EURATOM STRATEGY TOWARDS FUSION ENERGY

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Abstract – This paper describes the strategy of the EURATOM Fusion Programme to demonstrate that nuclear fusion is a long-term, safe and environmentally benign energy source suitable for the large-scale, base-load electricity production necessary for the sustainable development of our society.

Keywords: Fusion, EURATOM, ITER, DEMO, Fusion Power Station

1. Introduction

Research and development (R&D) activities in controlled thermonuclear fusion have been carried out since the 50's of the last century aiming at demonstrating that fusion, the process that powers the sun and other stars, might be a clean, powerful, practically inexhaustive, safe, environmentally friend and economically attractive energy source, suitable for the large-scale, base-load electricity production needed for the sustainable development of our society [1]. Clean because there are no greenhouse gas emissions. Powerful since one gram of fusion fuel could generate the same electricity (100 000 kilowatt hours) that is obtained by burning eight tonnes of coal. Practically inexhaustive because the basic fuels for the easiest fusion reaction to accomplish in Earth (Figure 1) [1]

$$D + T \qquad He + n + 17.4\ MeV$$

are abundant and widely distributed around the world: deuterium can be extracted from sea water and lithium, from which tritium can be produced within the reactor, is a readily available metal in the Earth crust. Inherent safe since only very small amounts of fuels are present in the reactor at any time and any malfunction results in a rapid shutdown, meaning that runaway or meltdown accidents are not possible since no chain reactions can occur. Environmentally friend because: (i) the day-to-day operation of a fusion power station does not require the transport of radioactive materials; (ii) there is a very low risk of radioactive emissions to the environment; and (iii) the waste from fusion will not be a long-term burden on future generations since the radioactivity of the reactor components that are activated, the structures close to the fusion plasma, will decay over several decades allowing possible reuse after about 100 years.

Figure 1 – The D-T fusion reaction

Controlled fusion reactions can be obtained in Earth by magnetic and inertial confinement. The Fusion Programme of the European Atomic Energy Community (EURATOM) [2] has the world-wide leadership of the magnetic confinement R&D activities due to its strategy and organization, leading to the excellent results obtained on JET (Figure 2) [3] and other specialized devices (Table 1) as well as on the development of the technologies that are needed for the operation of a fusion power station.

