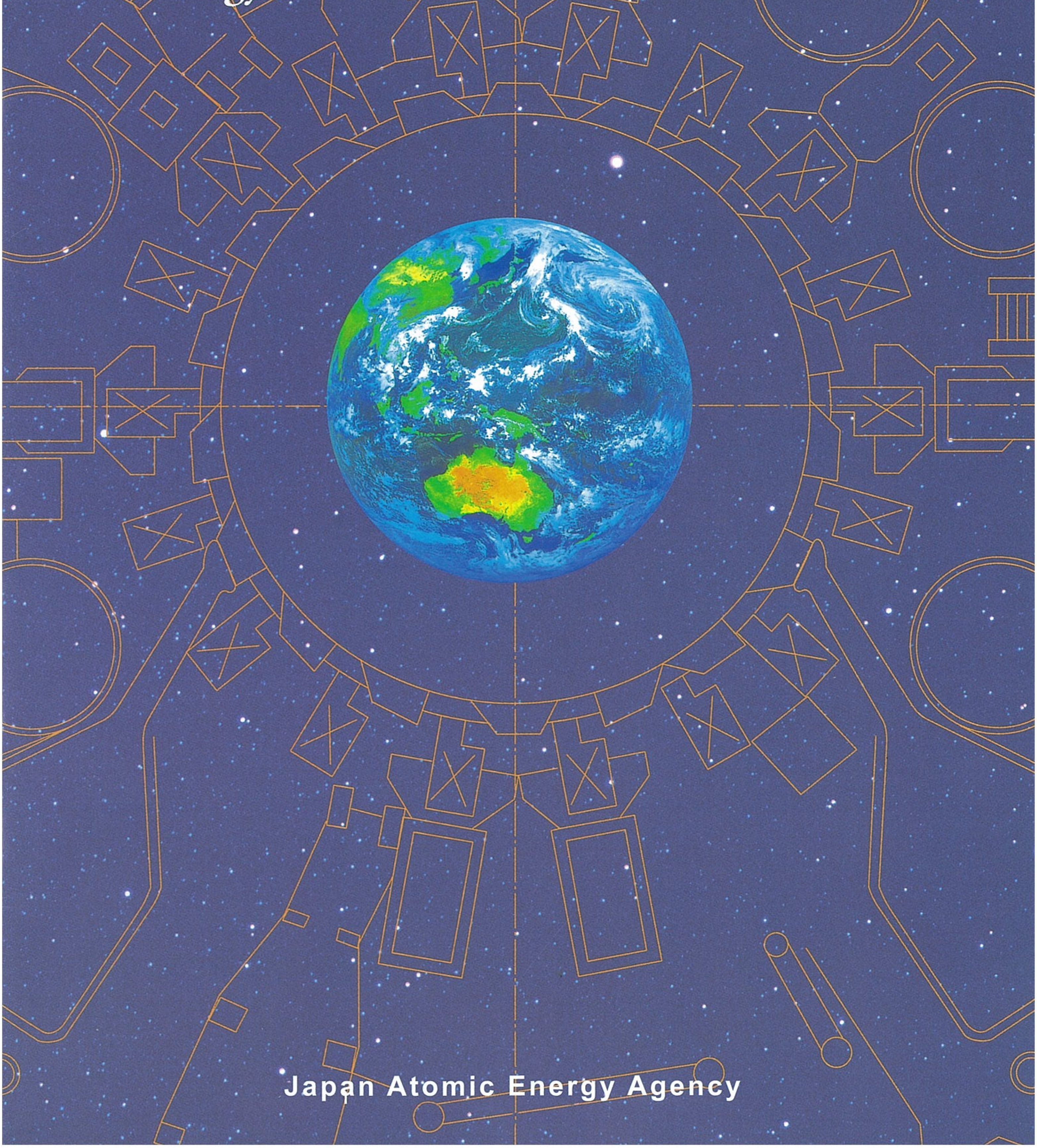
FUSION

Future Energy of the Earth

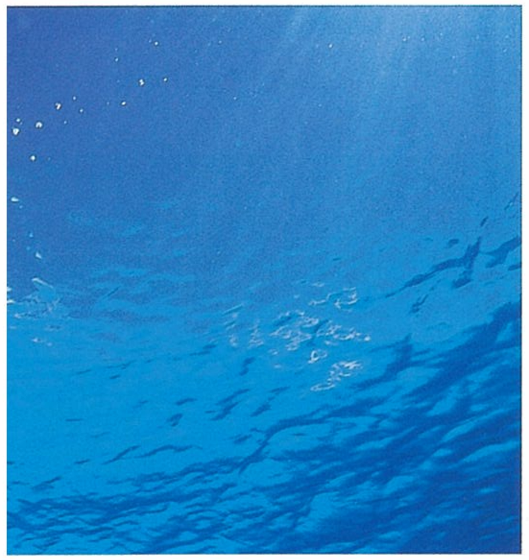
Naka Fusion Institute



Japan Atomic Energy Agency

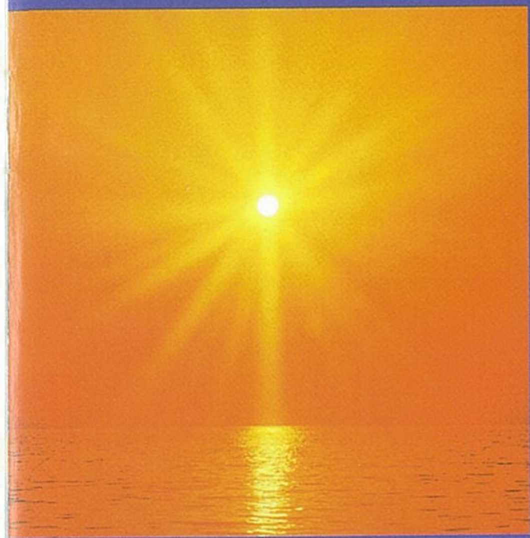
The Promise of Fusion Energy

FUSION—Nuclear fusion is the energy source that powers the sun and stars in which light atomic nuclei fuse together by thermonuclear reactions, releasing a large amount of energy. Fusion power can be generated on earth using the isotopes of hydrogen, heavy hydrogen (deuterium) and tritium at ultra high temperature.
By harnessing this power, mankind can obtain an abundant and inexhaustible energy resource.



Plentiful Fuel Resource

Deuterium exists in sea water at a ratio of approximately 33 grams per cubic meter. Tritium can be produced by nuclear reaction with lithium in the fusion reactor. Since this lithium exists plentifully as mineral resources and is included in sea water at approximately 0.2 grams per cubic meter, fusion has practically inexhaustible fuel resources.



High Energy Generating Rate

Fusion can generate energy equivalent to 8 tons of oil with 1gram of deuterium and tritium. The fusion fuel required for operating a 1,000MW electric power plant for 1 year is approximately 0.2 tons (at 70% duty factor).
(In order to obtain the same energy, approximately 1,400,000 tons of oil are required)

F U S I O N

From sea water... Safely... Abundant power... And toward the future...

Energy favorable for environment and safety

Fusion produces helium gas as a byproduct ("ash") of fuel burning. Carbon dioxide, nitric oxide and other gases which cause global environmental pollution are not generated in the reaction. Furthermore, similar to a gas burner, the reaction can be easily stopped by closing the fuel supply valve.

Contribution to Advanced Technologies

Fusion power plants need the integrated technologies of superconducting magnets, robots, heat resistant materials, ion beams, microwaves, etc. Realizing fusion energy will promote advanced technological development towards the future and will widely serve society.

To Utilize Fusion Energy

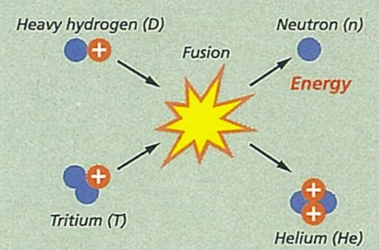
In Naka Fusion Institute, the comprehensive research and development for fusion energy are performed in three important areas;
"ITER Project" that demonstrates the scientific and technical feasibility of fusion energy by international cooperation,
"Fusion Plasma Research" that pursuits controlled burning of fusion fuels and
"Fusion Engineering Research" that supports the realization of fusion plasmas.
JAEA is accomplishing a remarkable result and progress that leads the world in recent years.

plasma production

To utilize the fusion energy, it is necessary to heat fuels to a temperature of more than 100 million ℃ and keep them in a plasma state for the fusion reaction to continuously take place.

