Approved: M-T. Chen 12-17-93

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InterOffice Memo

To: Dr. Edward Stone 180-904

From: Cronin B. Vining CBV

Date: November 30, 1993

Subject: **Report on Trip to two Conferences and four Laboratories related to Thermoelectric Energy Conversion in Japan, November, 1993**

Three JPLers (Dr. Jean-Pierre Fleurial, Dr. Thierry Caillat and myself) attended a thermoelectric energy conversion conference in Yokohama, Japan in November, 1993. Dr. Fleurial and I also visited the Electrotechnical Laboratory, a Japanese national laboratory. Largely because I have been elected president of the International Thermoelectric Society, I was also invited to attend a second energy-related conference in Japan as well as visit three additional laboratories. This report provides a summary of my overall impressions from this trip as well specific observations resulting from each of the sites visited.

Overall Impressions

My first impression concerns the rapid growth of energy-related R&D investment in Japan. Because of limited natural energy resources, the Japanese are pursuing a broad range of energy technologies, including a remarkable level of interest in thermoelectric energy conversion. The Japanese thermoelectric community has literally exploded in the last 2-3 years and is now easily the most active such community in the world. At the same time, they are experimenting with novel methods of financing specialized, state-of-the-art research facilities to support basic energy-related research. My feeling is that a significant fraction of this investment may yield little return, but because of the breadth and long-term nature of the commitment they will nevertheless achieve significant energy-related technology advances.

My second impression concerns a mood I sensed among the Japanese that they must pursue basic science more aggressively than in the past. Their energy problems are uniquely Japanese, for example, and they can no longer just borrow solutions from abroad. To this end, they are looking for ways to promote greater independence and creativity among their scientists. Their "third sector company" concept, in which advanced research facilities are leased to private companies, is a conscious attempt to stimulate more basic science activity. They are looking for ways to become leaders in basic science, rather than followers. They don't seem to know quite how to accomplish this yet, but they are trying very hard and it might be a mistake to underestimate their ability to adjust to the new realities.

The remaining comments are more specific in nature.

Comments on Specific Sites Visited

I will discuss the two conferences first and then I will discuss the four laboratories I visited on this trip.

XIIth International Conference on Thermoelectrics (ICT)

November 9-11, 1993, Yokohama Japan

This conference was sponsored by the Institute of Electrical Engineers of Japan and co-sponsored by the International Thermoelectric Society in order to provide a forum for thermoelectric specialists to meet and exchange recent findings. Substantial financial backing was provided by the Iketani Science & Technology Foundation. This was the first time the ICT has been held in Japan and the organizers went out of their way to arrange a world-class event. Even the organizers themselves were surprised and impressed by the large turnout.

On the day prior to the conference (November 8, 1993) the organizers also held a Short Course on Thermoelectricity covering thermoelectric materials, power generation, cooling and economics in eight lectures. I gave a lecture on the solid state physics of thermoelectric materials and Dr. Fleurial covered the properties of known thermoelectric materials. About 50 people attended the course. Most attendees came from Japan, but others came from Canada (1), China (3), France (1), Hong Kong (1), South Korea (1) and the US (3).

Perhaps the most significant conference statistic is the attendance of nearly 300 people, roughly 250 of whom were from Japan. The remainder represented about 17 different countries. There were some 155 papers presented, which is almost triple the previous record. Previous ICT conferences have attracted 100 to 110 people and 50-60 papers. It seems safe to say that there are now more people working on thermoelectricity in Japan than in the rest of the western world combined. Only the former Soviet Union has a community of comparable size.

The quality of the presentations varied greatly, as is usual at most conferences. But the average quality has improved considerably over the years. A few papers represented really first-rate science. A number of the conference regulars noted, however, that many of the Japanese papers exhibited what might be called "beginners" mistakes. Sometimes they were not familiar with related or previous work in the field. Sometimes they were trying things which veterans felt "clearly" wouldn't work.

Overwhelmingly, I feel, these mistakes were made by people new to the subject. My conversations suggest that most of the Japanese participants had been working on thermoelectric problems for less than 2 years. Given the recent growth and the magnitude of the effort in Japan, I feel sure that the competence will improve rapidly.

