Main aspects and lessons from the ITER project governance

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Abstract. ITER (International Tokamak Experimental Reactor), presently under construction at Cadarache, is a very important project in the path towards a nuclear fusion power plant. This paper addresses the main key aspects of the ITER governance, trying to take lessons for future international projects to be carried out in a world dominated by a global economy.

Key words: fusion reactor • governance • ITER • tokamak

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Introduction

ITER [10] is the first reactor relevant experiment of the tokamak configuration based on deuterium-tritium nuclear fusion reactions. It is a very challenging, scientific and technologically demanding as well as complex project, carried out in the frame of a very broad international collaboration, presently involving seven Members: Euratom (European Union plus Switzerland), Japan, Russian Federation, United States of America, People's Republic of China, Republic of Korea and India. The Project is challenging because its programmatic and technical objectives are ambitious: (i) to prove the scientific and technical feasibility of fusion energy by producing 500 MW of fusion power, during 300 s, with an energy amplification gain of at least 10; and (ii) to test the simultaneous operation of all necessary technologies for the operation of a fusion reactor. ITER is a demanding project since its design has required intensive research and development (R&D) programmes on tokamak physics, plasma engineering and fusion technologies. Most of the ITER components will be the first of the kind since several required technologies are well beyond the state-of-the-art. The project is complex because ITER is a nuclear facility and has a very complicated organization mainly due to the in-kind procurement and the large number of Members.

Some impressive ITER figures are [11]: the site has 180 hectares, the tokamak building measures 73 m (60 m above ground and 13 m below), the fabrication of the toroidal field (TF) coils will use 80 000 km of niobium-tin strands, each TF coil weight will be 360 tons, the tokamak will weigh 23 000 tons and will

Fig. 1. Construction progress in May 2011 on the ITER site.

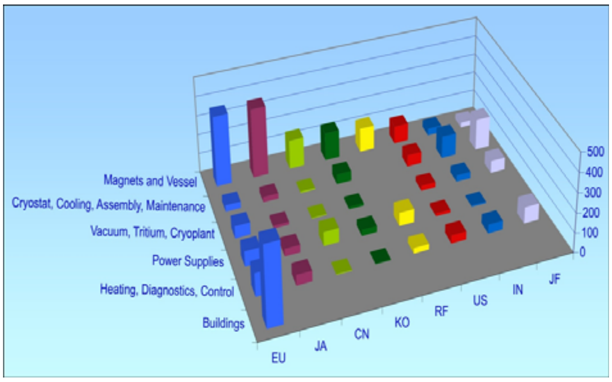

Fig. 2. Sharing of the main tokamak components by the ITER Members.

be made up by approximately 1 million components, the plasma volume will be 840 m^3 and the staff members are expected to reach 1000 in the operation phase.

The ITER Project was decided in the first Superpower Summit between Presidents Reagan (USA) and Gorbatchev (former the Soviet Union) held in Geneve in 1985. After eighteen years of Conceptual Design Activities (CDA), Engineering Design Activities (EDA), Co-ordinate Technical Activities (CTA) and ITER Transitional Arrangements (ITA) as well as the Exploration, Negotiation and Preparation activities, the ITER Agreement and also the Agreement on the Privileges and Immunities for the ITER Organization were signed in Paris, on 21 November 2006, under the auspices of the International Atomic Energy Agency (IAEA). The ceremony was hosted by the Presidents of France Jacques Chirac and of the Commission of the European Union José Manuel Barroso. The ITER Council approved in July 2010 the ITER baseline (scope, schedule and budget). At present, the site at Cadarache in the South of France near Aix-en-Provence is being prepared (Fig. 1) and the tokamak components are being manufactured by industries of all the Members.

This paper presents the main aspects and lessons learned from twenty years of activity as member of the Euratom delegations to the ITER Explorations, Negotiations and Preparations and to the ITER Council as well as Chair of the EFDA [7] Steering Committee and F4E [3] Governing Board. The next sections address issues related with the globalization of Science and Technology, project organization, procurement, management, long duration project, research/industrial project, stability and cost. The section "Implication in the Euratom Fusion Programme" presents the implications of the ITER Project in the Euratom Fusion Programme. Finally, the last section contains the conclusions.

