Coordinates: 43°42′17.84″N 5°46′9.1″E

ITER

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ITER (**International Thermonuclear Experimental Reactor**, and is also Latin for "the way") is an international nuclear fusion research and engineering megaproject, which will be the world's largest magnetic confinement plasma physics experiment. It is an experimental tokamak nuclear fusion reactor that is being built next to the Cadarache facility in Saint-Paul-lès-Durance, south of France.[1]

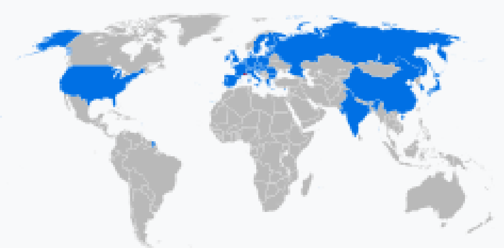
The ITER project aims to make the long-awaited transition from experimental studies of plasma physics to full-scale electricity-producing fusion power stations. The ITER fusion reactor has been designed to produce 500 megawatts of output power for several seconds while needing 50 megawatts to operate.[2] Thereby the machine aims to demonstrate the principle of producing more energy from the fusion process than is used to initiate it, something that has not yet been achieved in any fusion reactor.

The project is funded and run by seven member entities—the European Union, India, Japan, China, Russia, South Korea, and the United States. The EU, as host party for the ITER complex, is contributing about 45 percent of the cost, with the other six parties contributing approximately 9 percent each.[3][4][5]

Construction of the ITER Tokamak complex started in 2013[6] and the building costs are now over US$14 billion as of June 2015.[7] The facility is expected to finish its construction phase in 2019 and will start commissioning the reactor that same year and initiate plasma experiments in 2020 with full deuterium–tritium fusion experiments starting in 2027.[8][9] If ITER becomes operational, it will become the largest magnetic confinement plasma physics experiment in use, surpassing the Joint European Torus. The first commercial demonstration fusion power station, named DEMO, is proposed to follow on from the ITER project.[10]

International Thermonuclear Experimental Reactor

iter
china eu india japan korea russia usa



Thirty-five participating nations

Motto	The way to new energy
Formation	24 October 2007
Headquarters	Saint-Paul-lès-Durance, France
Director-General	Bernard Bigot
Website	www.iter.org (http://www.iter.org/)

ITER

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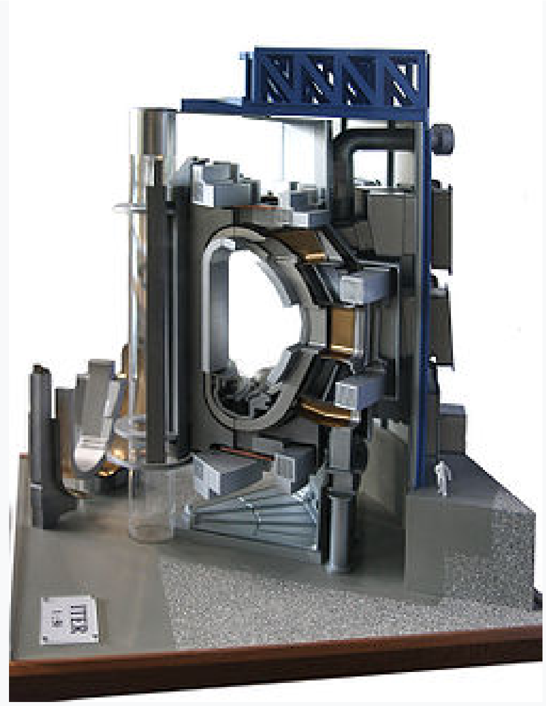


Type	Tokamak
Construction date	2013–2019
Major radius	6.2 m
Plasma volume	840 m^3
Magnetic field	11.8 T (peak toroidal field on coil) 5.3 T (toroidal field on axis) 6 T (peak poloidal field on coil)
Heating	50 MW
Fusion power	500 MW
Continuous operation	up to 1000 s
Location	Saint-Paul-lès-Durance, France

Background

Fusion power has the potential to provide sufficient energy to satisfy mounting demand, and to do so sustainably, with a relatively small impact on the environment.