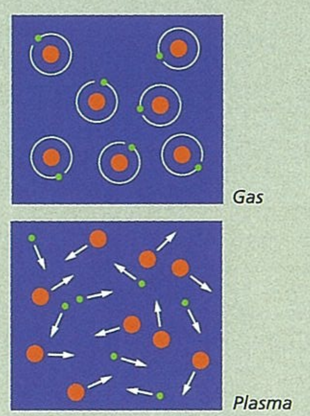
fusion reaction

Light nuclei collide with each other and form a heavier nucleus. At this moment, a huge amount of energy is released. The easiest fusion reaction to occur is the one between deuterium (D) and tritium (T).



plasma

Gas is a state where molecules or atoms move freely in space. When the temperature exceeds about ten thousand ℃, the state turns into another one in which the electrons and nuclei which form the atoms are separated and move freely. This state is called a plasma.

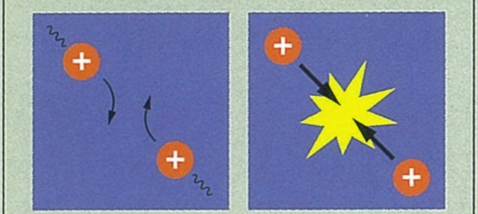


sustainment of high temperature plasmas

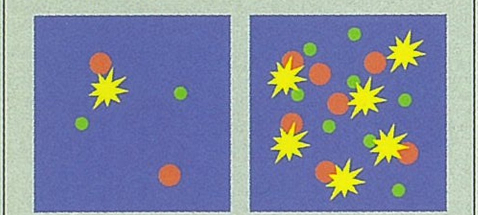
In order to produce and maintain the fusion reaction, the plasma has to be kept at a high temperature.

conditions for fusion reactions to occur

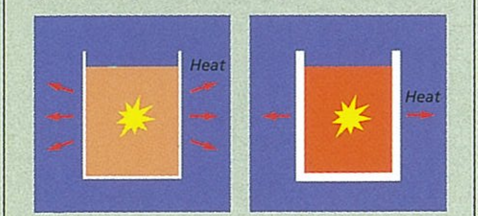
It is necessary to keep the plasma at a high temperature, in order to initiate and sustain the fusion reaction.



Keep the plasma density high enough to have effective fusion reactions.



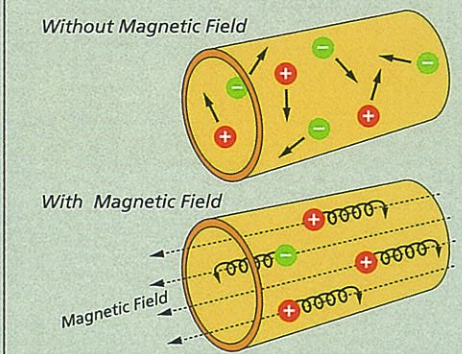
Make the plasma confinement (thermal insulation) good enough to maintain high temperature.



confine the plasma in a magnetic field

principle of magnetic confinement

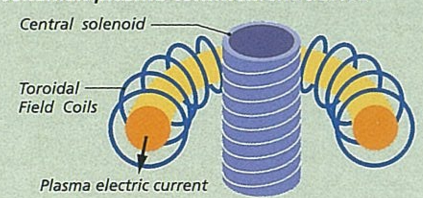
Both ions and electrons, of which the plasma consists, have electrical charge and move spirally along a magnetic field line by nature.



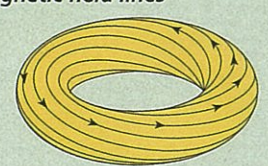
tokamak

In JAEA, the tokamak system, which is superior in producing and sustaining a high temperature plasma, is adopted for fusion energy research. In a tokamak system, a nest of magnetic field lines which are produced by external magnets located around the vacuum chamber and by a large current in the plasma confines the plasma in the vacuum chamber.

Tokamak plasma confinement device



Vessel of magnetic field lines



Introduction

FUSION

ITER Project

Research and Development of ITER

JAEA contributes as a domestic agency of Japan to the ITER Project by international cooperation.

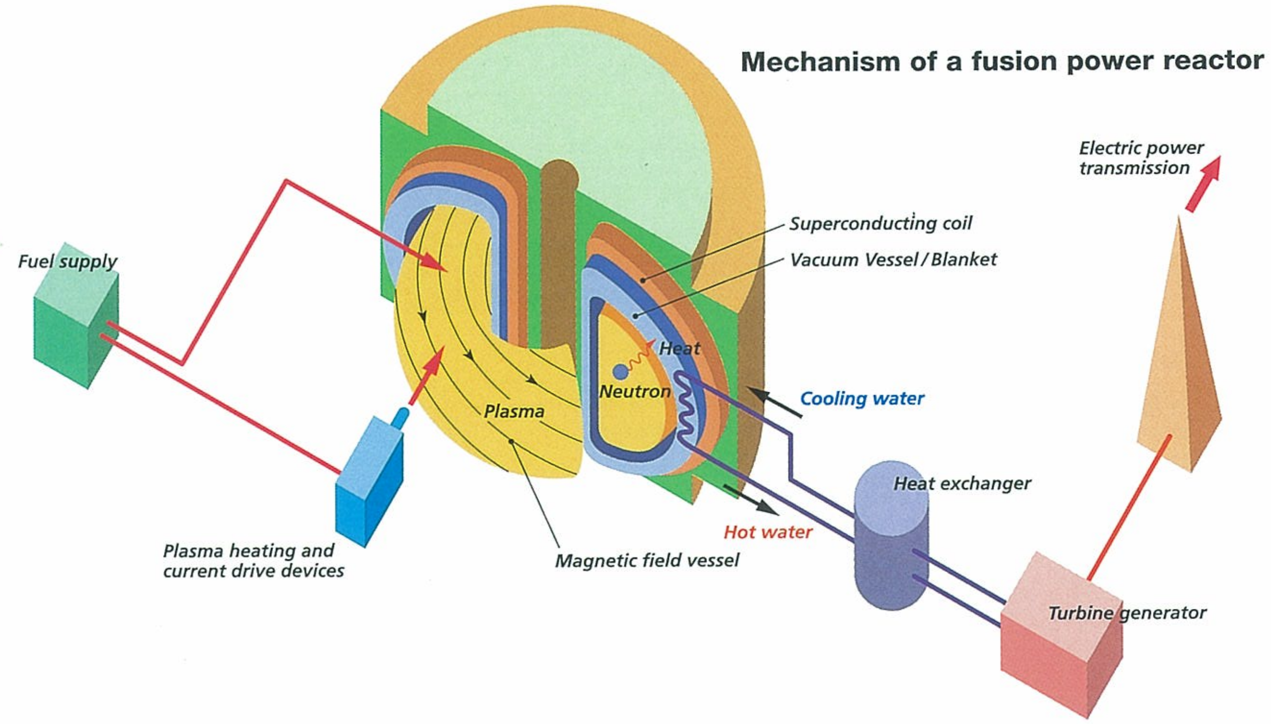
JAEA develops and procures the equipments and devices that Japan was allotted, and plays a role as the contact points of a personnel contribution, and also engages in Broader Approach Activities by cooperation of Japan and EU, in parallel with ITER Project.

Plasma Physics

Research and Development of Fusion Plasmas

JAEA continues research and development in producing and sustaining high temperature plasmas to utilize fusion energy.
Plasma research using the JT-60 tokamak, development of plasma control techniques related to plasma heating and plasma confinement, as well as theoretical research using super-computers are in progress.

