# **The Path to Fusion Power: a European View**

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### **FUSION**

powers the sun and stars

and a controlled 'magnetic confinement' fusion experiment at the Joint European Torus (JET) (in the UK) has produced 16 MW of fusion power

so it works

### The big question is

- How soon can we make it work reliably and economically on the scale of a power station?

First: Why bother? What are the major challenges?





### WHAT IS FUSION ?

Most effective fusion process involves deuterium (heavy hydrogen) and tritium (super heavy hydrogen) heated to above 100 million °C:



 \* ten million times more than in chemical reactions, e.g. in burning fossil fuels ⇒ while a 1 GW coal power station would use 10,000 tonnes of coal a day, a fusion power station would only use 1 Kg of D + T

#### Raw fuels are water and lithium:

- one in every 6,700 H<sub>2</sub>O molecules is H-D-O; easy to extract deuterium from water
- tritium will be generated in the walls of a fusion reactor:

neutron (from fusion) + lithium  $\rightarrow$  tritium + helium

### Why bother?

Used as fuel in a fusion power station, the Lithium in one laptop battery + 40 litres of water would provide 200,000 kW-hours of electricity =

(Japanese electricity production)/(population) for 25 years in an intrinsically safe manner with no CO<sub>2</sub>



Unless/until we find a barrier, this is sufficient reason to develop fusion power

#### According to Clive Cookson of the Financial Times

"Even it ITER goes well over budget and costs \$1 billion a year, that would be well worth it even for a 20% chance of another major energy option" This is surely right

- although 20% is very pessimistic



# **Fusion Challenges**

#### Plasma physics

Sustain a large volume (~2000 m<sup>3</sup>) of hot (over 100 M °C) plasma of deuterium and tritium in quasi-stable conditions for long periods at pressures that allow a large net energy gain from fusion
Being addressed: JET, JT-60, DIIID, ASDEX-U,...JT60-SA, ITER

#### Materials Science

Qualify materials with which to construct walls that will be capable of surviving bombardment of a few MW/m2 by 14 MeV neutrons for a few years, and tolerating large heat loads

Being addressed: modelling, proxy experiments, ... IFMIF

#### Technology

Ensure high reliability of many complex components in an operating fusion power station

**Only being addressed** in a just-in-time manner sufficient for ITER; need increased effort in preparation for DEMO

### **Outline of Rest of Talk**

#### Next steps and time needed to develop fusion power in a 'business as usual' approach

30-35 years to demonstrate electricity production, then  $\sim$  15 years to start of large scale deployment of fusion

#### European Programme

**Objective:** to realise ITER as the major step towards the creation of prototype reactors for power stations that are safe, sustainable, environmentally responsible, and economically viable

#### Can we ensure 30 years (not 35 years or more) for demonstration of electricity production, and speed up subsequent large scale deployment?

**Yes** – needs greater investment in technology (and physics) + increased involvement of industry

#### Could we go very much faster?

**Perhaps** by starting to build the first Demonstrator Power Station (DEMO) without waiting for full results from ITER and IFMIF



### **NEXT STEPS FOR FUSION**

# Construct ITER (International Tokamak Experimental Reactor)

- $\Rightarrow$  energy out = 10× energy in
- ⇒ "burning" plasma

During construction, further improve tokamak performance in experiments at JET, DIII-D, ASDEX-U, JT- 60...further develop technology, and continue work on alternative configurations [Spherical Tokamaks (pioneered in UK), Stellarators]

Intensified R&D on materials for plasma facing and structural components and test of materials at the proposed International Fusion Materials Irradiation Facility (IFMIF)









• Aim - demonstrate integrated physics and engineering on the scale of a power station

• Key ITER technologies fabricated and tested by industry

• 4.5 Billion Euro construction cost (will be at Cadarache in southern France)

 Partners house over half the world's population





## MATERIALS

- Structural materials subjected to bombardment of 2 MW/m<sup>2</sup> from 14 MeV neutrons
- Plasma facing materials subjected to an additional 500 kW/m<sup>2</sup> from hot particles and electromagnetic radiation (much more on 'divertor')
- Various materials have been considered, and there are good candidates that may survive in these conditions, BUT:

Further modelling + experiments essential:

Only a dedicated ( **300M**) accelerator-based test facility - the International Fusion Materials Irradiation Facility (IFMIF) - can reproduce reactor conditions: results from IFMIF will be needed before a prototype commercial reactor can be licensed and built





Overview of the IFMIF design, with major subsystems identified. The lithium target and all test modules are located in a common test cell. Post-Irradiation Examination (PIE) facilities are provided to examine irradiated specimens on site. Maximum availability is achieved by using two independent accelerators. The ion source, RFQ and HEBT of one deuteron beam line are indicated.