Nuclear fusion has many potential attractions. Firstly, its hydrogen isotope fuels are relatively abundant – one of the necessary isotopes, deuterium, can be extracted from seawater, while the other fuel, tritium, would be bred from a lithium blanket using neutrons produced in the fusion reaction itself.[11] Furthermore, a fusion reactor would produce virtually no CO_2 or atmospheric pollutants, and its other radioactive waste products would be very short-lived compared to those produced by conventional nuclear reactors.

On 21 November 2006, the seven participants formally agreed to fund the creation of a nuclear fusion reactor.[12] The program is anticipated to last for 30 years – 10 for construction, and 20 of operation. ITER was originally expected to cost approximately €5billion, but the rising price of raw materials and changes to the initial design have seen that amount almost triple to €13billion.[7] The reactor is expected to take 10 years to build with completion scheduled for 2019.[13] Site preparation has begun in Cadarache, France, and procurement of large components has started.[14]

ITER is designed to produce approximately 500 MW of fusion power sustained for up to 1,000 seconds[15] (compared to JET's peak of 16 MW for less than a second) by the fusion of about 0.5 g of deuterium/tritium mixture in its approximately 840 m^3 reactor chamber. Although ITER is expected to produce (in the form of heat) 10 times more energy than the amount consumed to heat up the plasma to fusion temperatures, the generated heat will not be used to generate any electricity.[16]

ITER was originally an acronym for ***I****nternational* ***T****hermonuclear* ***E****xperimental* ***R****eactor*, but that title was eventually dropped due to the negative popular connotations of the word "thermonuclear", especially when used in conjunction with "experimental". "Iter" also means "journey", "direction" or "way" in Latin,[17] reflecting ITER's potential role in harnessing nuclear fusion as a peaceful power source.

Organization history

Reagan and Gorbachev at the Geneva Summit in 1985

ITER began in 1985 as a Reagan–Gorbachev[18][19] initiative[19][20] with the equal participation of the Soviet Union, European Union (through European Atomic Energy Community), the United States, and Japan through the 1988–1998 initial design phases. Preparations for the first Gorbachev-Reagan Summit showed that there were no tangible agreements in the works for the summit.

One energy research project, however, was being considered quietly by two physicists, Alvin Trivelpiece and Evgeny Velikhov. The project involved collaboration on the next phase of magnetic fusion research — the construction of a demonstration model. At the time, magnetic fusion research was ongoing in Japan, Europe, the Soviet Union and the US. Velikhov and Trivelpiece believed that taking the next step in fusion research would be beyond the budget of any of the key nations and that collaboration would be useful internationally.

A major bureaucratic fight erupted in the US government over the project. One argument against collaboration was that the Soviets would use it to steal US technology and know-how. A second was symbolic — the Soviet physicist Andrei Sakharov was in internal exile and the US was pushing the Soviet Union on its human rights record. The United States National Security Council convened a meeting under the direction of William Flynn Martin that resulted in a consensus that the US should go forward with the project.

Martin and Velikhov concluded the agreement that was agreed at the summit and announced in the last paragraph of this historic summit meeting, "... The two leaders emphasized the potential importance of the work aimed at utilizing controlled thermonuclear fusion for peaceful purposes and, in this connection, advocated the widest practicable development of international cooperation in obtaining this source of energy, which is essentially inexhaustible, for the benefit for all mankind."[21]

Conceptual and engineering design phases carried out under the auspices of the IAEA led to an acceptable, detailed design in 2001, underpinned by US$650 million worth of research and development by the "ITER Parties" to establish its practical feasibility. These parties, namely EU, Japan, Russian Federation (replacing the Soviet Union), and United States (which opted out of the project in 1999 and returned in 2003), were joined in negotiations by China, South Korea, and Canada (who then terminated its participation at the end of 2003). India officially became part of ITER on December 2005.

