apt to peel off, and is going to have uneven thickness. Especially in composing cells, solid electrolyte is deposited in film on porous substrate and so, a smooth surface of the electrode is a must.

Giving a thought to these points, currently

further investigations are under way with a concept of a combined fuel cell with bismuth oxide-based solid electrolyte which is of high electric conductivity, but is unable to use in reducing atmosphere, together with the zirconia electrolyte. When it comes to the oxides electrode thin film, a concept of composing fuel cell based on the function that an electrode catalyst gives is currently being investigated.
Unit cells which were test-produced for using iridium sintered electrodes are still undergoing continuous study on heated condition (about 800°C).