1999 Fusion JAERI Seminar

European Fusion Programme

René PELLAT

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European Fusion Programme

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1 STATE OF THE ART
- Management
- International Co-operation
- JET and main facilities
- Past and present results

2 EUROPEAN STRATEGY
- Energy needs and source diversification
- Towards the fusion reactor
- New organisation and calendar

3 THE EFFICIENT FUTURE
- JET enhancement
- ITER burning plasma
- Power plant work
- European industry involvement
- European Council and Parliament support

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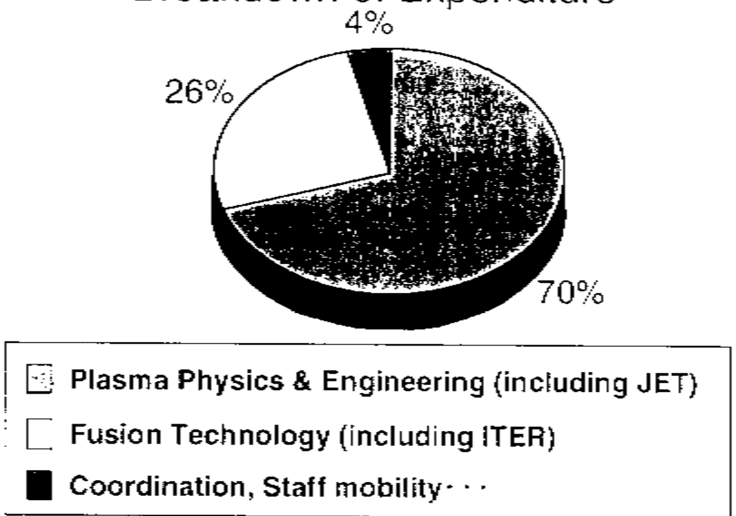
Fusion Programme Implementation

- **The EU Fusion Programme integrates all Fusion R&D in the EU and Associated Countries;**
- **Overall annual expenditure is 450 Mio Euro: 60% from the Member States, 40% from Community Budget (framework programmes agreed every 4 years);**
- **Professional staffing: 2000 scientists and engineers (including about 250 PhD students);**
- **A significant training and mobility effort is developed, in particular by the Associations and JET;**
- **Past investment over 30 years: of the order of 8000 millions Euros (€).**

Fusion R&D in the EU

Breakdown of Expenditure



Annual Expenditure in the European Fusion Programme

European Union		Associated Countries
●	> €120M	●
●	€60M - €120M	●
●	€10 - €60M	●
⊛	€5 - €10M	⊙
○	< €5M	○

1€ ≈ 110Yen

Fusion in the European Union

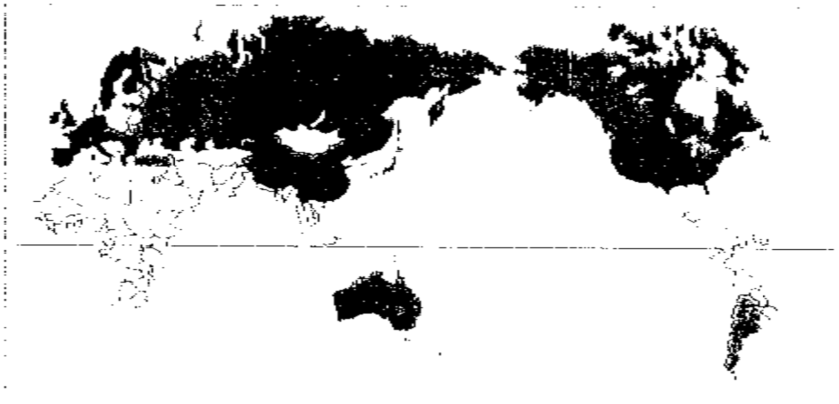
New associated countries will participate in the EURATOM programme:

Bulgaria
Czech Republic
Hungary
Latvia
Romania
Slovak Republic
Slovenia

International Cooperation

- Bilateral agreements with, Canada, Japan and Ukraine; Kazakhstan, Russia, and USA (in prep.)
- Eight multilateral implementing agreements under the auspices of the International Energy Agency (OECD - Paris)
- Agreement on the ITER EDA under the auspices of the International Atomic Energy Agency (United Nations - Vienna)