On 28 June 2005, it was officially announced that ITER would be built in the European Union in Southern France. The negotiations that led to the decision ended in a compromise between the EU and Japan, in that Japan was promised 20% of the research staff on the French location of ITER, as well as the head of the administrative body of ITER. In addition, another research facility for the project will be built in Japan, and the European Union has agreed to contribute about 50% of the costs of this institution.[22]

On 21 November 2006, an international consortium signed a formal agreement to build the reactor.[23] On 24 September 2007, the People's Republic of China became the seventh party to deposit the ITER Agreement to the IAEA. Finally, on 24 October 2007, the ITER Agreement entered into force and the ITER Organization legally came into existence.

Objectives

ITER's mission is to demonstrate the feasibility of fusion power, and prove that it can work without negative impact.[24] Specifically, the project aims:

- To momentarily produce ten times more thermal energy from fusion heating than is supplied by auxiliary heating (a *Q* value equals 10).
- To produce a steady-state plasma with a *Q* value greater than 5. (*Q* = 1 is breakeven.)
- To maintain a fusion pulse for up to 8 minutes.
- To ignite a "burning" (self-sustaining) plasma. (i.e. 'ignition' see Lawson criterion)
- To develop technologies and processes needed for a fusion power station — including superconducting magnets and remote handling (maintenance by robot).
- To verify tritium breeding concepts.
- To refine neutron shield/heat conversion technology (most of the energy in the D+T fusion reaction is released in the form of fast neutrons).

Timeline and current status

In 1978, the EC, Japan, USA, and USSR joined in the International Tokamak Reactor (INTOR) Workshop, under the auspices of the International Atomic Energy Agency (IAEA), to assess the readiness of magnetic fusion to move forward to the experimental power reactor (EPR) stage, to identify the additional R&D that must be undertaken, and to define the characteristics of such an EPR by means of a conceptual design.

Hundreds of fusion scientists and engineers in each participating country took part in a detailed assessment of the then present status of the tokamak confinement concept vis-a-vis the requirements of an EPR, identified the required R&D by early 1980, and produced a conceptual design by mid-1981.

Timeline:

- 1985. At the Geneva summit meeting in 1985, Mikhail Gorbachev suggested to Ronald Reagan that the two countries jointly undertake the construction of a tokamak EPR as proposed by the INTOR Workshop. The ITER project was initiated in 1988.[25][26]
- 1988. Conceptual design activities ran from 1988[27] to 1990.
- 1992. Engineering design activities started.[28]

- 1998. In June, the 'Final design' from the Engineering Design Activities was approved.[29]
- 2001. In July, the "cost-cutting" 'ITER-FEAT' design was agreed.[30]
- 2006. The ITER project was formally agreed to and funded with a cost estimate of €10 billion ($12.8 billion) projecting the start of construction in 2008 and completion a decade later.[12]
- 2007. In September, fourteen major design changes were agreed to the 2001 design.[31]
- 2013. The project had run into many delays and budget overruns. The facility is not expected to begin operations at the schedule initially anticipated.[8]
- 2014. In February, *The New Yorker* published the ITER Management Assessment report, listing 11 essential recommendations, for example: "Create a Project Culture", "Instill a Nuclear Safety Culture", "Develop a realistic ITER Project Schedule" and "Simplify and Reduce the IO Bureaucracy".[32] The USA considered withdrawal, but is still participating in ITER.[33]
- 2015. In November a project review concludes that the schedule may need extending by at least six years; (e.g. first plasma in 2026).[34]
- 2016. Atomic Energy Organization of Iran completed the preliminary work for Iran to join ITER[35]