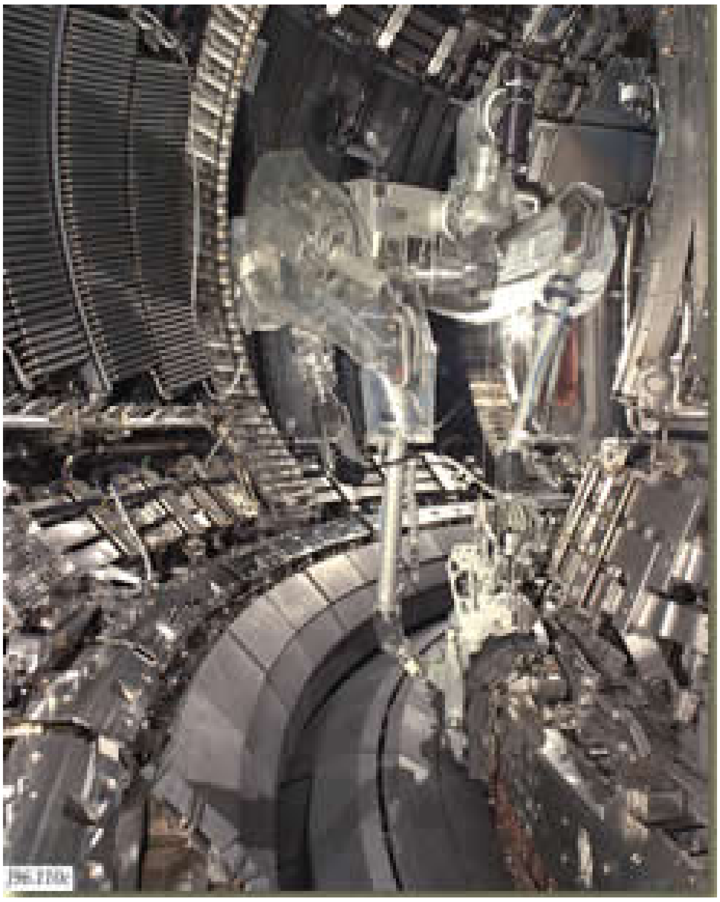

Figure 2 – Inner view of the JET vessel during remote handling maintenance

2. EURATOM Fusion Programme

2.1. General description

The European Union (EU) has understood very earlier that achieving the ultimate goal of fusion R&D, the joint realisation of prototype fusion power plants, would require a long-term and large-scale effort that could not be sustained by any single Member State. Therefore, the EU Member States and the Associated Third Countries have decided to collaborate in a single fully integrated and co-ordinated programme, carried out in the frame of the EURATOM Treaty [4]. Due to its peculiar organization, the EURATOM Fusion Programme (EFP) is since 1958 a good example of the concept of “European Research Area” introduced in 2000 in the EU Framework Programmes [5].

The EFP long-term objective is being achieved by steps. The first step, consisting in proving the magnetic confinement concept in toroidal configurations and the plasma auxiliary heating and current drive systems, has been fulfilled by the first generation of fusion devices. The second step, achieved by the following machines, aimed at establishing the physics, engineering and technology basis for the design of the first fusion experimental reactor as well as obtaining fusion power in a laboratory. JET, the largest magnetic confinement device in the world and the single machine that can operate with D-T discharges, established in 1997 the current world-wide record by producing 16 MW of fusion power, during 3 seconds and with a power amplification of 0.6 [3]. The next step is ITER (International Thermonuclear Experimental Reactor), which has been developed in the frame of a broad international collaboration [6]. The EFP initial strategy towards fusion energy foresaw three further steps beyond ITER: the Demonstration Reactor (DEMO), the Prototype Reactor (PROTO) and the prototype of a commercial fusion power station. Experts have recently proposed that DEMO and PROTO might be combined in a single device still called DEMO giving a 20 to 30-year “fast track” to electricity production [7].

Figure 3 illustrates the progress of fusion research, by presenting the evolution of the triple product: plasma density x ion temperature x energy confinement time. This product has increased 10000 times in the last thirty years, a rise faster than those of the computer chips and accelerators [8]. An additional increase of a factor 6 is still necessary to arrive at the level required for a fusion power plant.

The EURATOM Fusion Programme includes activities in physics (mainly related with the scientific exploitation of the magnetic confinement fusion devices (Table 1) and with keep-in-touch activities on inertial fusion energy), plasma engineering (including plasma heating and current drive systems, diagnostics, plasma wall interaction studies and control and data acquisition systems) and fusion power plant technologies (like, for instance, superconducting magnets, breeder blanket, advanced materials, remote handling, cryogenics and vacuum systems, safety and environment, socio-economics and power plant conceptual studies) [9].