Globalization of Science and Technology

International collaboration is an important political and strategic requirement for large-scale, long-duration, high-cost projects that are in the frontiers of scientific research and technological development and that may contribute to the solution of essential problems of mankind.

ITER may be considered as the first example of the globalization of Science and Technology since the ITER Agreement was signed by the most important members of G-20, which represent over half of the world's population. This fact was politically very important (energy is today a top priority for all governments), but has created some difficulties to the project. Indeed: (i) negotiations for the ITER Agreement were more complex and longer, mainly because the adhesion of the Members has occurred at different times (Euratom, Japan, Russia and USA since the beginning but USA was out between 2000 and 2003 due to Congress decisions, China and Korea in 2003, India in 2005 and Canada was a Member between November 2001 and December 2003); (ii) the Members had different knowledge of the project and most probably different levels of expertise on the required technologies; (iii) each time a new Member was admitted, all the procurement packages had to be re-discussed; (iv) the cost of the Project has increased because almost all Members have decided to contribute in all areas of the Project (Fig. 2).

In spite of the difficulties, the Members could agree on 28 June 2005, in Moscow, on the ITER Agreement and choose the ITER site after complex negotiations that have started in 2001 from proposals presented by Canada (Clarington), Japan (Rokkasho) as well as Euratom (Cadarache and Vandellós). During this process, it was agreed that the first ITER Director would be a Japanese, the first European ITER Vice-Director would be a Spanish and that F4E would be located in Barcelona. Furthermore it was agreed that Euratom will spend 5% of the construction cost in Japan and will give 9% of its share in the IO staff to Japan as well as the first Demonstration Reactor will be constructed in Japan if it will be developed in the frame of an international collaboration. Finally, the Agreement for the Broader Approach to Fusion Power was signed between Euratom and Japan [1].

There will be certainly in the future more international projects of the ITER size or even larger. It will be desirable that the adhesion of all Members should occur at the same time. Contributions from new Members should be made 100% in cash, avoiding changes in the previously agreed procurement packages.

Implementing structure

The Conceptual Design Activities (CDA) were carried out from April 1988 to December 1990, according to

Table 1. Summary of the ITER direct capital cost estimates

Component	Direct capital cost (kIUA)	Percentage of total (%)
Machine core		
magnet systems	762.1	28
vacuum vessel	230.0	8
blanket and divertor	241.2	9
other machine core	231.5	8
Machine core, subtotal	1464.8	53
Auxiliaries		
buildings	380.3	14
power supplies and distribution	214.7	8
cryoplant and cooling water system	131.5	5
other auxiliary systems	189.7	7
Auxiliaries, subtotal	916.2	33
Heating and current drive	205.7	7
Diagnostics, control and data acquisition	168.0	6
Grand total	2754.7	100

the Terms of Reference that have been agreed in meetings held in 1987 in Vienna by initiative of the IAEA Director-General, with participation of representatives from the world four major fusion programmes: Euratom, Soviet Union, Japan and United States of America.

The Engineering Design Activities (EDA) were conducted in the frame of the ITER EDA Agreement [22] approved in Washington on July 21st 1992 by representatives of the four Parties. Canada and Kazakhstan have also participated in EDA as associates of respectively Euratom and Russian Federation. EDA was implemented by the Joint Central Team, located in three sites (Naka, S. Diego and Garching), supported by ITER Home Teams at each Party territory. This work finished in 1998 with the delivery of the design of a tokamak with a foreseen direct capital cost of 2754.7 kIUA (Table 1) [21]. One ITER Unit of Account (IUA) is defined as the equivalent purchase power of US$ 1000 in January 1989. This virtual currency was created aiming at isolating the cost estimating process from fluctuating economic factors like, for example, the variations in exchange rates and domestic inflation rates. The conversion factor in 2000 of 1 IUA to each Party currency was 1.39 kUS$, 1.28 kEuro, 148 kYen and 39.5 kRouble.