Fusion Collaboration between the European Union and International Partners



● Eropean Union

Belgium, Denmark, Germany, Greece, Spain, France, Ireland, Italy, Luxembourg, The Netherlands, Austria, Portugal, Sweden, Finland, United Kingdom

⊛ Associated Countries

Bulgaria, Czech Republic, Hungary, Latvia, Romania, Slovak Republic, Slovenia, Switzerland

● International Partners

Australia (IEA), Canada, China (IEA), Japan, Kazakhstan, Russia, Turkey (IEA), Ukraine, USA

JET is Unique

One half Scale Model of ITER -Burning plasma version

- JET is the nearest in scale and operating conditions to the International Thermonuclear Experimental Reactor (ITER).
- JET has the plasma and divertor configuration of ITER.

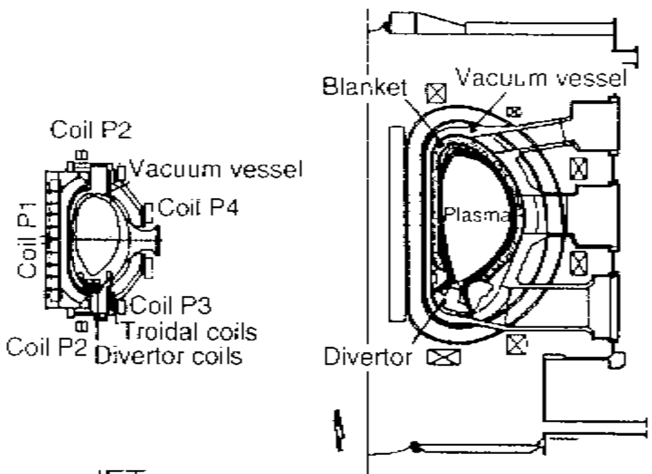
Tritium Compatibility

- JET is the only experiment world-wide able to study:
  (1) physics in the deuterium-tritium fuel mixture
  (2) fusion power production.

Remote Handling Capability

- JET has developed a unique capability for remote installation and repair, which was used successfully to exchange the divertor without manned in-vessel intervention in the activated environment following D-T operation in 1997.

Poloidal Cross-sections of JET and ITER-FEAT



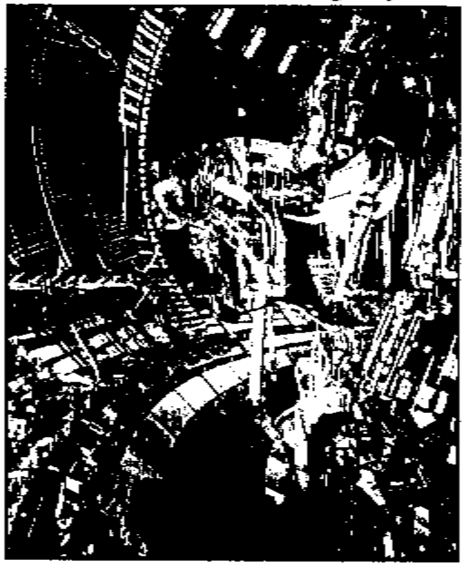
JET
R=3m; I=6MA

ITER-FEAT
R=6.2m; I=13MA

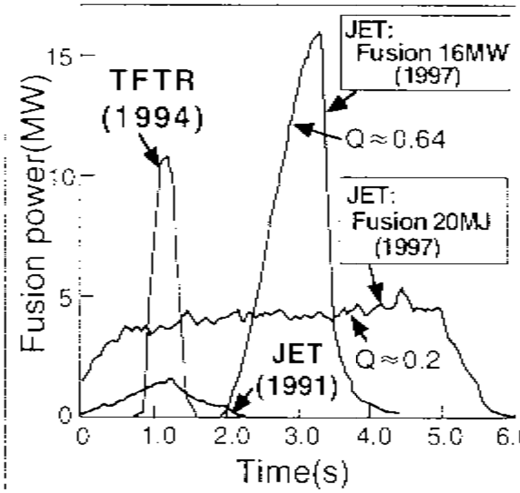
FEAT : **Fusion Energy Advanced Tokamak**

In-Vessel View of JET

In-Vessel Remote Handling Operation of JET



Fusion Power Development



The diagram encompasses:

- 10% T in D experiments in JET in 1991;
- a result from the D-T studies on TFTR (1993 to 1997);
- high fusion power and quasi steady-state fusion power in the JET D-T experiments of 1997.