Original schedule

Date	Event
2006-11-21	Seven participants formally agreed to fund the creation of a nuclear fusion reactor.[12]
2008	Site preparation start, ITER itinerary start.[36]
2009	Site preparation completion.[36]
2010	Tokamak complex excavation starts.[26]
2013	Tokamak complex construction starts.[36]
2015	Tokamak assembly starts.[37]
2019	Predicted: Tokamak assembly completion, torus pumpdown starts.[36]
2020	Predicted: Achievement of first plasma.[36]
2027	Predicted: Start of deuterium–tritium operation.[36]

Reactor overview

When deuterium and tritium fuse, two nuclei come together to form a helium nucleus (an alpha particle), and a high-energy neutron.

$${}^{2}_{1}\mathrm{D} + {}^{3}_{1}\mathrm{T} \rightarrow {}^{4}_{2}\mathrm{He} + {}^{1}_{0}\mathrm{n} + 17.6\ \mathrm{MeV}$$

While nearly all stable isotopes lighter on the periodic table than iron-56 and nickel-62, which have the highest binding energy per nucleon, will fuse with some other isotope and release energy, deuterium and tritium are by far the most attractive for energy generation as they require the lowest activation energy (thus lowest temperature) to do so, while producing among the most energy per unit weight.

All proto- and mid-life stars radiate enormous amounts of energy generated by fusion processes. Mass for mass, the deuterium–tritium fusion process releases roughly three times as much energy as uranium-235 fission, and millions of times more energy than a chemical reaction such as the burning of coal. It is the goal of a fusion power station to harness this energy to produce electricity.

Activation energies for fusion reactions are generally high because the protons in each nucleus will tend to strongly repel one another, as they each have the same positive charge. A heuristic for estimating reaction rates is that nuclei must be able to get within 100 femtometer (1×10^{-13} meter) of each other, where the nuclei are increasingly likely to undergo quantum tunneling past the electrostatic barrier and the turning point where the strong nuclear force and the electrostatic force are equally balanced, allowing them to fuse. In ITER, this distance of approach is made possible by high temperatures and magnetic confinement. High temperatures give the nuclei enough energy to overcome their electrostatic repulsion (see Maxwell–Boltzmann distribution). For deuterium and tritium, the optimal reaction rates occur at temperatures on the order of 100,000,000 K. The plasma is heated to a high temperature by ohmic heating (running a current through the plasma). Additional heating is applied using neutral beam injection (which cross magnetic field lines without a net deflection and will not cause a large electromagnetic disruption) and radio frequency (RF) or microwave heating.

At such high temperatures, particles have a large kinetic energy, and hence velocity. If unconfined, the particles will rapidly escape, taking the energy with them, cooling the plasma to the point where net energy is no longer produced. A successful reactor would need to contain the particles in a small enough volume for a long enough time for much of the plasma to fuse. In ITER and many other magnetic confinement reactors, the plasma, a gas of charged particles, is confined using magnetic fields. A charged particle moving through a magnetic field experiences a force perpendicular to the direction of travel, resulting in centripetal acceleration, thereby confining it to move in a circle or helix around the lines of magnetic flux.

A solid confinement vessel is also needed, both to shield the magnets and other equipment from high temperatures and energetic photons and particles, and to maintain a near-vacuum for the plasma to populate. The containment vessel is subjected to a barrage of very energetic particles, where electrons, ions, photons, alpha particles, and neutrons constantly bombard it and degrade the structure. The material must be designed to endure this environment so that a power station would be economical. Tests of such materials will be carried out both at ITER and at IFMIF (International Fusion Materials Irradiation Facility).

Once fusion has begun, high energy neutrons will radiate from the reactive regions of the plasma, crossing magnetic field lines easily due to charge neutrality (see neutron flux). Since it is the neutrons that receive the majority of the energy, they will be ITER's primary source of energy output. Ideally, alpha particles will expend their energy in the plasma, further heating it.