Mechanism of a fusion power reactor



Research and Development of Fusion Reactor Engineering Technology

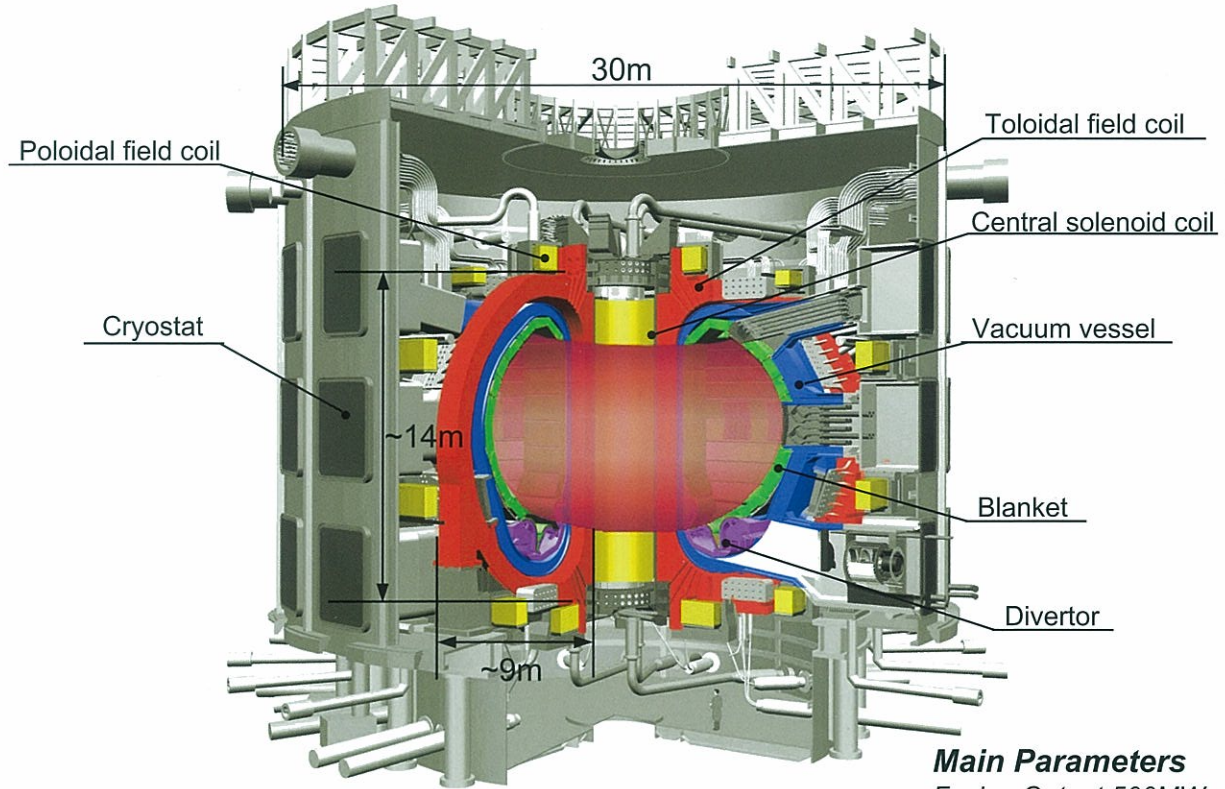
JAEA is striving toward the development of large vacuum vessels and superconducting magnets to produce and sustain high temperature plasmas, and devices to heat plasmas to more than 100 million℃.
Also JAEA emphasizes research in treating fuels, extracting the helium "ash", and technologies to utilize the fusion power generated.
Furthermore, remote handling technology to operate and maintain a fusion reactor safely, and research to establish effective safety procedures have been developed.

Fusion Technologies

ITER (International Thermonuclear Experimental Reactor) Project

Utilization of fusion energy is one of the most attractive options for a future long-term energy source which responds to a common demand of mankind.
The ITER Project is a research cooperation using international resources and expertise toward the practical realization of fusion energy.

Conceptual Drawing of ITER



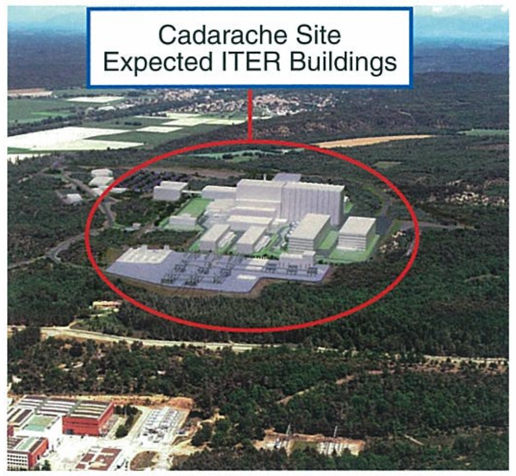
Target of ITER

Controlled ignited plasma and extended plasma burn
Demonstration of engineering technologies required for utilization of fusion energy

Main Parameters

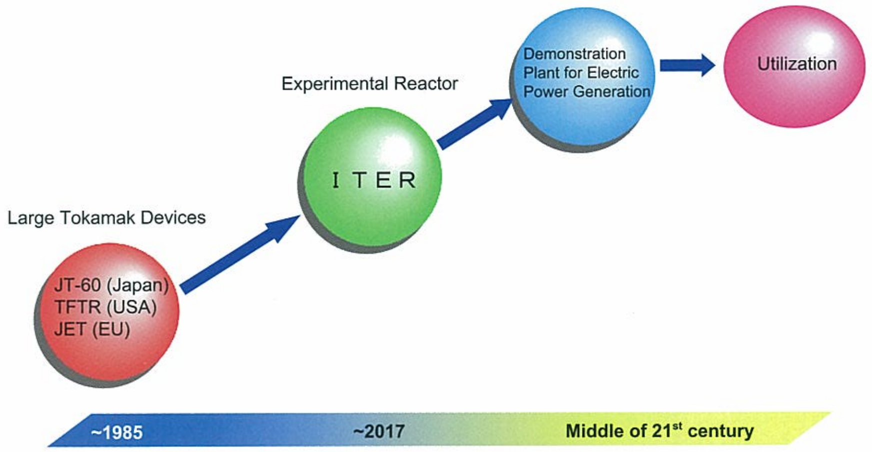
Fusion Output 500MW
Major Radius 6.2m~6.5m
Minor Radius 1.9m~2.4m
Plasma Current 13MA-17MA

Decision of ITER Site



ITER was decided to be constructed at Cadarache in France and Joint Declaration was signed by ITER parties in the ministerial meeting for ITER on June 28th, 2005 in Moscow.

A Way Towards Practical Use of Fusion Energy



ITER Domestic Agency Activities

The ITER Agreement was signed by Japan, European Union (EU), Russia, USA, China, Korea, and India in November 2006, and the activities to begin the ITER construction in full scale are performed by the ITER Organization, which was established at ITER site of Cadarache in France. JAEA was designated as a domestic agency of ITER Project in Japan, and procures the equipments and devices such as the superconducting coils that Japan was allotted, and plays a role as the contact points of a personnel contribution of Japan to the ITER Project.

History up to Today

1985
Joint statement of fusion research and development promotion at the USA and USSR summit conference

1988-1990
ITER Conceptual Design Activities (CDA)

1992-2001
ITER Engineering Design Activities (EDA)

2001-2002
ITER Coordinated Technical Activities (CTA)

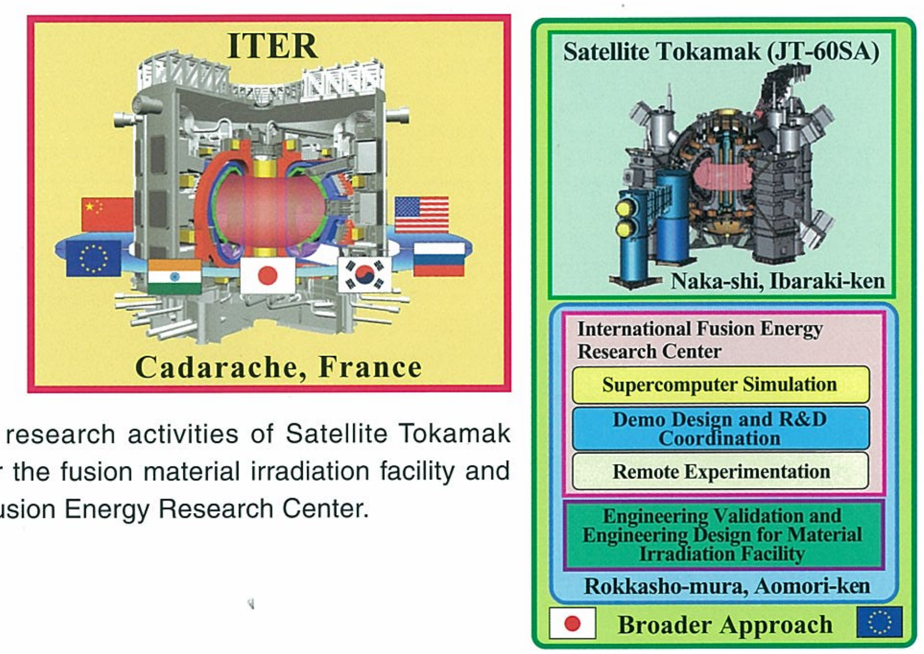
2003-2006
ITER Transitional Arrangements (ITA)