The ITER Parties in 1998 (Euratom, Japan and Russia) have decided not to accept this price due to the economic crisis, to extend the ITER EDA Agreement until 2001 and to ask the adaptation of the design to a device with reduced technical objectives, size and cost. The Final Design Report (FDR) [21, 23, 24], issued in July 2001, presented the design of the ITER-FEAT (Fusion Energy Amplification Tokamak) with a foreseen construction cost of 4000 MUS$ (Table 2).

After July 2001, ITER was forward in the frame of the ITER Joint Implementing Transition Agreement with the CTA and ITA phases, aiming at mainly adapting the design to the proposed sites and achieving a common understanding about the ITER Agreement. Canada, represented by ITER Canada a not-for-profit corporation formed in 1997 with support from the federal and Ontario provincial governments, has played an important role in 2000–2003 by contributing to keep the momentum of the project, presenting the first site and showing that ITER could be seen like a business, with a strong participation of financial institutions in its funding scheme. Canada left the project in December 2003 due to lack of financial support from the federal government.

The project has been developed after November 2006 by the ITER International Organization (IO) and by seven Domestic Agencies (DAs), one in each Member [3, 4, 6, 13–15, 19]. ITER IO was officially established on 24 October 2007 following ratification of the ITER Agreement by all Members. Its first tasks were to set-up the Organization as well as the professional and support teams, to revise the design, to finalize the drawings and specifications of all tokamak components and to sign Procurement Arrangements with the Domestic Agencies. As of end May 2011 ITER IO has a total of 475 staff members, out of which 305 are professionals (Table 3).

The interfaces between ITER IO (responsible for the Project) and the Domestic Agencies (providing human and financial resources) have been very difficult, specially during the first years after the signature of the ITER Agreement. Indeed: (i) conflicts between achieving the best or an efficient project have very often occurred; (ii) sometimes the DA were obliged to launch calls without all specifications completely defined (for example, the vacuum vessel); and (iii) there were serious delays in several procurement processes due to delays in the work of the ITER Central Team (lack of final drawings

Table 2. Main design parameters of JET, $ITER_{1998}$ and $ITER_{2001}$

Parameter	JET	$ITER_{1998}$	$ITER_{2001}$
Major radius (m)	2.96	8.15	6.2
Minor radius (m)	1.25–2.10	2.8	2.0
Plasma current (MA)	3.2–4.8	21	15.0
Toroidal magnetic field (T)	3.45	5.7	5.3
Fusion power (GW)	0.016	1.5	0.5
Plasma volume (m^3)	100	2000	840

Table 3. Distribution by Member in May 2011 of the IO staff

Member	Professional	Support	Total
China	16	4	20
European Union	185	125	310
India	12	16	28
Japan	26	7	33
Korea	21	5	26
Russia	19	3	22
United States	26	10	36
Total	305	170	475

and detailed specifications). Now these problems are solved due to decisions of the ITER Council, the activity of the Director Osamu Motojima and the increase of the dialogue between ITER IO and the DAs.

Future projects of this complexity should have a simpler implementation structure, with well defined responsibilities since the very beginning of the project. Careful attention should be given to technology transfer and intellectual property rights, two matters where a lot of time has been spent in ITER.

Procurement

The Member's contributions to ITER are mainly made in kind: components, staff and infrastructures for the project. This decision was taken with the following main objectives: (i) to guarantee that the money of each Member is mainly spent in its own territory; (ii) to contribute to the development of the expertise on fusion technologies of all Member industries; and (iii) to avoid that the high industrial costs of the European Union and Japan are also paid by the other Members.

The high number of Members and the procurement in-kind have created several additional difficulties to the project: (i) the main tokamak components will be provided by several Members (Fig. 2) leading to increases on cost and integration risks; (ii) ITER IO has very little control on the call for tenders; (iii) there will be most probably conflicts between who has the responsibility of the project (ITER IO) and who pays (DAs); (iv) Quality Assurance, already important due to the nuclear character of this project, is still more important aiming at reducing the integration risks; (v) delays in one DA will have impact on the work of other DAs; and (vi) the exact total cost of the project will most probably never be known since each DA will not publicise the cost of its contribution to ITER.