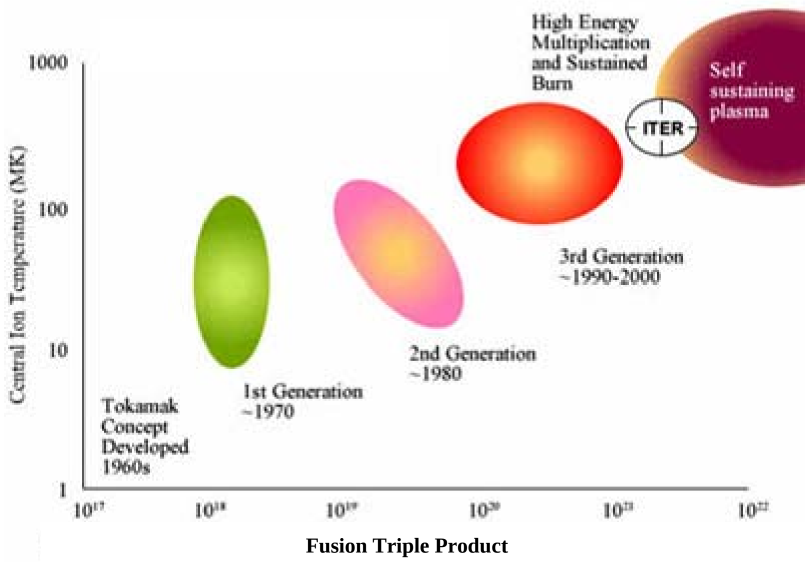

Figure 3 – Progress in thermonuclear controlled fusion

2.2. Fusion in FP-7

The Specific Fusion Programme in the 7th Framework Programme (FP-7) runs from 2007 to 2011, mainly focussed on the realisation of ITER as the next major step towards the EFP long-term aim and on the so-called Accompanying Programme. Its budget is 1947 MEuros of which at least 900 MEuros are reserved to activities other than the ITER construction [10].

The realisation of ITER will involve the site preparation, the establishing of the ITER Organisation and the Domestic Agency for ITER, the participation in the management and staffing of the Project, the construction of equipment and installations and the support to the Project during construction.

Name	Type	Institution	Beginning of operation
JET	T	Culham, UK	1983
ASDEX Upgrade	T	IPP Garching, Germany	1991
CASTOR	T	IPP.CR Prague, Czech Republic	1984
COMPASS-D	T	IPP.CR Prague, Czech Republic	in construction
EXTRAP–T2R	RFP	VR Stockholm, Sweden	1994 (2000)
FTU	T	ENEA Frascati, Italy	1990
ISTTOK	T	IST Lisbon, Portugal	1992
MAST	ST	UKAEA Culham, UK	1998
RFX	RFP	ENEA Padova, Italy	1991 (2000)
TCV	T	CRPP Lausanne, Switzerland	1992
TEXTOR-94	T	KFJ Jülich, Germany	1981 (1994)
TJ-II	S	CIEMAT Madrid, Spain	1997
TORE SUPRA	T	CEA Cadarache, France	1988
Wendelstein 7-X	S	IPP Greifswald, Germany	in construction

Table 1 – Current devices of the EURATOM Fusion Programme. T means Tokamak, S Stellarator, RFP Reversed Field Pinch and ST Spherical Tokamak

The Accompanying Programme aims to prepare the ITER scientific exploitation, the DEMO design and the concepts for fusion power stations. A substantial part of this programme will be carried out in the frame of the Broader Approach, an agreement signed by EURATOM and Japan [11]. The preparation for ITER operation includes theoretical and experimental activities aiming at assessing specific key ITER technologies, consolidating ITER design choices and preparing operation scenarios and staff. The DEMO-oriented activities includes the development of fusion materials and key technologies for fusion and the establishment of a dedicated project team to prepare for the construction of the International Fusion Materials Irradiation Facility (IFMIF) to qualify materials for

DEMO. Preparation of the concepts for fusion power stations includes theory and modelling activities on the tokamak configuration as well as the improvement of alternative schemes with potential advantages for fusion power stations, such as stellarators, reversed field pinches and spherical tokamaks. Special attention will be given to initiatives aimed at ensuring that adequate human resources will be available in the future.

2.3. Implementation

The EURATOM Fusion Programme is managed by the European Commission, assisted by the Consultative Committee for the Specific Research and Training Programme on Nuclear Energy (Fusion) (CCE-FU), composed by representatives of EURATOM, the Member States and Associated Third Countries (Figure 4), which advises the Commission on programmatic and strategic issues as well as on funding allocations.