### **FUSION 'FAST TRACK'**

- **During ITER construction** 
  - operate JET, DIII-D, JT60...  $\rightarrow$  speed up/improve ITER operation
- In parallel intensify materials work, approve and build IFMIF
- Then, having assimilated results from ITER and
- IFMIF, build a Prototype Power Plant ('DEMO')
  - $\Rightarrow$  Fusion a reality in our lifetimes



### Fast Track - Pillars Only



**Europe has a single/integrated fusion programme** based in many labs, and steered/coordinated by EURATOM and EFDA (European Fusion Development Agreement), **and a range of excellent fusion** 

facilities:

Tokamaks:JETASDEX-UMAST (ST)MAST (ST)Torre SupraTEXTORTCVFTUCompass D(→ Prague)

. . .



+ <u>Stellarators</u>: W7X (under construction) + <u>test facilities</u> TJ2

### **Introduction to the official description of the Euratom Fusion Programme 2007-11**

# Fusion has the potential to make a major contribution to the realisation of a sustainable and secure energy supply for the EU

ITER ...lies at the heart of the present EU strategy ...it must be accompanied by a strong and focused European R&D programme to prepare for... ITER and to develop the technologies and knowledge base ...needed during its operation and beyond.

"Broader Approach" projects ( $\in$  340M from Japan +  $\in$  340M from Europe over ten years) to accelerate the development of fusion energy.

The rapid development of fusion also requires a wide industrial base to ensure a timely deployment of fusion energy.

**Overall objective of the programme:** 

To develop the knowledge base for, and to realise ITER as the major step towards the creation of prototype reactors for power stations that are safe, sustainable, environmentally responsible, and economically viable.

### **Reinforcing and Accelerating the Path to DEMO**

I was recently asked to convene a group to provide input to the European Commission's proposed Strategic Energy Technology Plan. The following is *my personal summary* of the key input made by the group, whose members are

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all participating as individuals, not as representatives of their parent organisations

1 UKAEA, 2 AREVA NP, 3 Tractebel Engineering/SUEZ, 4 RFX Padua, 5 CEA, 6 EFDA, 7 EPFL Lausanne, 8 IPP Garching



### My personal summary of our input:

The EU has an excellent fusion R&D programme, based on a sound plan designed to lead systematically to demonstration of electricity production by fusion in ~ 30-35 years (assuming no political delays and no major adverse surprises). We propose that:

The plan should be strengthened by additional investment in technology & physics, and perhaps also the construction of a European 'satellite tokamak' and/or a Component Test Facility, to reduce the risk of delays, and bring forward the subsequent deployment of reliable fusion power on a large scale.

As soon as resources (money & manpower) allow, the EU should set up a 'DEMO design team' with substantial industrial involvement. The design would guide the present R&D plan and the ITER programme. The team should *consider* whether to move directly to a 'new paradigm' of construction of an early relatively low performance DEMOnstrator Power Plant without waiting for (full) results from ITER and IFMIF.

The group should also evaluate the potential of a CTF, and if it seems desirable design a CTF.



We think early/major involvement of industry is needed to bring a stronger culture of 'design for buildability, operability, reliability and maintainability' into fusion

The lesson of fission is that availability is more important than any other parameter (except the discount rate), and studies of fusion power costs suggest that the same will be true of fusion

- Currently we are developing (or planning to develop)
- Plasma physics at existing devices...ITER, JT-60-SA,...
- Materials in parallel at IFMIF
- Technology/reliability in a 'just in time/just enough' manner for ITER...

Designing/Building EDEMO (with industry) would put us on a parallel track in attacking all three sets of problems and ensure DEMO works in ~ 30 years (not 35 years or more) and speed up the subsequent large scale deployment of fusion power

### A possible early DEMO ('EDEMO') – What? Why?

The 'canonical' DEMO, which would follow ITER and IFMIF, is supposed to demonstrate electricity production with performance (plasma, availability, materials, cost/kW-hr) close to that required for a commercial fusion power station

We suggest *considering* demonstrating electricity production as soon as possible in an EDEMO with less ambitious goal (plasma performance ~ ITER and known materials [ferritic steel] in a device that might initially be pulsed [~ 5-10 hours]) Such a device could *(in the most aggressive imaginable case)* demonstrate electricity production in ~ 20 years

- IF (building on results from ITER, IFMIF, JT60-SA, FDF,) EDEMO could be followed by high performance 'commercial' fusion power stations without an intermediate step, this could significantly speed up fusion development
  - this should be studied by the proposed DEMO design group

### **CONCLUDING REMARKS**

- Fusion should be developed as rapidly as reasonably possible as a potentially major new, environmentally responsible, source of energy
- Approval of ITER and the joint EU-Japan 'Broader Approach' fusion activities is a major step forward for fusion – which puts fusion firmly on the route to building DEMO
- However, the present approach could and I think should be strengthened and speeded up, by greater investment in technology with greater involvement of industry
- It is encouraging that, recognising the potential importance of fusion, the ITER partners are working together in increasing harmony. I hope that some or all of them (with Europe and Japan in the lead?) will, in the not too distant future, adopt a more aggressive approach on something like the lines I have presented