A better choice for future ITER-like projects would probably be a mix scheme where the core of the machine is procured in cash and the auxiliary systems are provided in kind. In any case, each component should be provided by a single Member and responsibilities between the Central Organization and Member Institutions (MIs) as well as between MIs should be very well defined since the beginning of the project.

Management

As a result of the compromises assumed during the negotiations and the wish of each Member to be represented in the high-level management, the first internal organization and the choice of the first senior staff of ITER IO were mainly dominated by political considerations rather than by the project needs. Aiming at assuring balance between members, ITER IO had a Director-General (DG), a principal Deputy Director--General and six Deputy Directors-Generals (DDGs). DG Kaname Ikeda had little to say on the choice of his team.

After three years of activity and an external assessment, the ITER Council has decided to nominate a new DG as well as to approve different rules for the selection of the senior staff and a new internal organization with three DDGs and a Bureau for International Cooperation, which will be in charge of the essential IO-DAs coordination (Fig. 3).

Although the contributions to the Project are different (Euratom contributes with 45% while the other Members contribute 9% each), all Members have one vote in the ITER Council. This question is not very important because almost all the key decisions of the ITER Council have to be taken by unanimity.

It is advisable that the organization of future international projects shall be mainly determined by the characteristics and needs of the project. Staff shall be chosen in open calls for applications based on the expertise and on the capability for work in a team.

Long duration project

ITER is a long duration project (20 years for design, 10 for construction, 20 for operation) in an area where progress is being continuously achieved in other fusion devices: JET [17], DIII-D [9], JT-60SA [18], KSTAR [20] and EAST [2]. The experience from JET permits to conclude that the ITER design should have enough flexibility and room to incorporate new developments in fusion physics and technology performed during the ITER Project.

During the project lifetime significant changes will certainly occur in each Member and world-wide. The ITER Agreement foresees how to deal with difficult situations like, for example, budgetary problems, the willing of a Member to leave the project and natural events with major damages in R&D facilities.

Research/industrial project

ITER was a research project until 2007. Fusion Research Institutions (FRI) have played an important role in the tokamak design and have the accumulated