EU Fusion Devices (1)

- Tokamaks

- JET	Abingdon, UK
- TORE SUPRA	Cadarache, F
- TEXTOR 94	Julich, D
- ASDEX-Upgrade	Garching, D
- FTU	Frascati, I
- TCV	Lausanne, CH
- COMPASS-D	Culham, UK
- ISTTOK	Lisbon, P
- MAST	Culham, UK

EU Fusion Devices (2)

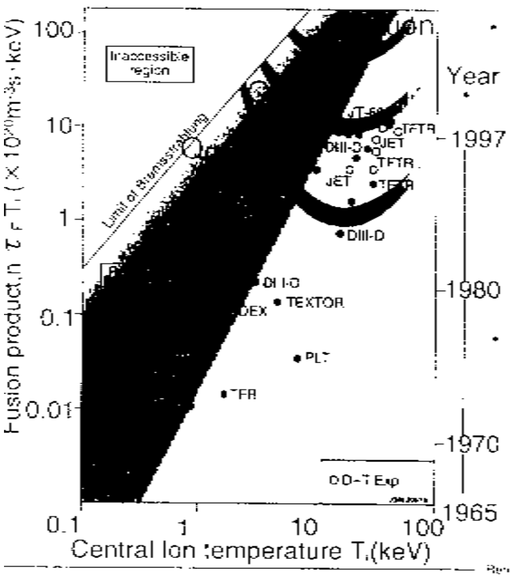
- Stellarators

- WENDELSTEIN 7-X	Greifswald, D
- WENDELSTEIN 7-AS	Garching, D
- TJ -11	Madrid, E

- Reversed Field Pinches

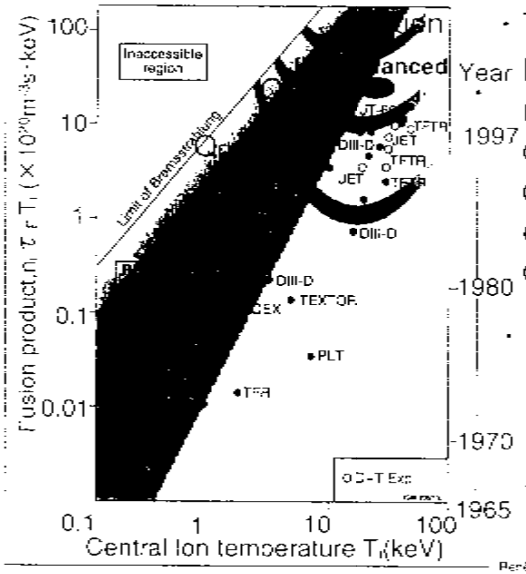
- RFX	Padova,I
- EXTRAP-T2	Stockholm, S

Progress Towards Reactor Conditions



- The Fusion Triple Product ($P_i \tau_E = n_i T_i \tau_E$) required to reach reactor conditions can be compared with leading edge performance of the devices year-on-year.
- The best plasmas now need an improvement of only ×6 in performance. This requires a new larger device.

Progress Towards Reactor Conditions



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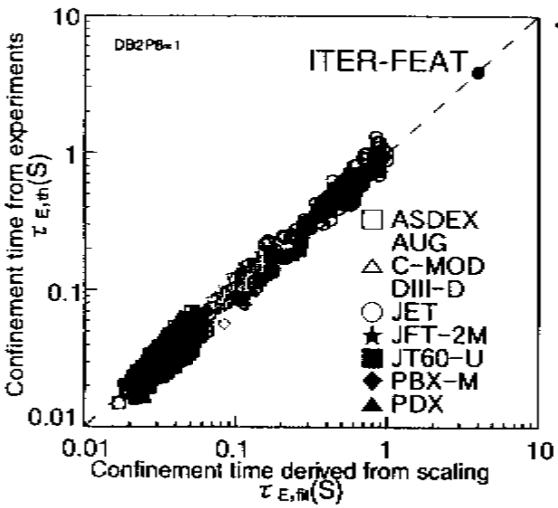
René PELLAT / Fusion JAERI Seminar 1 Tokyo, November 30, 1999