Many people were trying to understand *why* there is so much interest in Japan. Not even the conference organizers could give a simple answer to this question. But whatever the answer, one thing is clear: significant amounts of R&D monies are being

broadly invested in thermoelectricity in Japan. Also, they appear to be prepared to sustain the investment over time.

Symposium on New Energy Technologies

November 16-17, 1993, Ube, Japan

This conference was organized by the local prefecturate government as part of a series of conferences to promote high-technology issues in the region. There were 11 one-hour presentations on energy-related issues. Four of the talks were rather high-level discussions of national energy issues and programs. The president of Yokohama National University spoke on "Problems of energy demand in the 21st century" and the director of Chugoku Electric Power spoke on "Importance of new energies developments," for example.

The remaining talks focused on various particular energy-related technologies. I was invited to speak on "Thermoelectric Technology of Today and Tomorrow," while other speakers addressed fuel cells, AMTEC, solar cells, fusion and superconductors.

This was a truly unique experience for me as I was the only one of 179 attendees who was not from Japan. While I do not speak Japanese, I was able to get some sense of the proceedings from the figures and conversations during the breaks. The sense I get is that the Japanese are very concerned about not only the supply and cost of energy, but also about the environmental impact of energy technologies. They have virtually no natural energy resources and construction of new nuclear energy facilities has slowed dramatically. Moreover, Japan is so densely populated that pollution from any power plant directly affects agriculture and/or population centers.

They are particularly interested in recovering low grade heat (~200 ^{o}C). Even if the efficiency is low, this represents energy which is otherwise wasted. This is one reason for their strong interest in thermoelectric technology, which actually becomes fairly competitive for this application. One initiative alone under the "New Sunshine" project plans to spend ¥50 billion over eight years (about $60M/year) on waste heat recovery. A large fraction of this effort is devoted to thermoelectric R&D.

Electrotechnical Laboratory (ETL) of the Ministry of International Trade and Industry (MITI)

Tsukuba Science City, Ibaraki prefecturate, Japan

Dr. Jean-Pierre Fleurial (JPL) and myself were invited to visit ETL by Dr. Toshitaka Ohta, who spent one year as a visiting scientist in our group at JPL. Tsukuba Science City is a planned city with about four dozen national research labs, and about 200 foreign and domestic laboratories in the vicinity. ETL itself has a budget of about $100 million and about 634 staff. ETL's role is to foster basic science related to electronics, energy, information and standards. Dr. Ohta is part of the Environmental Energy Section and his interests are in thermoelectricity. We visited six different laboratories within ETL covering work on amorphous Si, silicon-germanium molecular beam epitaxy,

crystal growth, EXAFS (extended X-ray absorption fine structure), laser fusion and Dr. Ohta's own thermoelectric laboratories.

My impression is that some first-rate science is being done at ETL. Each of the people we met were articulate (even in English) and very well informed. Particularly in collaboration with some of the other groups at ETL, Ohta seems well positioned to do some excellent work on thermoelectrics. Like many other Japanese researches, he has spent much of the last year or two writing proposals and trying to land research funding. Now, however, he has funding commitments good for many years.

Yamaguchi University

Ube city, Yamaguchi prefecturate, Japan.

I visited two different laboratories at Yamaguchi University. The first laboratory, under Dr. Matsubara, focuses on thermoelectric energy conversion and the second, under Dr. Fukumasa, focuses on plasma-jet reactors for materials synthesis. The materials preparation facilities in both laboratories were modern, well maintained and capable of state-of-the-art research. Dr. Matsubara has a particularly unique facility of his own design for processing powders in a plasma environment. His laboratory also has various characterization equipment such as X-ray diffraction and SEM.

The only disappointing feature of this laboratory was the thermoelectric measurement capabilities. These facilities are critical to thermoelectric research and the facilities at Yamaguchi could be significantly improved. They use the simplest possible techniques which would require extreme care to yield reliable results. And, they have no thermal conductivity facilities at all so overall thermoelectric performance can only be estimated.

The Japan Ultrahigh-Temperature Materials Research Center (JUTEM)

Ube city, Yamaguchi prefecturate, Japan.