2006.11
ITER Agreement was signed

2007.10
ITER Agreement entered into force

Broader Approach Activities

It is a joint project by Japan and EU, which executes the supportive research for ITER and the research and development for a DEMO reactor, the next step of ITER, aiming at the early realization of fusion energy. It is implemented in Japan during the term of ITER construction (about 10 years).
It consists of three projects; the research activities of Satellite Tokamak (JT-60SA), the design activities for the fusion material irradiation facility and the activities of the International Fusion Energy Research Center.



Research and Development of Fusion Plasmas

In fusion plasma research, plasma control techniques for achieving a self-ignition condition, in which the plasma is kept burning only by self-generated fusion power, is under development.
This study is conducted by utilizing a large tokamak device, JT-60.
Fusion research for scientific feasibility is progressing steadily under the leadership of JT-60.

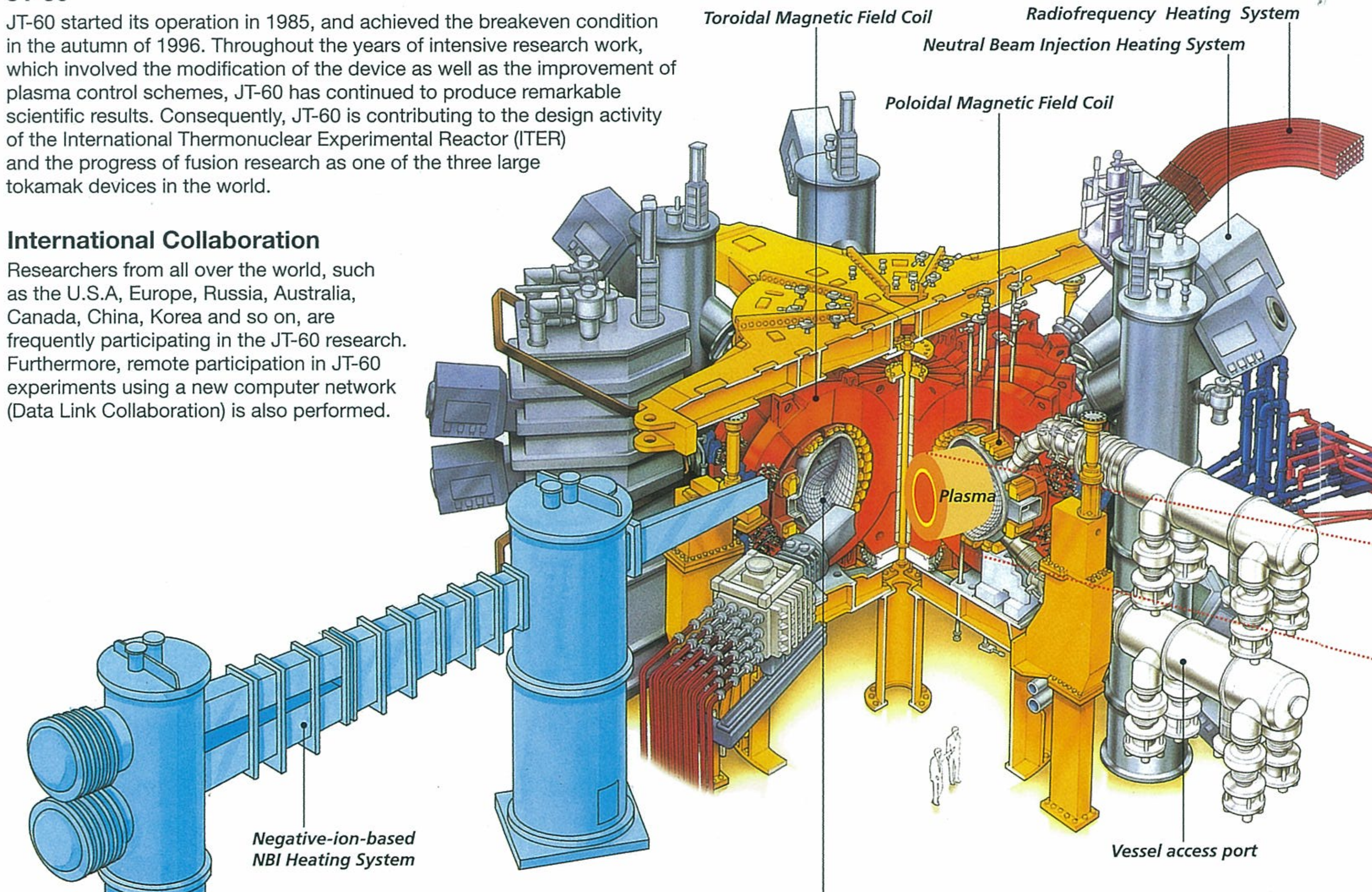
Research and Development by Tokamak Devices

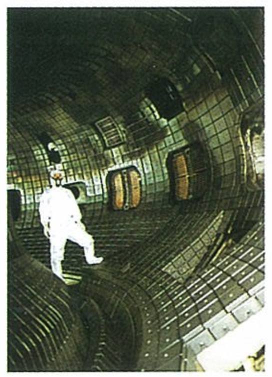
JT-60

JT-60 started its operation in 1985, and achieved the breakeven condition in the autumn of 1996. Throughout the years of intensive research work, which involved the modification of the device as well as the improvement of plasma control schemes, JT-60 has continued to produce remarkable scientific results. Consequently, JT-60 is contributing to the design activity of the International Thermonuclear Experimental Reactor (ITER) and the progress of fusion research as one of the three large tokamak devices in the world.

International Collaboration

Researchers from all over the world, such as the U.S.A, Europe, Russia, Australia, Canada, China, Korea and so on, are frequently participating in the JT-60 research. Furthermore, remote participation in JT-60 experiments using a new computer network (Data Link Collaboration) is also performed.





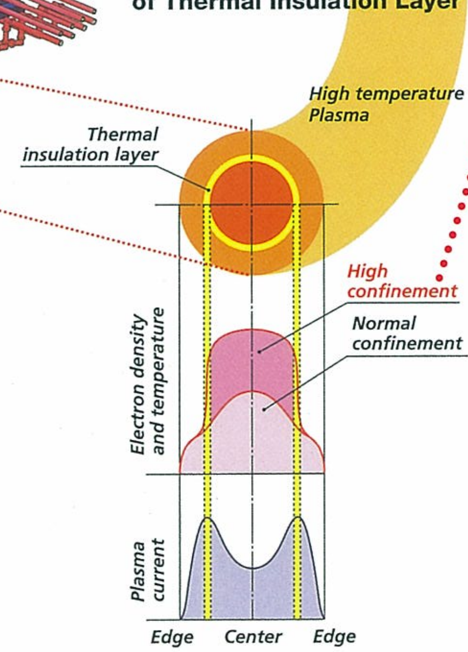
Inside of Vacuum Vessel
About ten thousand carbon tiles protect the vacuum vessel from the high temperature plasma.
In 1997, the divertor geometry at the bottom of the vacuum vessel was modified, in order to improve the heat and particle flux controllabilities.