Confinement Scaling



- Extrapolation of global thermal confinement time to ITER-FEAT, using the IPB98(y,2) scaling (τ_E=3.9s)
- ITER-FEAT represents an extrapolation of a factor ~4 beyond existing database

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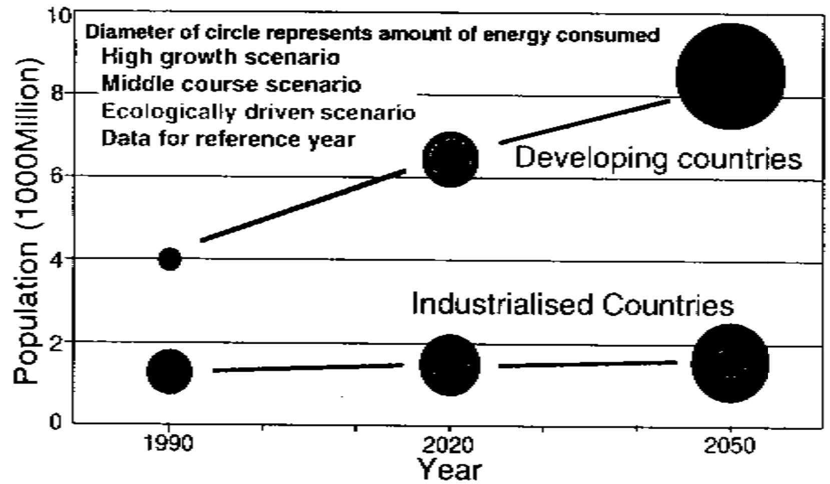
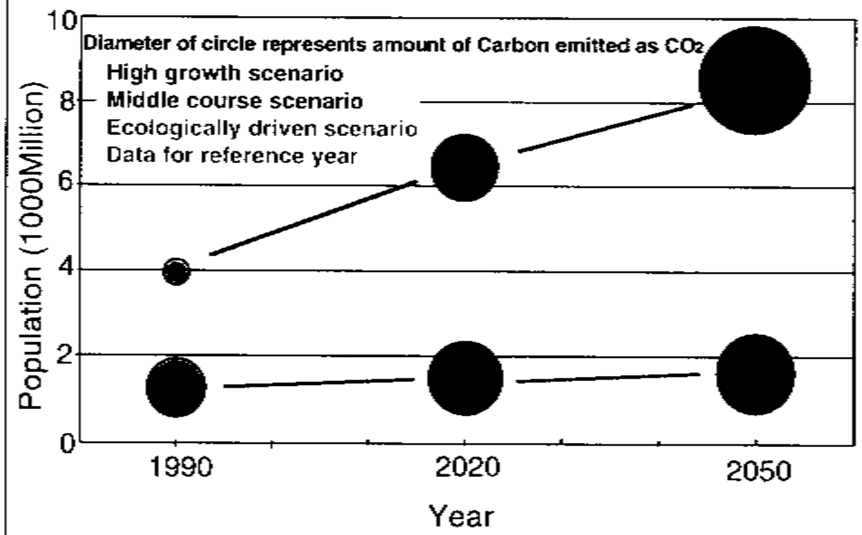
Projected Growth in World Population and Energy Consumption



Data from IIASA/WEC "Global Energy Perspectives", Cambridge University Press, 1998

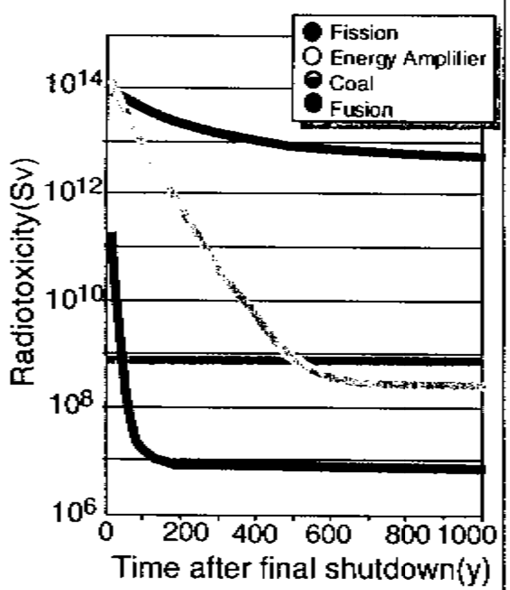
Projected Growth in World Population and CO_2 Production



RADIOTOXICITY

Induced by :
- Fission
  without reprocessing
- Energy amplifier
- Fusion
- Coal-fired plant

For the same total electrical energy generation



Fusion European Union Strategy

The next goal of the strategy is the demonstration of a thermonuclear burning plasma on a long time scale:
- It is a synthesis of the 40 year past investment.
- It will open the route towards the reactor.