JUTEM (opened in 1992) is one of about seven major new R&D facilities organized by NEDO (New Energy and Industrial Technology Development Organization), a quasi-governmental agency under MITI (Ministry of International Trade and Industry) intended to promote fundamental research. An attachment describes the NEDO initiative in more detail. JUTEM is called a "third sector company," because these facilities are capitalized (~$45M total capitalization) using a combination of government and private investment. Their intent is to provide a place where companies can send personnel and, for a fee, have access to state-of-the art facilities for performing R&D. The private investors eventually hope to show a profit operating the facilities, while the users have the opportunity to do advanced research without the cost of establishing advanced facilities.

I was treated to a personal tour by the president of JUTEM. Virtually every piece of equipment will operate at 2000 °C or greater. I saw materials preparation facilities such as arc-melting, Bridgman growth, zone melting, gas atomization and various powder metallurgy and plasma coating facilities. The HIP (hot isostatic press) was

typical of the temperature and size capabilities of these facilities: temperatures up to 3000 °C, 10" diameter by 24" long compacts can be prepared. The facility also has very complete materials evaluation facilities for metallographic, thermal and mechanical characterizations. All of the equipment was very new, very state-of-the-art and appeared to be competently staffed.

If one wishes to do research here they will provide private office space, private labs (if desired) and access to the facilities. They expressed a significant concern over protecting the intellectual rights of the users and have made every effort to protect the privacy of individual researchers. My impression was that the facility is currently significantly under-utilized and that relatively favorable terms could be negotiated. To date, they have had no foreign users. I've attached a copy of an advertisement they placed in *Nature* which gives further details.

Ion Engineering Center Corporation (IECC)

Hirakata city, Osaka prefecturate, Japan.

IECC (~$74M total capitalization) is another "third sector company" intended to make available for lease specialized research facilities. IECC is located near Osaka and Kyoto in a new, planned city called KANSAI SCIENCE CITY. Eventually, Kansai will be home to many high-tech R&D laboratories serving the southern part of Japan, just as Tsukuba Science City now serves the northern part.

As the name implies, IECC emphasizes ion techniques ranging in energies from eV to MeV. Again, I received a personal tour from the president. I saw an impressive range of facilities including epitaxial growth, plating, sputtering, etching, and various implantation and irradiation facilities ranging in size up to an 8 MeV implantation system. The preparation facilities were again supported by a wide range of analysis facilities including various spectrometers (Raman, FTIR, XPS, Auger, SIMS, UV-visible, etc.) and thermal facilities (thermal diffusivity, C_p, thermal expansion, etc.). Interestingly, they have one of the few high temperature Hall effect facilities I've seen outside of JPL.

Like the JUTEM facility, all of the equipment is state-of-the-art and appears to be under utilized. Both facilities blame the recession for the low occupancy rate and expect business to pick up as the economy improves.

Attachments:

1) National R&D Projects in Japan
2) JUTEM advertisement from *Nature*.