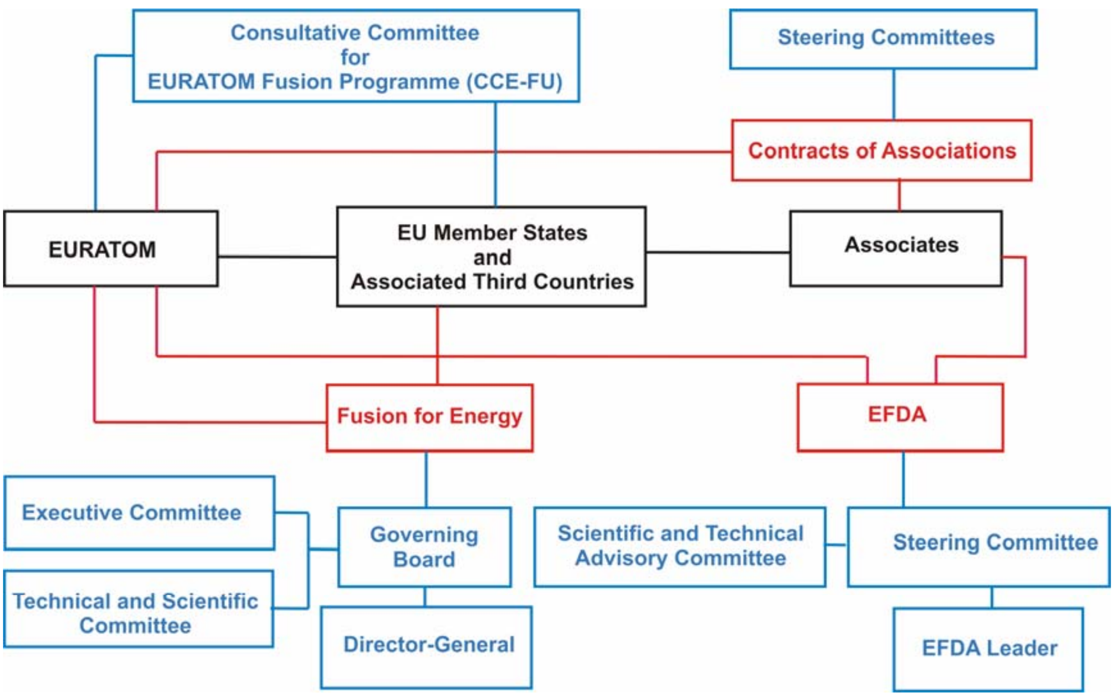

Figure 4 – Instruments and management bodies of the EURATOM Fusion Programme

This Programme has been mainly implemented by the Associates, universities and industry, using the Contracts of Association, the European Fusion Development Agreement (EFDA), the European Joint Undertaking for ITER and the Development of Fusion Energy (“Fusion for Energy”) and the Mobility Agreement (Figure 4). Training of young researchers is supported by the EURATOM Fellowship Scheme. Other contracts of limited duration are used for specific purposes and a number of technological developments are contracted directly to the European industry [12].

The Associations are long-term, bilateral contracts signed by EURATOM and organizations in, or acting for, Member States or Associated Third Countries. Each Association has a Steering Committee composed by local and Commission representatives to direct its overall programme. In the beginning of FP-7, there are twenty five Associations [13].

EFDA (14) is a framework contract signed in 1999 between EURATOM and its Associates in the Fusion Programme, with three main goals: (i) to provide a legal frame for the collective use of the JET facilities by the Associates, through the JET Implementing Agreement and the JET Operation Contract; (ii) to co-ordinate the EU contributions to large-scale international collaborations, such as the ITER Engineering and Design Activities (EDA); and (iii) to co-ordinate and support the technology activities carried out by the Associations and the European industry. After the re-organization in FP-7 of the Fusion Programme, EFDA shall cover the following interrelated activities: (i) co-ordination of the physics and emerging technology activities carried out by the Associations; (ii) collective use of the JET facilities; (iii) training and career development of researchers, promotion of links to universities and support actions for the benefit of the thematic area of research "fusion energy"; and (iv) co-ordination of the European contributions to international collaborations that are outside the scope of “Fusion for Energy”. The overall planning and supervision of the EFDA activities are carried out by a Steering Committee (Figure 4), composed by representatives from the Commission and all Associates, assisted by a Scientific and Technical Advisory Committee. The implementation of the EFDA programmes is made under the responsibility of the EFDA Leader, assisted by Associate Leader(s).