Beyond the inner wall of the containment vessel one of several test blanket modules will be placed. These are designed to slow and absorb neutrons in a reliable and efficient manner, limiting damage to the rest of the structure, and breeding tritium for fuel from lithium and the incoming neutrons. Energy absorbed from the fast neutrons is extracted and passed into the primary coolant. This heat energy would then be used to power an electricity-generating turbine in a real power station; in ITER this generating system is not of scientific interest, so instead the heat will be extracted and disposed of.

Technical design

Vacuum vessel

The vacuum vessel is the central part of the ITER machine: a double walled steel container in which the plasma is contained by means of magnetic fields.

The ITER vacuum vessel will be twice as large and 16 times as heavy as any previously manufactured fusion vessel: each of the nine torus shaped sectors will weigh between 390 and 430 tonnes.[38] When all the shielding and port structures are included, this adds up to a total of 5,116 tonnes. Its external diameter will measure 19.4 metres (64 ft), the internal 6.5 metres (21 ft). Once assembled, the whole structure will be 11.3 metres (37 ft) high.

The primary function of the vacuum vessel is to provide a hermetically sealed plasma container. Its main components are the main vessel, the port structures and the supporting system. The main vessel is a double walled structure with poloidal and toroidal stiffening ribs between 60-millimetre-thick (2.4 in) shells to reinforce the vessel structure. These ribs also form the flow passages for the cooling water. The space between the double walls will be filled with shield structures made of stainless steel. The inner surfaces of the vessel will act as the interface with breeder modules containing the breeder blanket component. These modules will provide shielding from the high-energy neutrons produced by the fusion reactions and some will also be used for tritium breeding concepts.

The vacuum vessel has 18 upper, 17 equatorial and 9 lower ports that will be used for remote handling operations, diagnostic systems, neutral beam injections and vacuum pumping.

Breeder blanket

Owing to very limited terrestrial resources of tritium, a key component of the ITER reactor design is the breeder blanket. This component, located adjacent to the vacuum vessel, serves to produce tritium through reaction of ^{6}Li isotopes with high energy neutrons from the plasma. Concepts for the breeder blanket include helium cooled lithium lead (HCLL) and helium cooled pebble bed (HCPB) methods. Test blanket modules based on both concepts will be tested in ITER and will share a common box geometry. Materials for use as breeder pebbles in the HCPB concept include lithium metatitanate and lithium orthosilicate.[39] Requirements of breeder materials include good tritium production and extraction, mechanical stability and low activation levels.[40]

Magnet system

The central solenoid coil will use superconducting niobium-tin to carry 46 kA and produce a field of up to 13.5 teslas. The 18 toroidal field coils will also use niobium-tin. At their maximum field strength of 11.8 teslas, they will be able to store 41 gigajoules. They have been tested at a record 80 kA. Other lower field ITER magnets (PF and CC) will use niobium-titanium for their superconducting elements.

Additional heating

There will be three types of external heating in ITER:

- Two Heating Neutral Beam injectors (HNB), each providing about 17MW to the burning plasma, with the possibility to add a third one. The requirements in terms of deuterium beam energy (1MeV), total current (40A) and beam pulse duration (up to 1h). The prototype is being built at the a Neutral Beam Test Facility (NBTF)[41] prototype is being constructed in Padova
- Ion Cyclotron Resonance Heating (ICRH)
- Electron Cyclotron Resonance Heating (ECRH)

Cryostat

The cryostat is a large 3,800-tonne stainless steel structure surrounding the vacuum vessel and the superconducting magnets, in order to provide a super-cool vacuum environment. Its thickness ranging from 50 to 250 mm will allow it to withstand the atmospheric pressure on the area of a volume of 8,500 cubic meters. The total of 54 modules of the cryostat will be engineered, procured, manufactured, and installed by Larsen & Toubro Heavy Engineering.[42][43]