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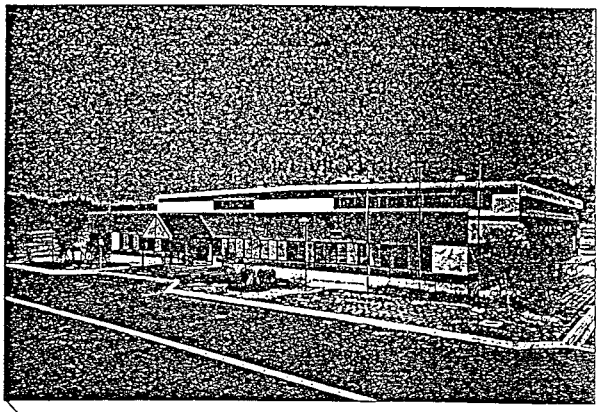
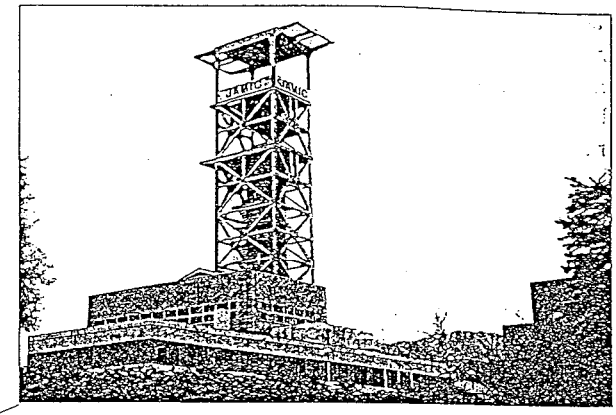
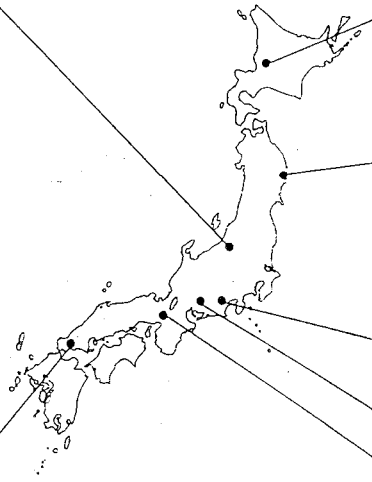
■ Applied Laser Engineering Center (ALEC)



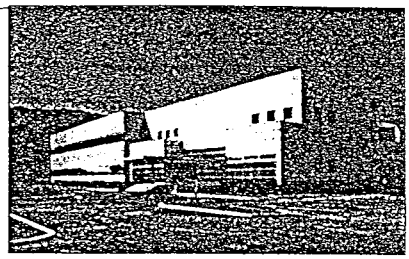
■ Japan Microgravity Center (JAMIC)



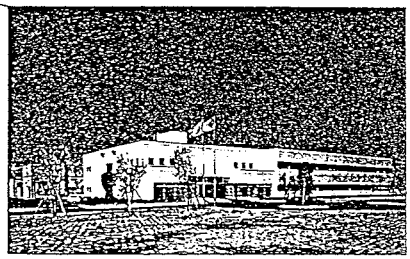


■ Research Center for the Industrial Utilization of Marine Organisms

— Kamaishi Center —

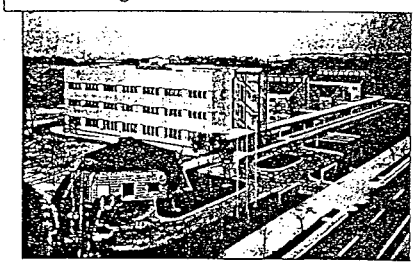


— Shimizu Center —

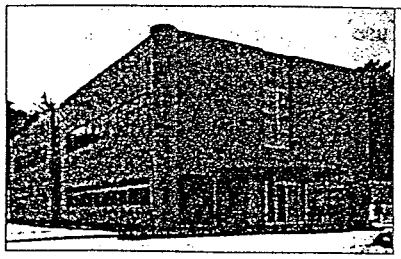


■ Japan Ultrahigh-Temperature Materials Research Center (JUTEM)

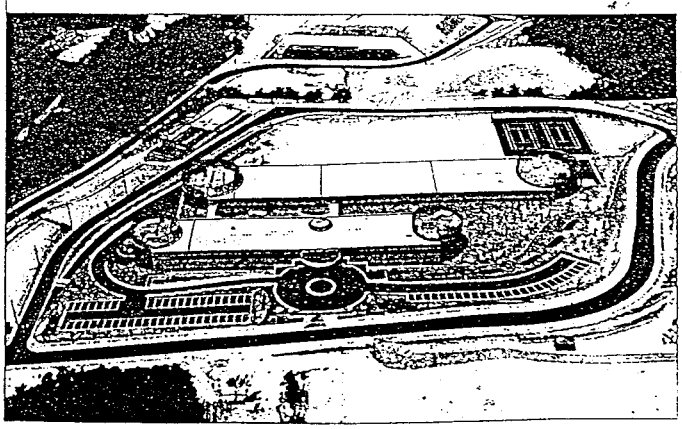
— Yamaguchi Center —



— Gifu Center —



■ Ion Engineering Center Corporation (IECC)



These facilities, which were established as described above, are open to researchers belonging to the governmental, industrial and academic sectors, and will promote domestic technology research, welcome foreign researchers, and enable Japan to contribute to the advancement of research for technology development.