“Fusion for Energy” [15] was established by the Council of the European Union at its meeting on 27 March, between EURATOM and the governments of the Member States and Associated Third Countries, with a lifetime of 35 years and a total budget of 9653 MEuros. This legal entity, located in Barcelona, has the following main objectives: (i) to be responsible for the EURATOM contribution to ITER; (ii) to manage the EURATOM contribution to 'broader approach' activities with Japan for the rapid realisation of fusion energy; and (iii) to prepare and co-ordinate the activities in preparation for construction of a demonstration fusion reactor and related facilities. The main management bodies are the Governing Board, composed by one delegate and one fusion expert from each Party, and the Director-General (Figure 4).

The Mobility Agreement, signed between EURATOM and its fusion Associates, provides financial support for the exchange of personnel between the Associations.

3. ITER

ITER (International Thermonuclear Experimental Reactor) is a joint international large-scale R&D project, of the tokamak-type, developed by the ITER Organization established in an international agreement signed in Paris, on November 24th 2006, by EURATOM, Japan, Russia Federation, United States of America, South Korea, China and India [6]. The ITER Project is a first example of the globalization of Science and Technology since more than half of the world population is represented in the Project.

The Project has two main objectives: (i) to prove the scientific and technical viability of fusion energy by producing 500 MW, during 300 seconds and a energy amplification between 10 and 20; and (ii) to test the simultaneous and integrated operation of the technologies needed for a fusion reactor. Its duration is estimated in 35 years (10 for construction, 20 for scientific exploitation and 5 for decommissioning) and the total budget is 10 000 MEuros. The Party contributions to the tokamak construction (about 4 000 MEuros) are mainly in kind, being 50% provided by EURATOM (Figure 5) and 10% by each other Party, including 10% for contingencies.