*
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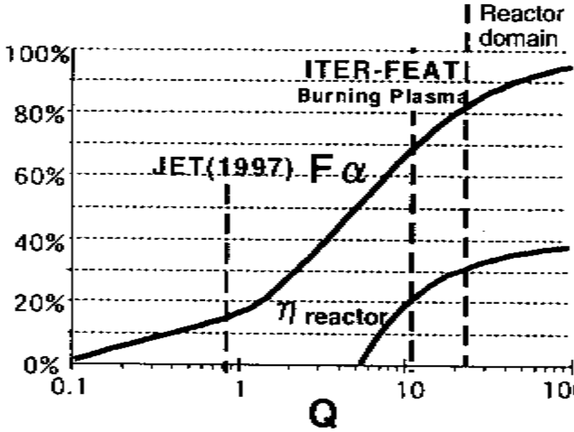
To reach this goal, the following orientations are taken
- Promote the international ITER Programme and the decision of the construction of a burning plasma facility around 2003.
- Consolidate the fusion physics and technology base using the existing devices and enhancing the deuterium-tritium Joint European Torus (JET).
- Focus technology in accordance with the two above orientations.

Operating Range of Fusion Reactor



$$Q = \frac{\text{Fusion Power}}{\text{Injected Power}}$$

$$F\alpha = \frac{\text{Alpha Power}}{\text{Alpha Power+Injected Power}} = \frac{Q}{Q+5}$$

$$\eta_{\text{reactor}} = \frac{\textbf{Electrical Power}}{\textbf{Fusion Power}}$$

Fusion Programme Implementation

- The Commission, with the advice of the CCE-Fusion Committee, is responsible for the implementation of the Programme which will be executed through :
- Associations
- EFDA (European Fusion Development Agreement)
- Limited duration contracts[1]
- Industrial contracts
- Mobility Agreement

[1] in countries without a fusion association

Fusion Programme Implementation

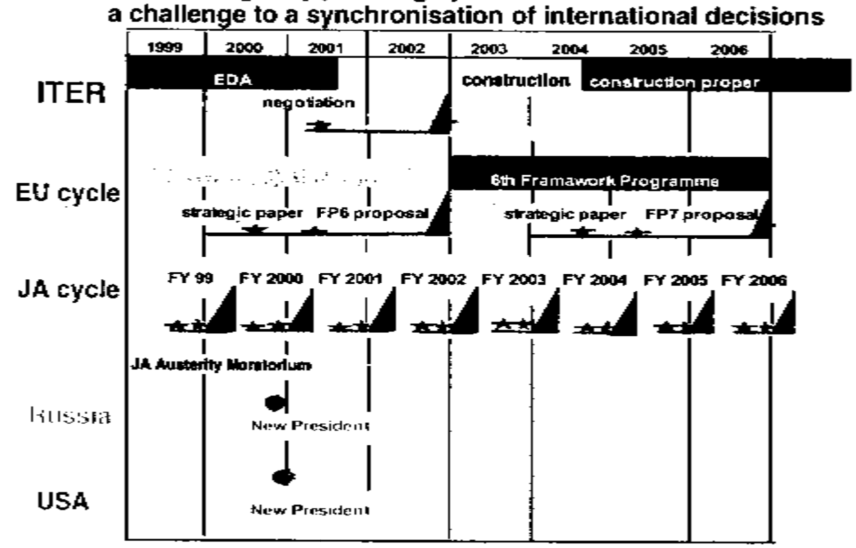
European Fusion Development Agreement (EFDA)

EFDA provides a framework for implementing design and R&D in 3 interrelated areas :

- Collective use of JET facilities for the period beyond 1999 (with possible enhancements);
- Technology activities, including Next Step and long-term technology ;
- Euratom contribution to international collaborations, including the ITER-Engineering Design Activities.