Outline of the Facilities

At present, five Research Facility Development Corporations (Centers) have been established in seven regions throughout the country, as shown in the accompanying table. (The details for each center will be described in the following issue of this publication.)

The Research Center for the Industrial Utilization of Marine Organisms opened in April 1990 ahead of the other centers, followed by the opening of the Japan Microgravity Center in October 1991. The Ion Engineering Center Corporation and the Applied Laser Engineering Center were both opened in April 1992, and the Japan Ultrahigh-Temperature Materials Research Center in June the same year.

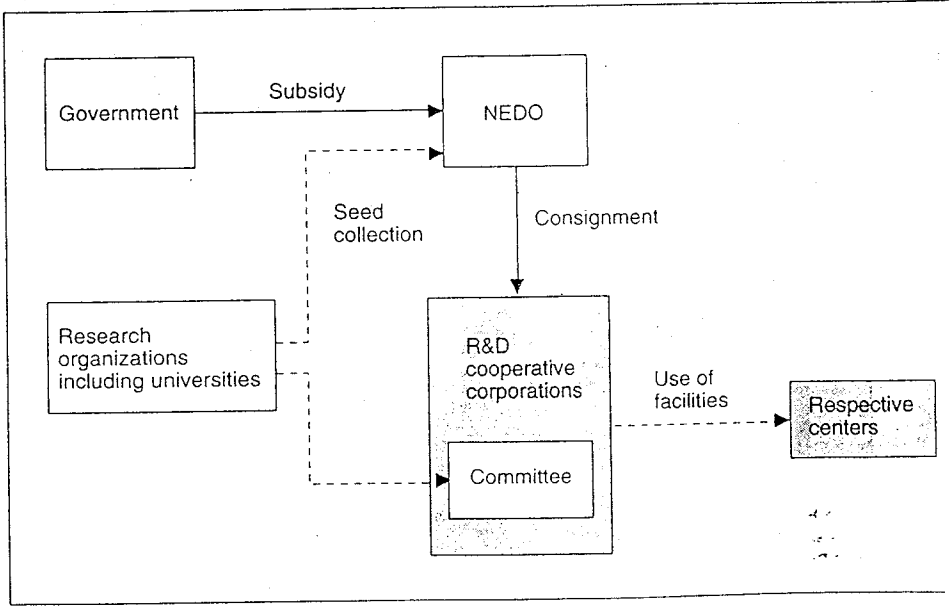
The research facilities provided at these five centers are the most advanced in their fields of research, and are attracting the interest and admiration of both domestic and foreign researchers and specialists. Already, the results of research conducted by these advanced facilities are being announced at international science and technology meetings and acclaimed highly. Also, these centers are all established outside the Kanto (Tokyo) Region, and are therefore expected to increase the technological levels of these regions and to correct the present situation of science and industrial research and development potential being concentrated in the Tokyo region.

Each center has established laboratories called R&D cooperative corporations, and the center's research facilities are increasingly used by these R&D cooperative corporations to carry out self-implemented research programs and research under consignment. A typical example is the Research for the Leading Fundermental Studies Optimum for the Advanced Research Facilities. This system was implemented in FY 1992, with NEDO taking the leadership by selecting the leading fundamental research themes from the research and development activities advanced by domestic and foreign universities and other

List of Research Facility Development Corporations

Name of Center	Location	Investment (¥100 million)	Construction Period (FY)
Ion Engineering Center Corporation	Hirakata City, Osaka	78	1988 -1991
Research Center for the Industrial Utilization of Marine Organisms	Kamaishi City, Iwate (Kamaishi Center) Shimizu City, Shizuoka (Shimizu Center)	60	1988 -1989
Japan Microgravity Center	Kami-Sunagawa-cho, Hokkaido	52	1988 -1992
Japan Ultrahigh-Temperature Materials Research Center	Ube City, Yamaguchi (Yamaguchi Center) Tajimi City, Gifu Pref. (Gifu Center)	45	1989 -1992
Applied Laser Engineering Center	Nagaoka City, Niigata	21	1989 -1991

Schematic diagram of the Research for the Leading Fundermental Studies Optimum for the Advanced Research Facilities



use of the advanced research facilities in the future. Studies following the selection such as how the research activity will use the facilities and the potential of the results are consigned by NEDO to the R&D cooperation corporations.