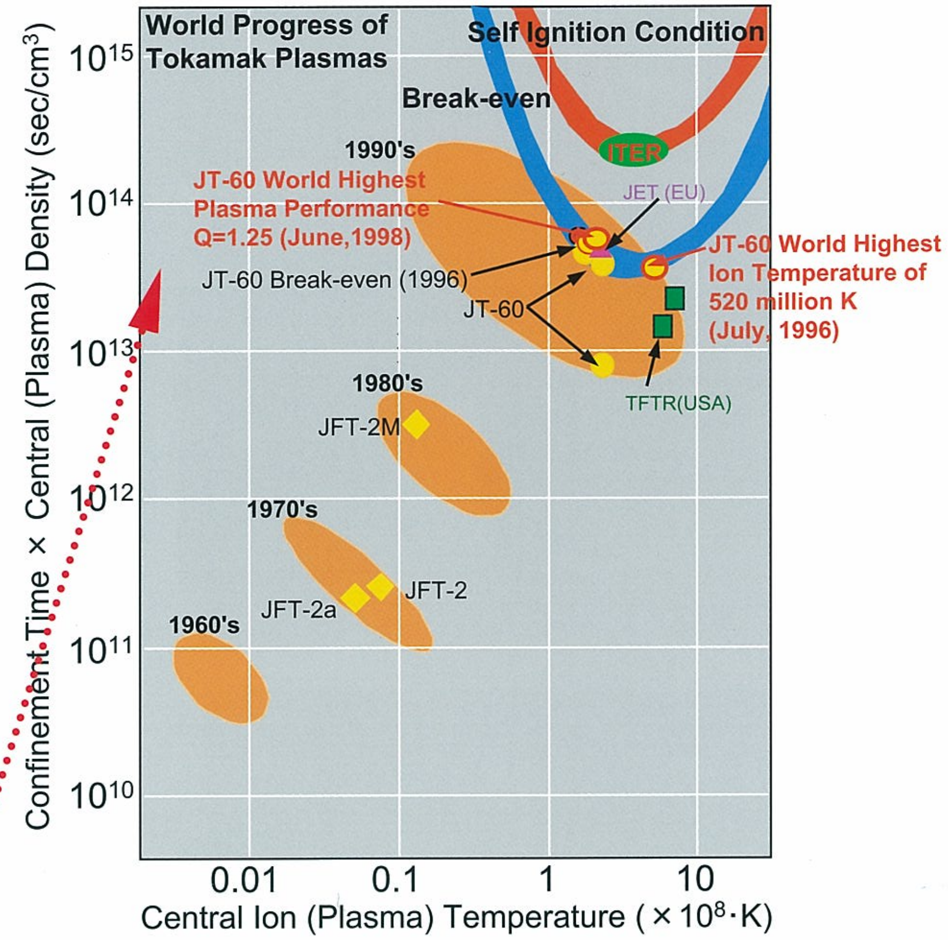
JT-60 Main Parameters
Diameter 15m
Height 13m
Weight 5000t
Plasma Current 7MA
Toroidal Field 4.4T
Plasma radius 3.0-3.4m
Plasma volume 40-100m³

Achievement of Breakeven

On the 31st of October 1996, a deuterium plasma with an energy confinement time of 1second, temperature higher than 100 million degrees and ion density of 50 trillion /cm³ was produced. This is equivalent to the breakeven condition, where the input power to produce the high temperature plasma and the output power generated by the DT fusion reactions are balanced, in a DT plasma where deuterium and tritium are equally mixed.
This achievement was established by an innovative technique to form a thermal insulation layer in a plasma to prevent heat from escaping from the plasma.
The technique is suggested by JAERI as a standard operational regime of a steady state fusion reactor in the future.
Impurities in plasma were decreased by a newly installed divertor and the research for the improvement of plasma performances was advanced further. On the 10th of June 1998, a deuterium plasma with an energy multiplication factor of 1.25, the world's highest record, was successfully produced.

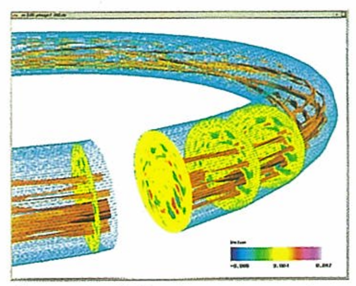
Improvement of Confinement Performance by Formation of Thermal Insulation Layer





Research on Plasma Theories

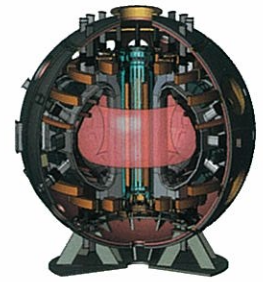
In order to understand the physical characteristics of plasmas, various phenomena in plasmas are studied by numerical simulations and theoretical analysis. Moreover, physics models and computer codes are also developed to assist tokamak experiments and reactor engineering development.



Plasma simulation by supercomputer

Upgrade to Satellite Tokamak (JT-60SA)

The supportive research for the effective and efficient utilization of ITER and the research complementing ITER toward a DEMO reactor will be performed internationally, aiming at the early realization of fusion energy.



Purpose
- Steady-state operation with high-pressure plasma
- Long control of plasma (ITER shaped, Advanced shaped)

JT-60 is upgraded to a superconducting machine (JT-60SA: JT-60 Super Advanced) which has the capability of achieving breakeven plasma conditions.

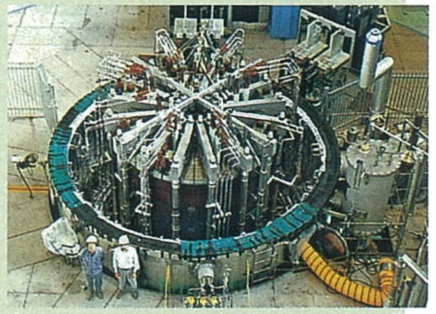
Plasma Physics

Research and Development of Fusion Technology

Research and development (R&D) of various advanced technologies has been extensively conducted aiming at the realization of fusion energy.
This R&D is playing an important role in advancing the International Thermonuclear Experimental Reactor (ITER) project.

Development of Superconducting Coil

The superconducting coil which generates a high magnetic field to confine the plasma is one of the most advanced technologies.
Currently, a large, high performance coil for ITER, which is 17m in height, 11m in width and 13 tesla in magnetic field strength is under development.



Superconducting central solenoid model coil for ITER

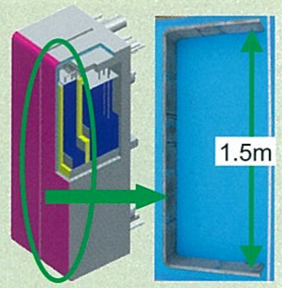
Development of Reactor Structure and Remote Handling Technologies

The development of remote maintenance technology and reactor structures compatible with remote handling is essential for ITER.
JAEA is proceeding with R&D of various remote handling equipment such as the in-vessel manipulator, which can move a heavy component of several tons weight with millimeter accuracy.

ITER In-vessel Remote Maintenance Device for blanket

Development of Blanket

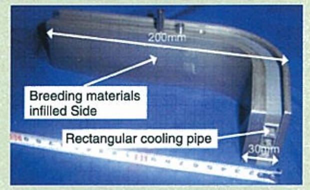
The blanket has functions of shielding neutrons and extracting heat from fusion reactor and also producing the fuel of tritium. JAEA has established the technology of the blanket which can shield neutrons for ITER. In addition, toward the DEMO reactor, JAEA is developing the fabrication technologies of the test blanket, which is investigated in ITER to extract heat and produce fuels.



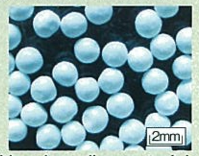
Concept Chart and Full-Size Test Component of the Test Blanket (Height: 1.5m, Width: 0.25m)

Development of material

Functional materials for the fusion reactor in future, such as the long-life material (Reduced Activation Ferritic Steel), the multiplier material (Beryllium) and the breeding material (Lithium) to produce fuel of tritium are developed.