Tentative ITER Schedule

Different budgetary planning cycles:
a challenge to a synchronisation of international decisions



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Future Prospects for the JET Facilities

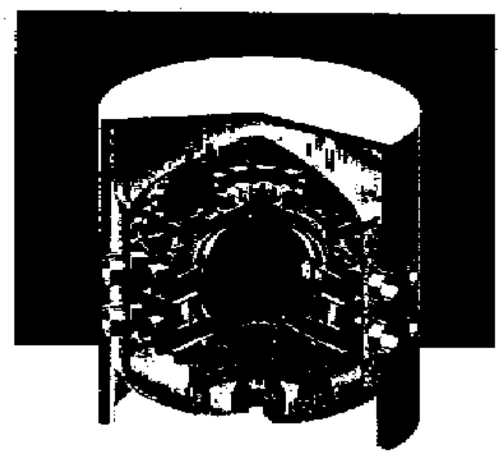
- The main physics issues for reactor-oriented fusion research are:
  1. The consolidation of the physics basis for the reference operating mode: the ELMy H-mode
  2. The development of understanding and scaling of advanced plasma regimes
  3. The study of burning plasma conditions with alpha heating ratio (F_α) values closer to reactor conditions
- JET can provide unique new data on items 1) and 2) even without significant upgrades
- New investments in JET would allow further progress on item 3) as well as increasing significantly the physics operating domain (items 1) and 2)).

With its deuterium - tritium capability JET will remain, for many years to come, the most relevant device for supporting reactor-oriented fusion research

Physics Issues for the Reference Operating Mode

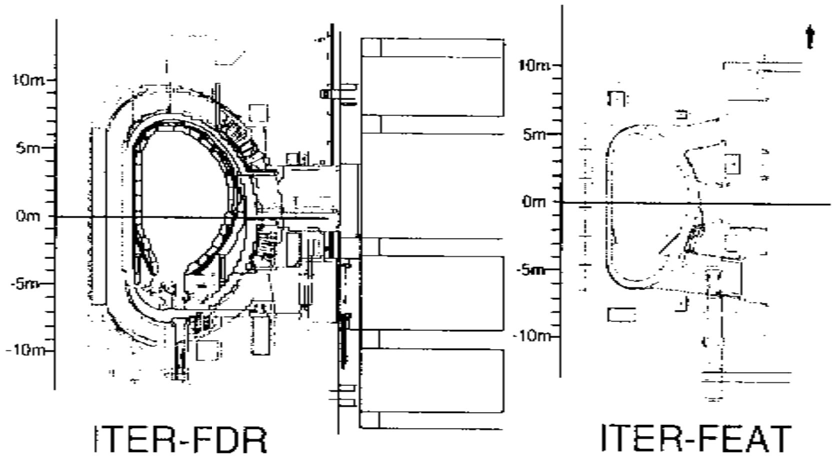
- Plasma shaping optimisation by plasma shaping (elongation, triangularity)
- Edge Localised Modes ELMs effect on energy content and divertor power loads
- Neoclassical Tearing Modes(NTM) stability and control

ITER Design for Reactor Relevant Long Sustained Burn in Stable Regime



Major Radius:6.2m(8.14m)
Minor Radius:1.9m(2.8m)
Plasma Current:13.3MA (21MA)
Fusion Power:500MW (1500MW)
Burn time:>400s (>1000s)
$Q(P_{fus}/P_{inj})$:10(∞)
(red: ITER FDR)

Comparison of the Cross-sections of the ITER EDA Final Design Report(FDR) and ITER Fusion Energy Advanced Tokamak(FEAT) Designs