Postscript

As pointed out earlier, the Research Facility Development Program is vital in 1) promoting industrial technology research and development in Japan, 2) contributing advancement of industrial technology r search and development, and 3) region promotion of industrial technologie These research facilities are expected to a as the driving force for accelerating a tivities in the sectors of fundamental r search.

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ACCESS TO JAPAN'S HIGH-TECH RESEARCH FACILITIES

★ OPPORTUNITIES FOR RENTAL AND COLLABORATIVE RESEARCH ★

NEDO

Introduction

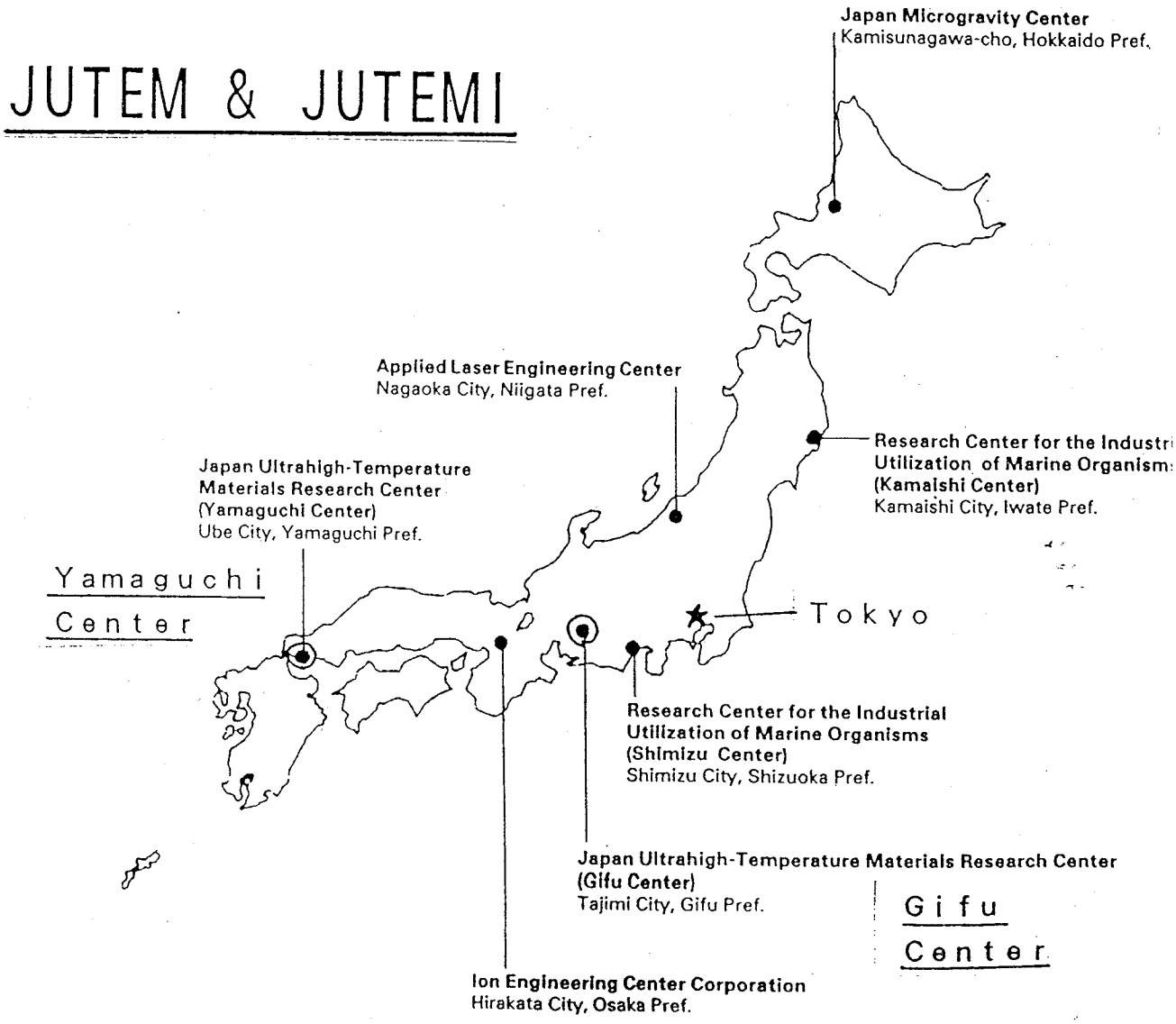
Since October 1988, the New Energy and Industrial Technology Development Organization (NEDO, an implementing agency of the Japane Government) has been engaged in the implementation of a research facility development program. The purpose of the program is to establ "Research Facility Development Corporations" for the promotion of research and development of advanced industrial technology. In particul these corporations are devoted to the development of research facilities that are too expensive to be tackled by the private sector alone. The facilit thus developed are made available for the use of both domestic and foreign researchers.