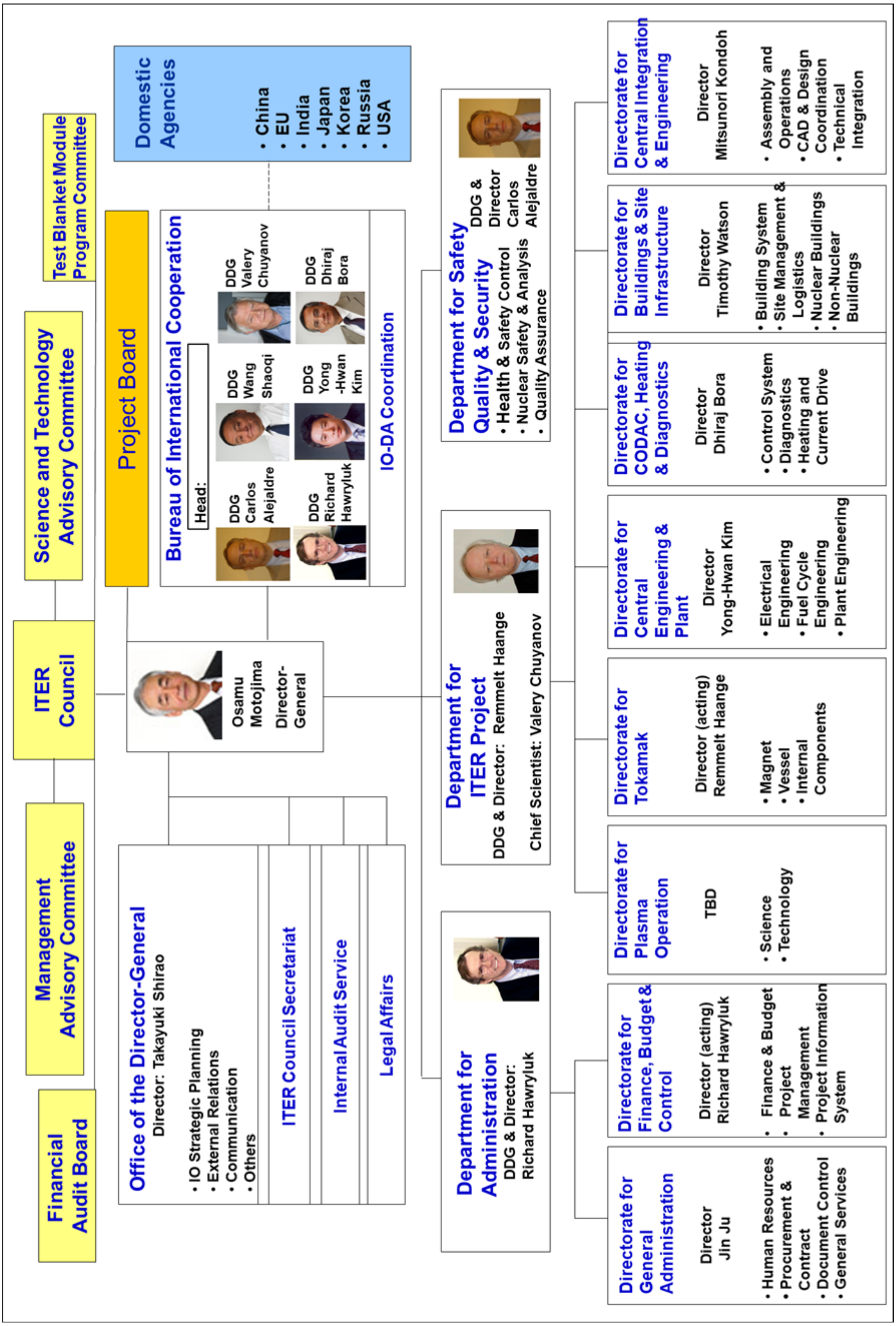

Fig. 3. Internal organization of the ITER Project (in May 2011).

expertise necessary for this well-beyond the state-of--the-art project.

After 2007, ITER became an industrial project due to the weight of the procurement. However research is still needed, in support to construction, in preparation of operation as well as to exploit the tokamak, in the following main areas: (i) control and mitigation of magnetohydrodynamics (MHD) instabilities (adaptation of the present techniques (coils and pellets) to ITER and development of new techniques); (ii) alpha-particle physics (influence of these particles on the plasma confinement, stability and self-heating); (iii) tritium and dust technologies; (iv) plasma facing components (strategy for the use of C, Be and W in the different ITER phases); (v) heating and current drive (development of a 1 MeV, 40 A negative neutral beam system, a 20 MW, 170 GHz, continuous wave gyrotron and the transmission line for electron cyclotron, a 24-strap antenna (40–55 MHz) for ion cyclotron); (vi) diagnostics (about 40 large scale diagnostic systems for protection, control and physics studies); (vii) vacuum technology (development of the cryogenic pump, leak detection techniques and instrumentation); (viii) remote handling for large scale systems: blanket modules, divertor modules and port plugs; (ix) real-time control (hardware and algorithms); and (x) control and data acquisition, storage and processing (new approach for long duration discharges).

With the integration of the International Tokamak Physics Activities (ITPA) [12] in ITER IO, the project could have a research programme that answers to the ITER needs. However, there are still some questions that need to be addressed by ITER IO and the DAs concerning the transfer of the expertise from the FRI to industry, the use of the FRI expertise in the benefit of ITER and the preparation by FRI of the operation phase.

Stability

ITER had already five Directors: Paul-Henry Rebut (1992–1994), Robert Aymar (1994–2003), Yasuo Shimomura (2003–2005), Kaname Ikeda (2005–2010) and Osamu Motojima (after July 2010). This fact was not very positive for the project since usually each new Director asks a technical assessment of the project and tries to introduce his own ideas in the project design and organization. This behavior implies at least delays, although in same cases has also improved the project and reduced the cost of some components.