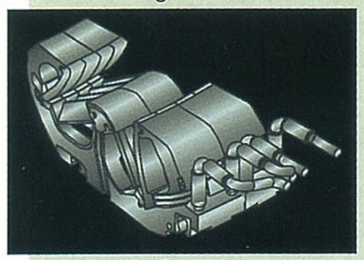
Reduced Activation Ferritic Steel



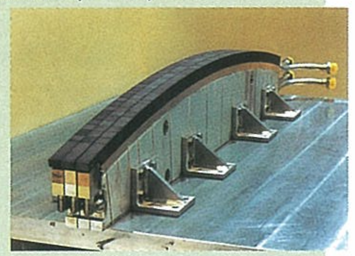
Tritium breeding material

Development of High Heat Flux Components

JAEA develops advanced materials and high performance cooling structures to protect in-vessel components against the high heat load from the plasma. The heat load from the plasma is more than 50 times higher than that of a conventional power plant.



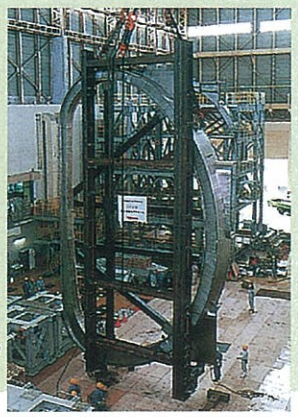
Divertor cassette for ITER



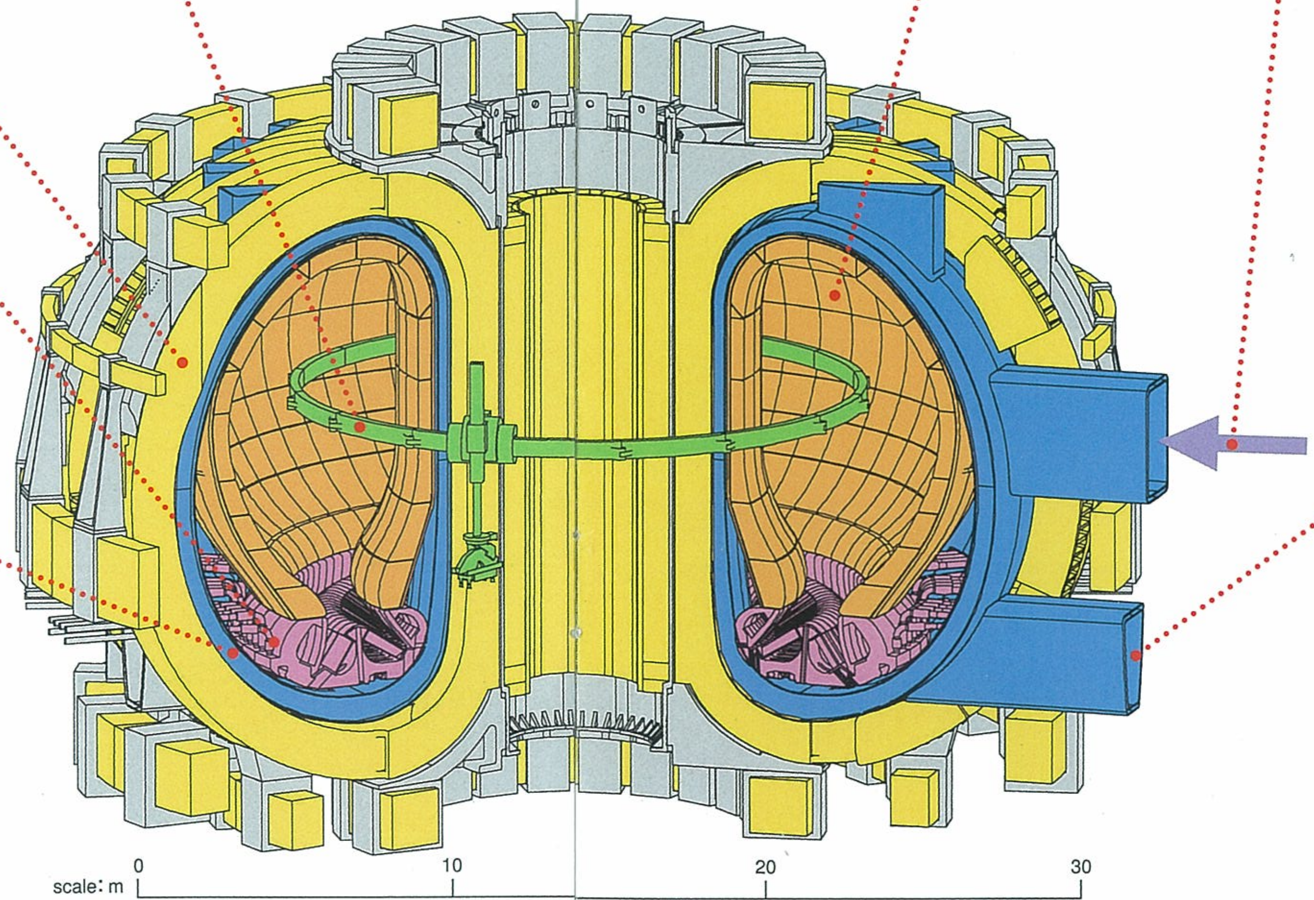
Full size test component of thermal resistant tile

Development of Vacuum Vessel

The vacuum vessel is a vacuum chamber which supports heavy components such as the divertor, the blanket, etc., and needs to endure high magnetic forces and pressure during operation.
JAEA has developed a vacuum vessel sector for ITER ,and the technical database on mechanical stiffness, manufacturing procedures, etc., has been accumulated.



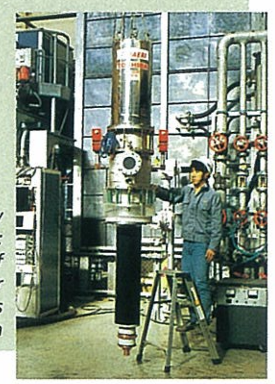
A segment of a full-scale model of the ITER vacuum vessel



Development of Plasma Heating and Current Drive Devices

JAEA is developing the devices which heat plasmas up to 100 million℃.

MeV class Neutral Beam Injection (NBI) device generating high energy neutral beam of 1MeV



Radiofrequency heating device(RF): Oscillating tube of high power millimeter waves called Gyrotron

Tritium Fuel Cycle and Tritium Handling Technologies

Tritium is a hydrogen isotope which emits β rays. Its energy is low, and it can be stopped by a sheet of paper, but radiation control must be intensively studied to insure safety. JAEA is proceeding in research and development of fusion fuel technology and tritium safety technology and also in establishing stringent radiation control systems for personnel safety.

A tritium handling system with glove box

Fusion Technologies

Progress of Fusion Research and Development

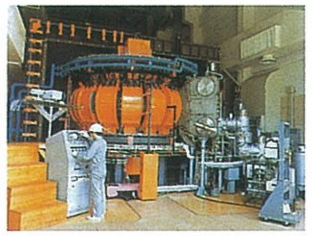
FUSION

In the fusion research at JAEA, since the start in 1961, the scale of devices was progressively increased from JFT-2, JFT-2a, JFT-2M to JT-60, incorporating the latest achievements in experiment and discoveries in theory.
JAEA also supports the ITER Project on an international cooperation basis, and proceeds to further research aiming at the realization of a fusion reactor which is environmentally safe and an inexhaustible energy resource.