Each Research Facility Development Corporation, which operates the facilities it develops, is funded by NEDO, private companies and lo governments. NEDO promotes research and development projects that will make the maximum use of these corporations. At at the same tir NEDO supports these corporations so that they will contribute to the progress of the international community through the development of advanc research facilities and industrial technology. Five Research Facility Development Corporations have been established of which (1)-(5) are be introduced worldwide at this time.

Research Facility Development Corporations

(1) Ion Engineering Center Corporation [IECC] (Hirakata City, Osaka Prefecture)
(2) Research Center for the Industrial Utilization of Marine Organisms (Kamaishi City, Iwate Prefecture, and Shimizu City, Shizuoka Prefectu
(3) Japan Microgravity Center [JAMIC] (Kamisunagawa-cho, Hokkaido Prefecture)
(4) Japan Ultrahigh-Temperature Materials Research Center [JUTEM] (Ube City, Yamaguchi Prefecture, and Tajimi City, Gifu Prefecture
(5) Applied Laser Engineering Center [ALEC] (Nagaoka City, Niigata Prefecture)

Locations of Research Facility Development Corporations



ACCESS TO JAPAN'S HIGH-TECH RESEARCH FACILITIES

★ OPPORTUNITIES FOR RENTAL AND COLLABORATIVE RESEARCH ★

NEDO

Defying the Impossible

2000°C — Development of materials that can withstand ultra-high temperature environments.

1. Japan Ultrahigh-Temperature Materials Research Center (JUTEM)

Although work on the facilities at the Japan Ultrahigh-Temperature Materials Research Center (JUTEM) has been in progress since 1989, in Ube (Yamaguchi Pref.) and Tajimi (Gifu Pref.), full-scale operations as a "Research Facility Development Corporation" will begin from April, 1992. The center aims to provide an environment for fundamental research development for the purposes of development of materials that can be used at ultrahigh-temperatures.

The desire to develop the sorts of advanced, ultrahigh-temperature materials that will retain their strength and functional characteristics even under extreme high temperature conditions of not less than 2000°C, particularly for application in leading edge high-technology fields such as aerospace and energy, has led to the inclusion of an advanced research facility for original research in these areas as part of the Yamaguchi Center (Ube City, Yamaguchi Prefecture) and of a similar leading edge research facility, specializing in the evaluation of material characteristics from an applicational point of view, as part of the Gifu Center (Tajimi City, Gifu Prefecture).

When this facility comes into operation, it will constitute the largest single integrated research organization of its kind in the world with a research program specifically attuned to the development and practical evaluation of an extremely wide range of new metal, ceramic, carbon and related composite materials. This marks the start of the final assault on the 2000°C high temperature barrier.

(Head Office: Ube City, Yamaguchi Prefecture. Research Centers: Yamaguchi Center: Ube City, Yamaguchi Prefecture; Gifu Center: Tajimi City, Gifu Prefecture.

2. Fields of application:

It is anticipated that ultrahigh-temperature materials will be developed for use in the following areas.