Since stability is a prerequirement for the success of a R&D project, the ITER Council should proceed with the approval of measures that could provide stability to the project allowing the achievement of its main goal as soon as possible, without further delays and cost increase.

Cost

As it often happens when other large-scale projects arrive to the construction phase, the cost of the ITER construction has increased in the last years. ITER IO presently estimates the cost of ten year construction in 12.8 billion euros.

The cost of the Euratom contribution for the ITER construction until 2020 has increased from 2.7 billion euros in 2001 to 5.9 billions euros in 2008, based on the work of an Ad-Hoc Group set-up by the F4E Governing Board and chaired by Prof. Romano Toschi. Justifications for the cost increase of ITER construction are: (i) increase in 30% of the ITER IO cost mainly due to the increase of staff, the missing items, the spare components, new direct investments and the increase of the number of Members; (ii) use of 2008 values; (iii) the increase of the commodities cost was much higher than the inflation rate; and (iv) cost was based on industrial estimates instead of research calculations.

ITER shall be built within the budget approved in July 2010 by the ITER Council, which implies that construction shall be made following the budget and not the programme. The ITER IO and the DAs shall proceed with the implementation of measures to contain and reduce costs. If additional cost increases occur, the ITER Council should defer the installation of components and/or to use the budget of the operation phase, since further rises in the Member's contributions are highly unlikely.

The budget of new large-scale projects should be constructed based on industrial data, indexed to the price of the raw materials for the most expensive components and with contingencies for unforeseen events (at least 10% of the total cost).

Implications in the Euratom Fusion Programme

ITER has implied important changes in the strategy, content and organization of the Euratom Fusion Programme, although the ultimate goal has remained unchanged: the construction of a prototype of a nuclear fusion reactor. The main changes were: (i) disregard in 1991 of the design of NET (Next European Torus), a tokamak with parameters very similar to those of the present ITER; (ii) transformation of the NET Team on the ITER European Home Team; (iii) development of a R&D programme in support to the ITER design; (iv) set-up of the Committee Fusion-Industry to deal with specific aspects of the Fusion-Industry Policy; (v) progressive adaptation of the Association Work--Programmes to ITER oriented projects; (vi) creation on 19 April 2007 of the European Joint Undertaking for ITER and the Development of Fusion Energy (F4E) to act as the European Domestic Agency for ITER.

Being mainly an industrial project, ITER provides new business opportunities for the European industry. F4E has three main tools for the procurement of the Euratom contribution to ITER: contracts, grant agreements and service contract funded at respectively 100, 40 and 100%. All these legal instruments are signed after competitive calls for tender, which have to follow the adequate rules approved by the F4E Governing Board, with administrative and technical assistance from the Executive Committee (ExCo) and the Technical Advisory Panel (TAP), without any considerations about just or geographical returns, concepts that are not applied in the Euratom Fusion Programme. Figure 4 presents the data about the number of contracts and agreements signed by F4E until March 2011