1956
Formation of the Japan Atomic Energy Research Institute

1961
Start of fusion research at JAERI

1972
Start of JFT-2 operation



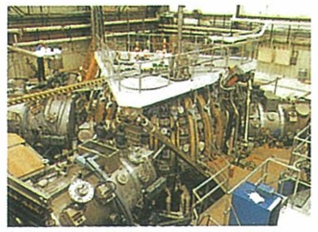
March 1973 Success of long time confinement of plasma (electron temperature: 7 million℃ and confinement time: 0.02s) in the medium-β torus system (JFT-2) (Tokai Research Establishment)

1974
Start of JFT-2a (The first divertorTokamak) operation

August 1974 Completion of high stabilized magnetic device equipped with world's first divertor (JFT-2a)

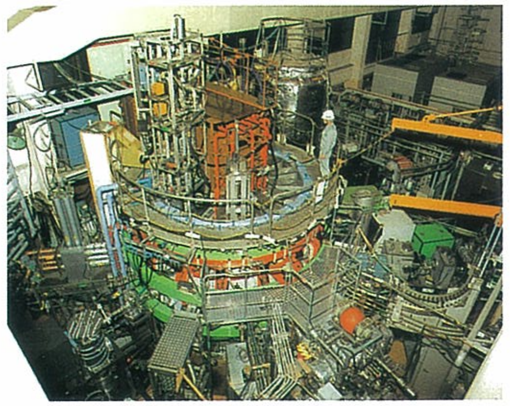
1975
Start of JT-60 design

1979
Start of joint experiment with Doublet Ⅲ (USA)



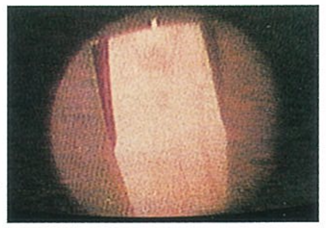
DoubletⅢ: A medium Tokamak device constructed at GA company in USA by Japan-USA cooperation program

1983
Start of JFT-2M operation



JFT-2M: Medium Tokamak device which achieves pioneering research by using it's mobility

1985
Inauguration of the Naka Fusion Research Establishment
Start of JT-60 experiments



JT-60: Success of first plasma ignition

JT-60: Large tokamak device

1988
Start of ITER Conceptual Design Activities (CDA)

1991
Start of upgraded JT-60 operation

1992
Start of ITER Engineering Design Activities (EDA)
Achievement of 440 million ℃ (world's highest ion temperature at that time) in JT-60

1993
Success of world record 3.6 million A of non-inductive current drive by JT-60 Radiofrequency

1994
Achievement of the world's highest fusion triple product by JT-60

1996
Achievement of 520 million ℃, world's highest ion temperature in JT-60.
Achievement of break-even plasma conditions in JT-60

1998
Achievement of 1.25, world's highest energy multiplication factor in JT-60

2005
Japan Atomic Energy Agency NAKA Fusion Institute

2007
ITER Construction Beginning
Start of BA

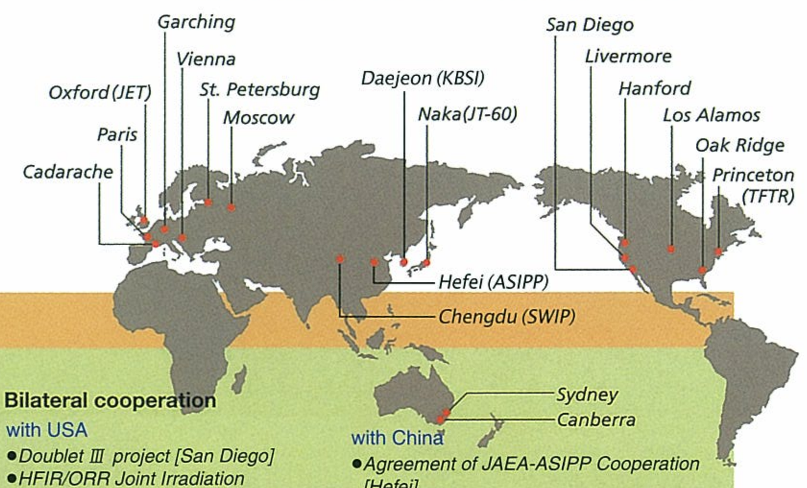
~2017
Experimental Reactor ITER

Demonstration Reactor

Practical plant

JT-60 central control room

International Cooperation of Fusion



JAEA International Collaborations

Multilateral cooperation

OECD/IEA (Organization of Economic Cooperation and Development/International Energy Agency, Headquarters: Paris)
- *Cooperation on the Large TOKAMAK Facilities*
- *Research and Development Radiation Damage in Fusion Materials*
- *Environmental, Safety and Economic Aspects of Fusion Power*
- *Nuclear Technology of Fusion Reactors*

IAEA (International Atomic Energy Agency, headquarters: Vienna)
- *Fusion Energy Conference*
- *Energy Technology Data Exchange Program*
- *Other Expert Meetings*

ITER Project

Bilateral cooperation

with USA
- *Doublet Ⅲ project [San Diego]*
- *HFIR/ORR Joint Irradiation Experiment Program [Oak Ridge]*

with Europe
- *Agreement of JAEA–IPP/ASDEX Cooperation [Garching]*
- *Agreement of Broader Approach Activities*

with Australia
- *Japan–Australia Joint Committee [Sydney, Canberra]*

with China
- *Agreement of JAEA-ASIPP Cooperation [Hefei]*
- *Agreement of JAEA-SWIP Cooperation [Chengdu]*

with Korea
- *Agreement of JAEA-KBSI Cooperation [Daejeon]*

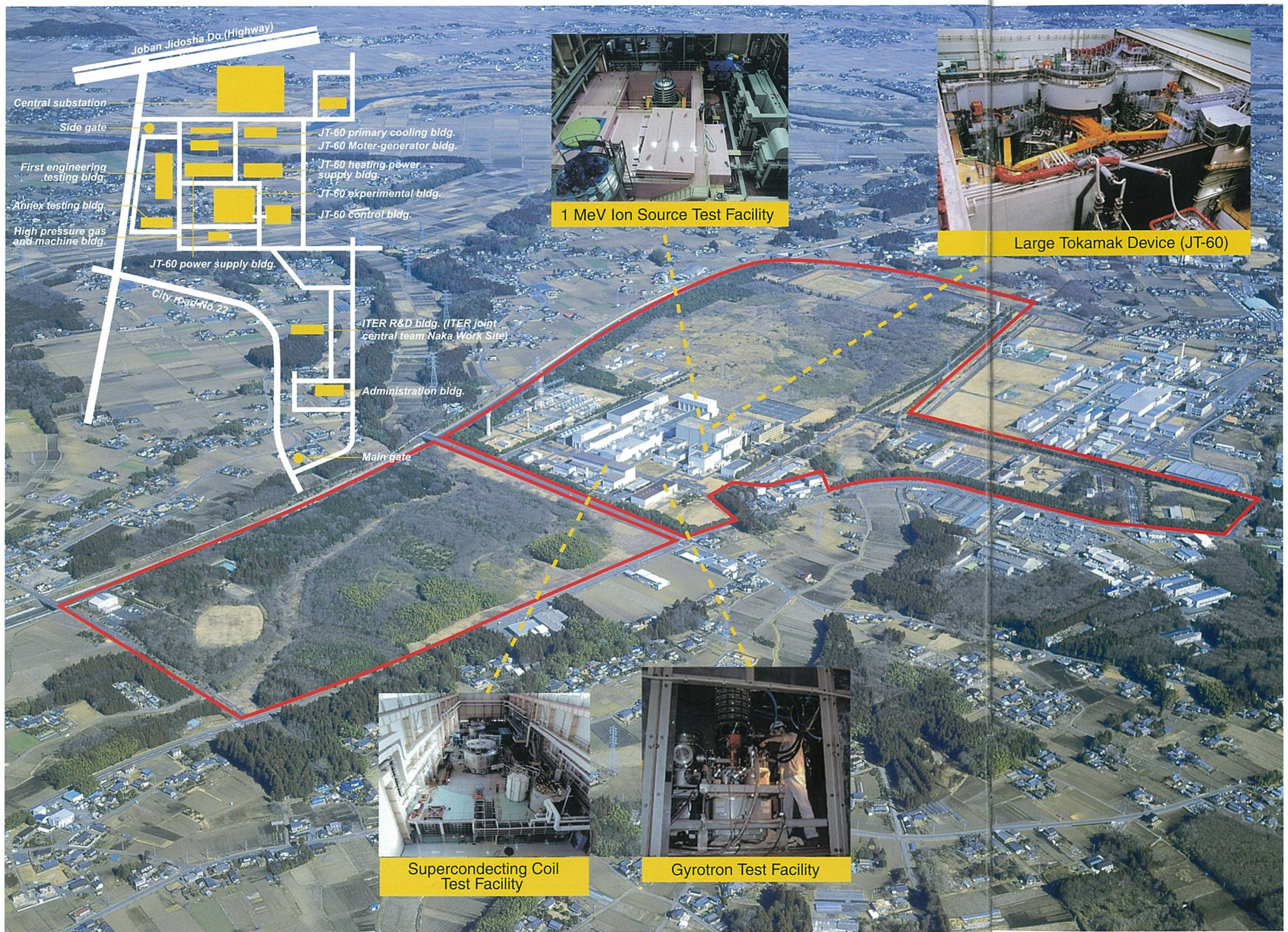
with Russia
- *Agreement Japan-Russia Scientific and Technological Cooperation [Moscow, St.Petersburg]*