① ITER Programme : past and future

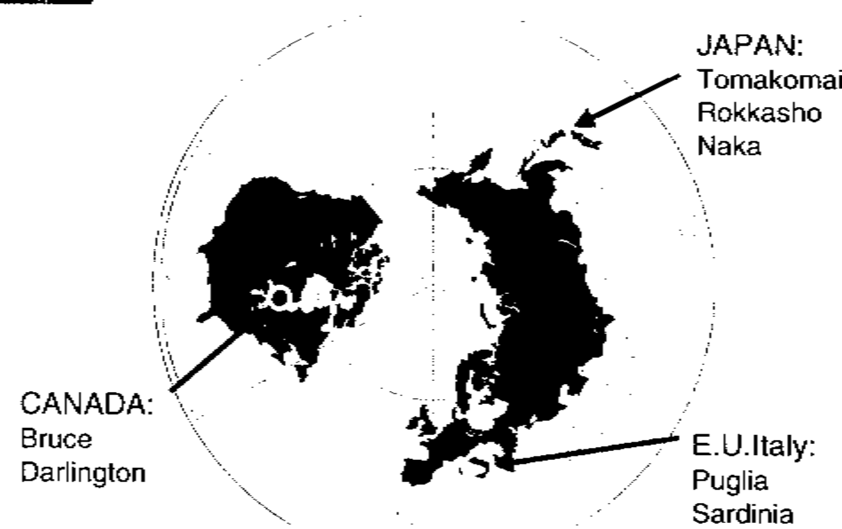
- ITER, a 1985 presidential summit initiative, is an ambitious long term international R & D venture.
- Two EU - JA - RF - US phases have been successful
  - 1988 - 1991 : Conceptual Design Activities.
  - 1992 - 1998 : Engineering Design Activities extended to 2001.
- Today, it is essential to increase the momentum of ITER project and to launch the construction phase around 2003.
- The exploration and negotiations will allow to solve the key issues of such a EURO 3.5 billion megascience project, among the EU - JA - RF Parties.

② ITER Programme : issues

To make the ITER venture a success for the benefit of all the Parties, the main issues are :

- To set a broad-based collaboration for the construction and the exploitation of the facility, assuring :
  - Benefits and cost equity between the Parties.
  - Stability and flexibility of this 20 - 30 year lifetime project.
- To define a legal entity compatible with hosting and non-hosting Parties rights and obligations.
- To guarantee an efficient governance of the project with a clear organisation and clear responsibilities, especially from the safety point of view.

The ITER Parties and Potential ITER Sites



European Power Plant Conceptual Study

- A Power Plant Conceptual Study has been launched and will contribute to focus on fusion program activities towards the fusion reactor.
- The scope of the study is to:
  - Assess fusion energy status features and prospects,
  - Establish coherence and priorities in the EU fusion program.
- The study follows from previous safety and socio-economic activities with the objective to maximize the credibility of fusion energy as a safe, environmentally friendly, technically feasible and economically viable energy source.

Safety and Environmental Assessment of Fusion Power

The two main results of SEAFP activities are:

- **Health** : the most severe accidents will not require any public evacuation with appropriate design provisions

- **Waste** : almost all activated material could be cleared or recycled (with present low activation martensitic steel, or future advanced materials)

Cooperation with European Industry

Main role for industry was to manufacture the components for European devices, JET (520 MEuro of contracts) and other facilities.

A Consortium of 9 companies is now associated to the fusion R & D, including design and fabrication of ITER Mock Ups.

Present collaboration increases high technology competences of European Industry allowing applications in other fields (supra conduction, robotics, electronics ...).

Decisions on Fusion in the European Union

The governance of Fusion R&D in the European Union (EU) involves 3 Institutions

- The European **Commission** has the **initiative** of **proposals** and is responsible for the **implementation** of decisions.
- The European **Parliament** deliberates on **budgets** and **proposes** amendments.
- The **Council** of the EU **decides** on proposals, possibly amended.

Fusion is part of multi-annual (4 years) Framework Programmes (FPs):

- JET is a successful example of a long-life, co-operative venture extending over several FPs.
- The preparation for the formal proposal of FP6 (2003-2006) will soon be initiated. Proposing the construction of a burning plasma facility is under consideration, preferably as an international co-operation.

The Parliament has now a greater say in the EU's decision making process.
Contacts between Members of the Parliaments of ITER partners could contribute to improve the ITER budgetary stability.

Conclusion

http://fire.pppl.gov

- Fusion research has established a well funded physics and technology basis.
  High fusion performances have been realised, reaching 16 MW of peak power and 23 MJ of energy.
- Today, the demonstration of a sustained burning plasma is the next goal which opens the route towards the reactor.
- To reach this goal, we have essentially to:
  - Consolidate the fusion basis, exploiting existing facilities with required enhancements.
  - Increase the ITER project momentum and launch the construction phase around 2003.

➲ Strengthening the international broad-based collaboration is the key to harness the benefits of fusion for mankind.