1) Aerospace: High performance jet engine turbine blade materials, space shuttle engine materials, high strength, light weight, ultrahigh-temperature resistant materials for space shuttle engines.

2) Energy: High efficiency gas turbine blade materials for electric power generation, coal gasification plant materials, nuclear fusion furnace wall materials, electrolytes and electrodes for high temperature fuel cells.

3) Transport and other private sector equipment: Gas turbine blade materials for motor vehicles, brake materials.

4) Materials manufacturing, etc.: Thermal radiation tubes and heat resistant materials for heating furnaces, heat exchanger materials, ultrahigh-temperature furnace heaters.

3. Fundamental research facilities:

These research facilities have been specifically designed for the development and evaluation of ultrahigh-temperature materials but could equally, of course, be used for the development and evaluation of regular structural materials. Some of the more important facilities are listed below.

1) General material development facilities:

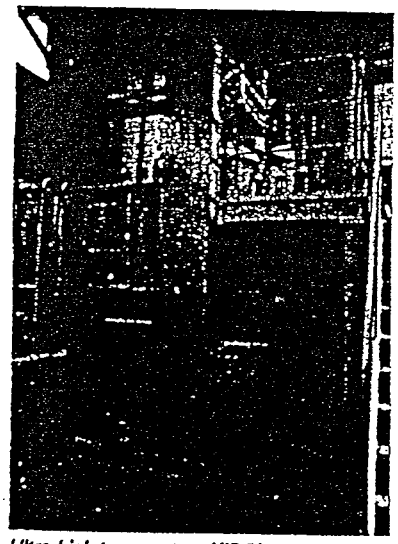
★ Plasma are melt layered coagulation furnace: Capable of melting metal materials up to a maximum of 2,500°C. Maximum melting weight equivalent to 30kg of steel.

★ Ceramic gas phase synthesizer: Synthesis of nanometer size ceramic particles by gas phase reaction.

★ Ultra-high temperature HIP: Sintering and forming of metal ceramic and carbon particulates at maximum temperature 3,000°C and pressure 2,000 atmospheres. Maximum product size = diameter 250 x length 500mm.

★ Ultra-high pressure HIP: Sintering and forming of metal ceramic and carbon particulates at maximum temperature 2,000°C and pressure 10,000 atmospheres. Maximum product size = diameter 50 x length 100mm. Oxidizing HIP at 1,400°C under 5% oxygen atmosphere can successfully be carried out.

★ Hot press: Sintering and pressing of metal ceramic and carbon particulates at maximum temperature 2,500°C, 355 ton f. Maximum external diameter of mold = 450mm. Ultra-plastic working of metals and ceramics possible at 10^{-4}/sec.



Ultra-high temperature HIP (Yamaguchi Center).

2) Characteristic evaluation facilities:

★ X-ray diffraction unit: Ultra-sensitive, high-speed imaging plate effective up to maximum of 2,500°C.

★ Thermal characteristics evaluation unit: Measurement of 6 types of thermal characteristics including thermal expansion and thermal conductivity up to a maximum of 2,500°C.

★ High temperature multi-axial characteristic evaluation facility: Evaluation of breaking behavior of composite materials under application of tensile and compression loads of 10 ton f along two axes at maximum 1,800°C. Immediate observation of surface possible using scanning laser microscope.

★ Mechanical characteristic evaluation facility: Evaluation of tensile, compression and bending characteristics and fatigue and creep strength up to maximum 2,500°C.

★ Environmental evaluation facility: Evaluation of a range of characteristics including heat cycle, thermal shock, oxidation, volatility and erosion up to maximum 2,300°C.

Erosion test equipment (Gifu Center).

4. Enquiries about using the centers should be made to the following addresses in Japan.

The Japan Ultrahigh-Temperature Materials Research Center:

Yamaguchi Center:
573-3 Oaza Okiube
Ube-shi
Yamaguchi-ken 755
Japan
Tel: 0836-51-7007
Fax: 0836-51-7011

Gifu Center:
3-1-8 Higashi-machi
Tajimi-shi
Gifu-ken 507
Japan
Tel: 0572-25-5380