Progress

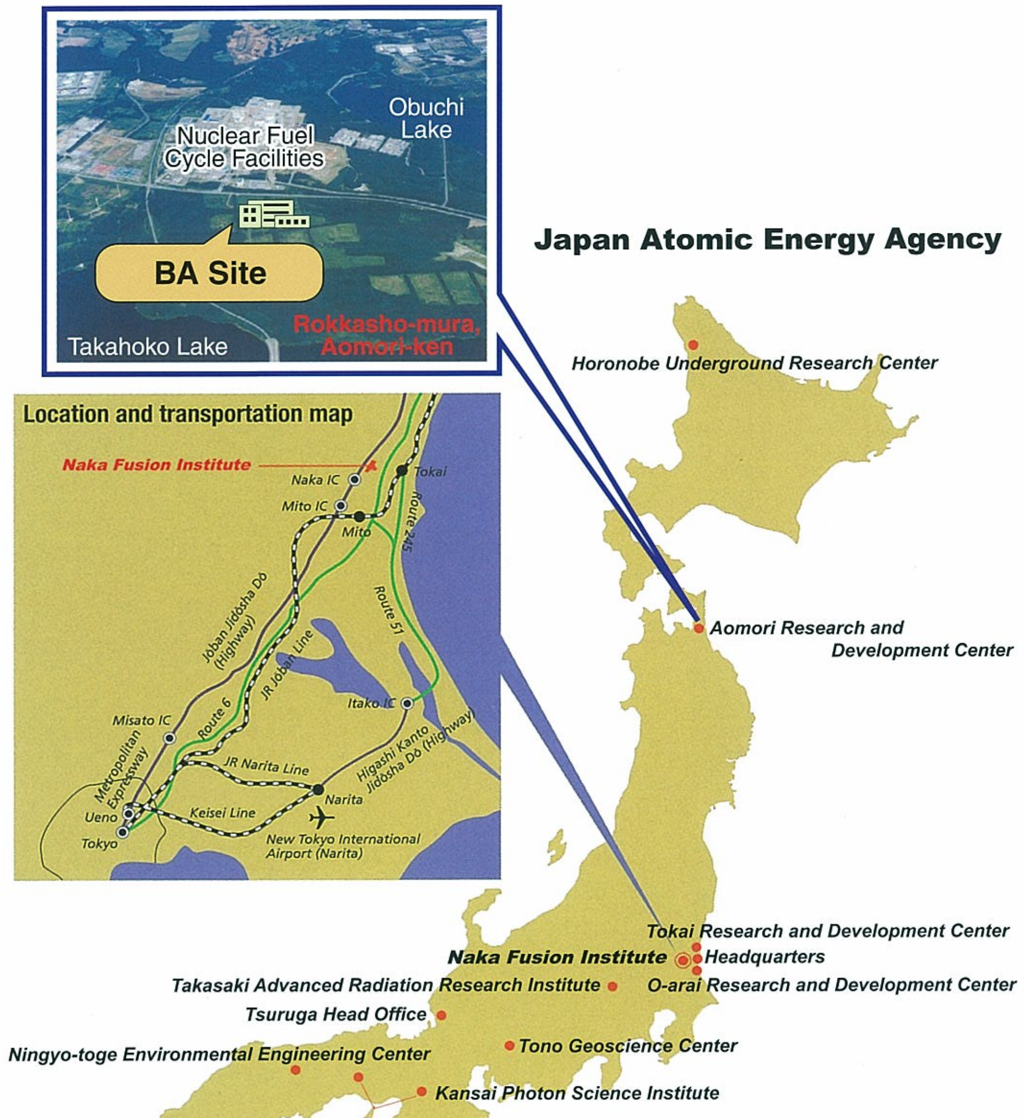
Major Facilities of Naka Fusion Institute

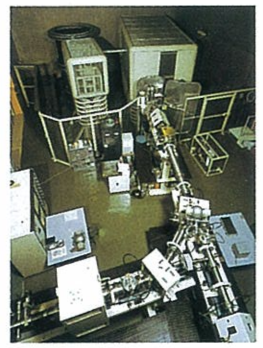
The Naka site of JAEA was established in 1985, and the large tokamak device JT-60 and various fusion testing and research facilities are installed in the area of approximately 1.3 million square meters.

In addition, for the establishment of a fusion reactor, overall fusion research activities are being carried out at the Naka site.



Bird's-eye view of Naka Fusion Institute





Fusion Neutronics Source

Facilities

Naka-city

City's flower **Sunflower**

City's bird **Swan**

City's tree **Yaezakura**

Ibaraki-ken

Prefecture's flower **Rose**

Prefecture's bird **Skylark**

Prefecture's tree **Japanese apricot**

Japan Atomic Energy Agency

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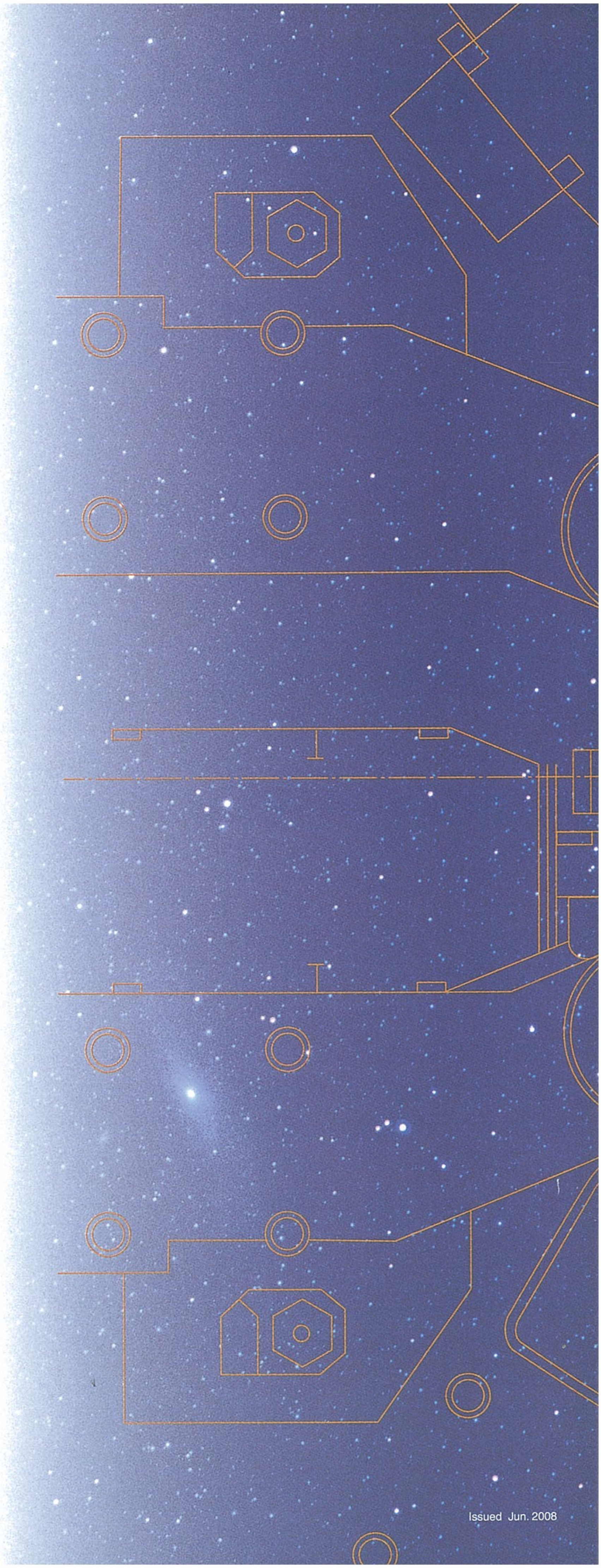

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