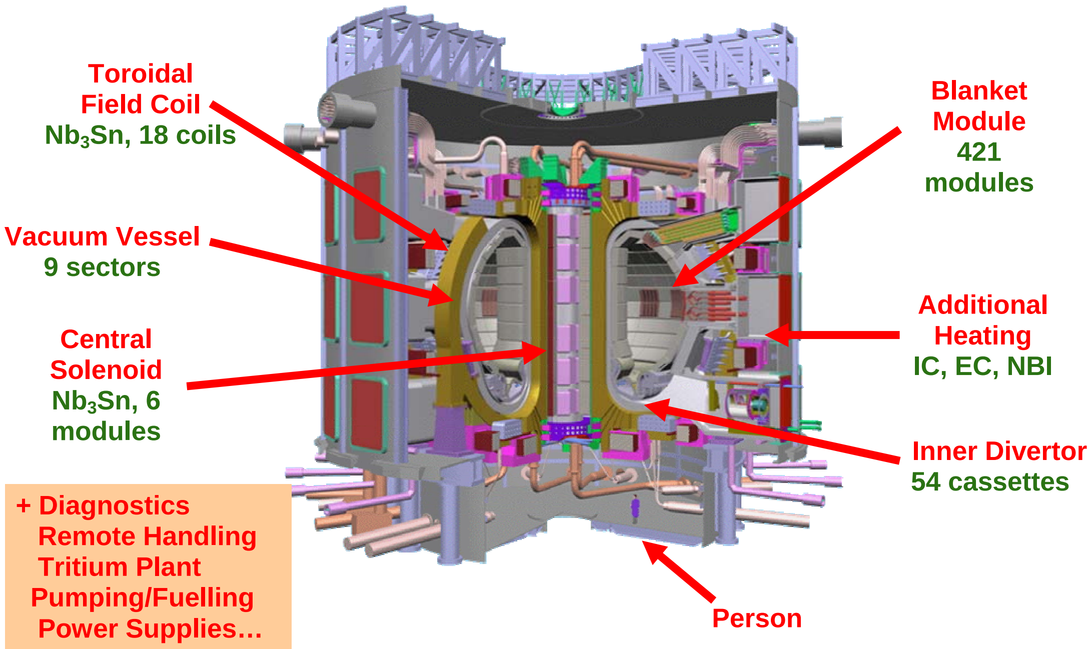

Figure 5 - ITER components to be provided by the EU

The ITER Organization has its headquarters at Cadarache, in the South of France and is composed by the Council, the Director-General and the Project Team (Figure 6) [16]. The Council, composed by four delegates of each Party, is assisted by two advisory committees (Scientific and Technical Advisory Committee and Management Advisory Committee) and the Auditors. The Director-General (DG) is the Chief Executive Officer, responsible for the day-to-day running of the Project. He/She is assisted by a Principal Deputy Director-General (PDDG), in charge with the tokamak construction, and six Deputy Directors-Generals (DDG), three reporting directly to the DG (DDGs for Administration, Safety and Security and Fusion Science and Technology) while the other three report to the PDDG (DDGs for Tokamak, Central Engineering and Plant Support and CODAC, Heating and Current Drive and Diagnostics). The Project Team is composed by the Central Team, also located at Cadarache, and Field Teams, one in the territory of each Party.

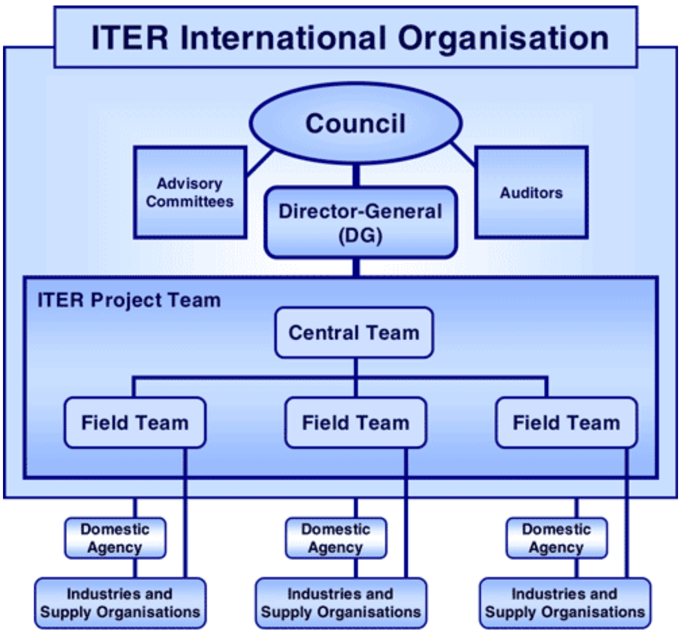

Figure 6 – ITER organization

4. Steps beyond ITER

The route towards a fusion power plant (Figure 7) includes currently DEMO and the prototype of a commercial fusion reactor.

DEMO will integrate the optimised reactor core design from ITER and will be designed to: (i) produce thermal fusion power in levels relevant for commercial power production; (ii) have the capability of net electricity production; (iii) demonstrate tritium self-sufficiency; and (iv) demonstrate high reliability and the performance of low-activation materials.

The prototype of a fusion reactor should demonstrate the economically viability of fusion technology by producing electricity at commercial scale.

The current plans foresee that the first injection in the public grid of electricity produced by fusion reactions might occur 35 years after the beginning of ITER construction.