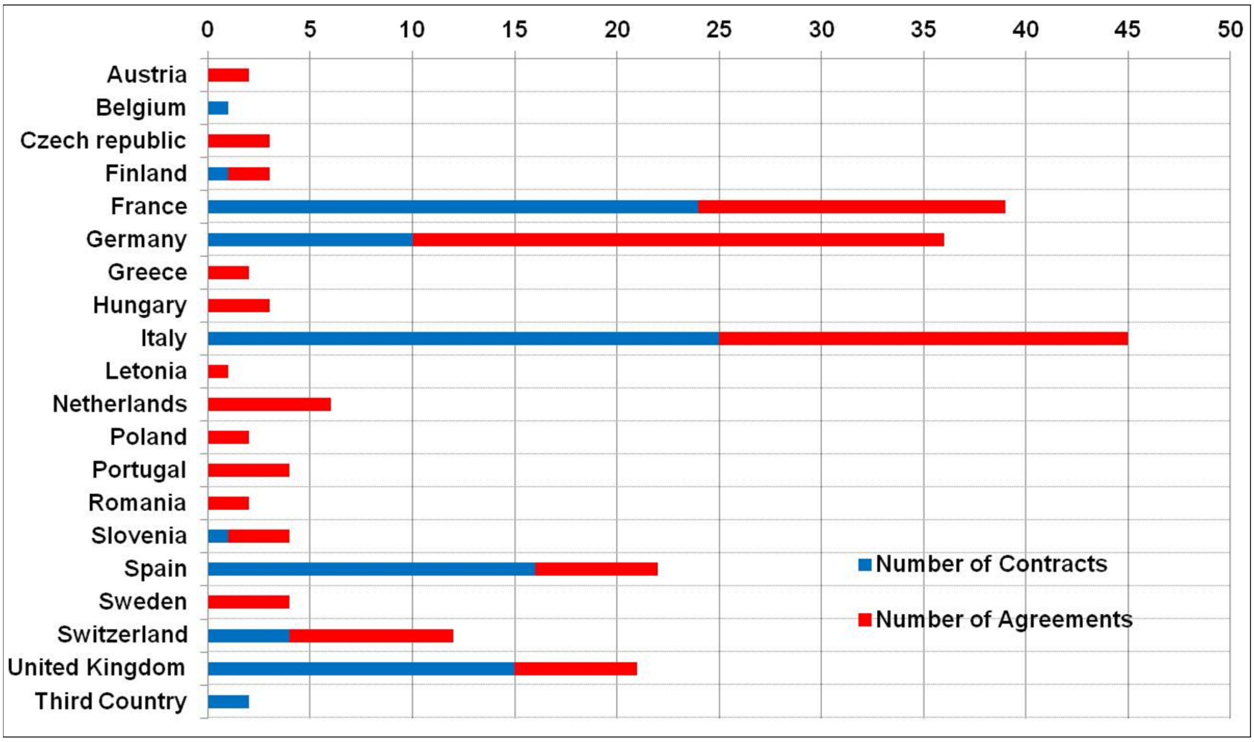

Fig. 4. Distribution by EU Member State and Third Countries of contracts and agreements signed by F4E until March 2011.

with each Euratom Member State and Third Countries. As it would be expected, more than fifteen contracts and agreements were signed with the four big Members States (Italy, Germany, France and United Kingdom) and the F4E host country (Spain). The Netherlands is the only small country that had more than five contracts, most probably due to the action of ITER-NL [16], a consortium of four Dutch research institutes. The distribution of the sum of the awarded value with the maximum F4E contribution is more unbalanced (three countries received more than 80% of the F4E budget for contracts and grants) mainly due to the weight of the large contracts regarding the vacuum vessel as well as the toroidal and poloidal magnetic coils (Fig. 5).

Another important goal of the F4E activity is to avoid conflicts of interest between the participation in

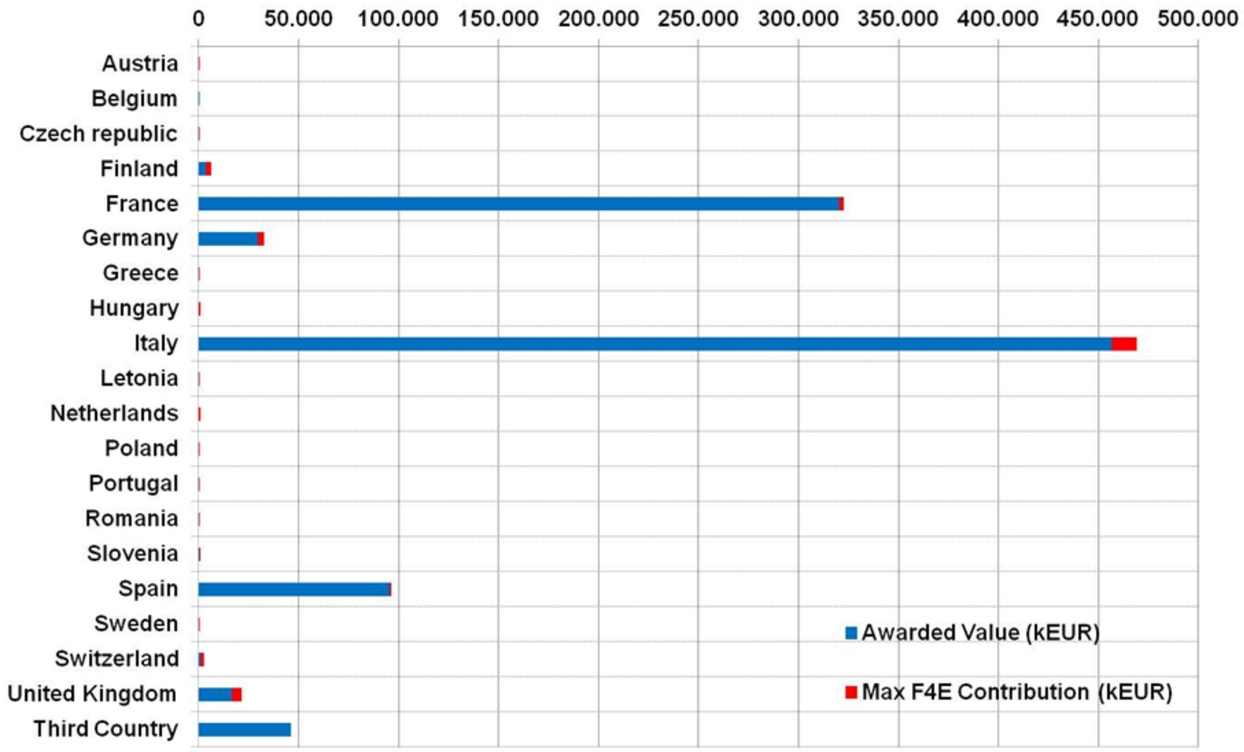

Fig. 5. Distribution by EU Member State and Third Countries of the value of the contracts and agreements signed by F4E until March 2011.

different phases of the process leading to the delivery of a component to ITER IO.

F4E will be responsible for at least the International Fusion Material Irradiation Facility (IFMIF) and the Demonstration Reactor (DEMO). In the beginning of these projects clear rules for the participation of research institutions and industries as well as for project control and auditing shall be approved.

Conclusions

ITER (the way in Latin) is one of the largest and most ambitious international science and technology project ever performed in the frame of a very broad international collaboration. ITER combines the state-of-the-art and the frontiers of the knowledge on Fusion Physics, Plasma Engineering and Technologies aiming at contributing to the development of an energy technology for the future. Since the ITER Members share all aspects of the project (science, technologies, procurement, staffing,…) each Member will have the know-how to built its own fusion power plant.

Although ITER IO has benefited from the expertise acquired in other large-scale international projects, like JET, CERN [5] and ESA [8], the establishment of ITER IO was a very complicate process that is now on track as a result of the decisions of the ITER Council, the activity of the DG Motojima and an improved collaboration and mutual understanding between the ITER Members and between the International Organization and the Domestic Agencies.

The complexity of the Project has led to delays and cost increase. The lessons learned from ITER will be certainly very important for the next projects, in fusion (like, for instance, as well as in other areas, that most probably will be also developed in the frame of international collaborations.

ITER will have to be a success due to its importance in the path to bring nuclear fusion energy to a commercial stage. For that it is important a good mutual understanding between the ITER Members, leadership at ITER International Organization, full cooperation between IO and the DAs and dedication and professionalism from the staff.

ITER is now the main focus of the Euratom Fusion Programme. The Commission and Member State funding to Nuclear Fusion should be oriented to ITER relevant work. Areas where each EU Member State may contribute to ITER have to be identified and a fully integrated programme has to be elaborated. Each EU Member State should implement its own organization, involving industries, research institutions and universities, which has to be dynamic in time as well as adequate to the level and nature of its participation in the ITER Project.

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