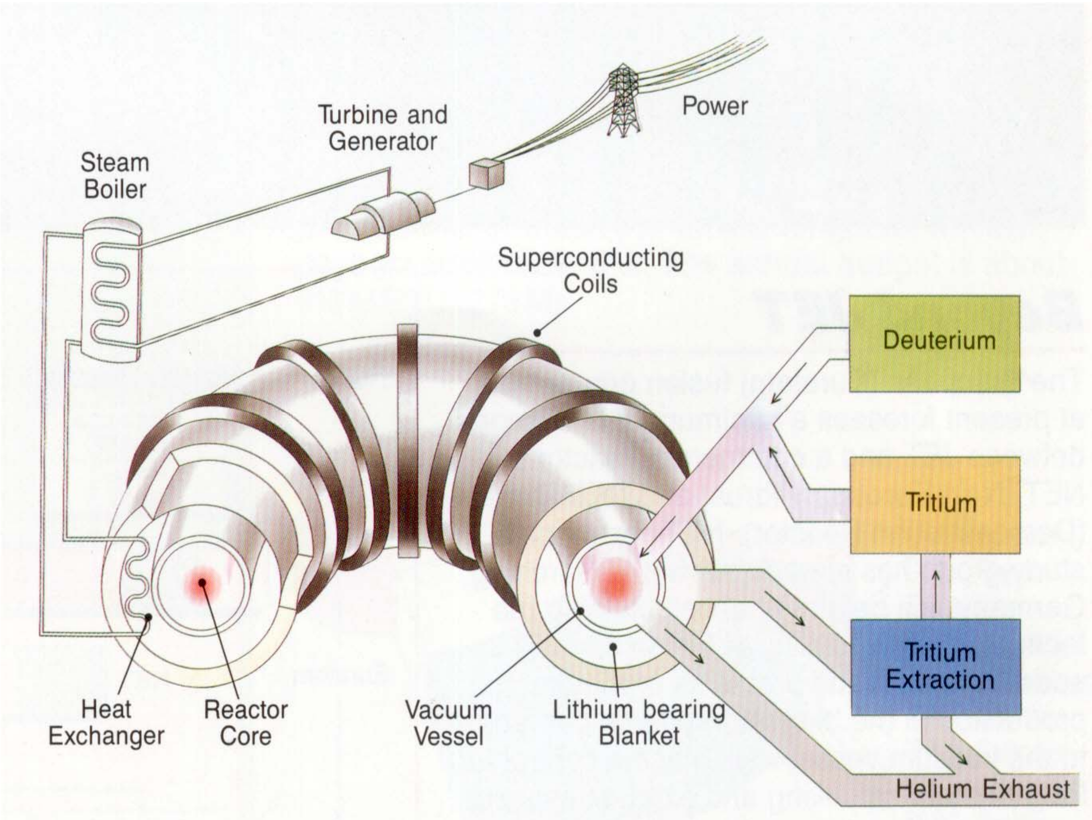

Figure 7 – Schematic of a fusion power plant

5. Role of industry

The EURATOM Fusion Programme has always promoted interactive knowledge transfer between the research community and industry [17]. The leading-edge technologies needed for fusion R&D has led to many spin-off technologies and the formation of new companies. Industry has given important contributions to the success of JET and other medium size fusion devices as well as to the ITER EDA. A sub-committee of CCE-FU was established until the end of FP-6, the Committee for Fusion-Industry, aiming at acting as a contact point between EFP and industry, advising the Commission and CCE-FU on industrial policies and promoting the participation of new firms, specially SMEs, in fusion activities.

One example of a successful joint project is the ITER toroidal field model coil, a Nb3Sn superconducting coil of unprecedented sise and performance (Figure 8). It was designed and tested by the EURATOM Fusion Associations and constructed by a consortium of European companies [17].

Figure 8 – View of prototype of the ITER toroidal magnetic field coil

ITER, being one of the most challenging scientific and engineering enterprises of this century with about 80% of its construction budget dedicated to industrial contracts, will be an excellent opportunity for industry not only to develop and establish, at industrial level, cutting-edge technologies relevant for ITER and fusion devices beyond ITER, but also to grow within an international endeavour and to establish new standards for the technical management of complex engineering projects.

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