Cooling systems

The ITER tokamak will use three interconnected cooling systems. Most of the heat will be removed by a primary water cooling loop, itself cooled by water through a heat exchanger within the tokamak building's secondary confinement. The secondary cooling loop will be cooled by a larger complex, comprising a cooling tower, a 5 km pipeline supplying water from Canal de Provence, and basins that allow cooling water to be cooled and tested for chemical contamination and tritium before being released into the Durance River. This system will need to dissipate an average power of 450 MW during the tokamak's operation. A liquid nitrogen system will provide a further 1,300 kW of cooling to 80 kelvins, and a liquid helium system will provide 75 kW of cooling to 4.5 K. The liquid helium system will be designed, manufactured, installed and commissioned by Air Liquide.[44][45]

Location

Location of Cadarache in France

The process of selecting a location for ITER was long and drawn out. The most likely sites were Cadarache in Provence-Alpes-Côte-d'Azur, France, and Rokkasho, Aomori, Japan. Additionally, Canada announced a bid for the site in Clarington in May 2001, but withdrew from the race in 2003. Spain also offered a site at Vandellòs on 17 April 2002, but the EU decided to concentrate its support solely behind the French site in late November 2003. From this point on, the choice was between France and Japan. On 3 May 2005, the EU and Japan agreed to a process which would settle their dispute by July.

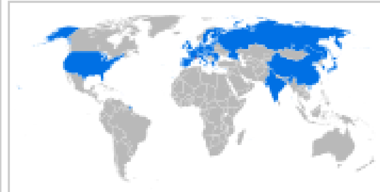
At the final meeting in Moscow on 28 June 2005, the participating parties agreed to construct ITER at Cadarache in Provence-Alpes-Côte-d'Azur, France. Construction of the ITER complex began in 2007, while assembly of the tokamak itself is scheduled to begin in 2015.[14]

Fusion for Energy, the EU agency in charge of the European contribution to the project, is located in Barcelona, Spain. Fusion for Energy (F4E) is the European Union's Joint Undertaking for ITER and the Development of Fusion Energy. According to the agency's website:

> "F4E is responsible for providing Europe's contribution to ITER, the world's largest scientific partnership that aims to demonstrate fusion as a viable and sustainable source of energy. [...] F4E also supports fusion research and development initiatives [...]"[46]

The ITER Neutral Beam Test Facility aimed at developing and optimizing the neutral beam injector prototype, is being constructed in Padova.[47] It will be the only ITER facility out of the site in Cadarache.

Participants



Thirty-five countries participate in the ITER project

Currently there are seven parties participating in the ITER program: the European Union (through the legally distinct organisation EURATOM), India, Japan, China, Russia, South Korea, and the United States.[14] Canada was previously a full member, but has since pulled out due to a lack of funding from the federal government. The lack of funding also resulted in Canada withdrawing from its bid for the ITER site in 2003. The host member of the ITER project, and hence the member contributing most of the costs, is the EU.

In 2007, it was announced that participants in the ITER will consider Kazakhstan's offer to join the program[48] and in March 2009, Switzerland, an associate member of EURATOM since 1979, also ratified the country's accession to the European Domestic Agency Fusion for Energy as a third country member.[49]

ITER's work is supervised by the ITER Council, which has the authority to appoint senior staff, amend regulations, decide on budgeting issues, and allow additional states or organizations to participate in ITER.[50] The current Chairman of the ITER Council is Won Namkung. [51]

Participating countries

- Australia
- Austria
- Belgium
- Bulgaria
- China
- Croatia
- Cyprus
- Czech Republic
- Denmark
- Estonia
- Finland
- France
- Germany
- Greece
- Hungary
- India
- Ireland
- Italy
- Japan
- Latvia
- Lithuania
- Luxembourg
- Malta
- Netherlands
- Poland
- Portugal
- Romania
- Russia
- Slovakia
- Slovenia
- South Korea
- Spain
- Sweden
- Switzerland
- United Kingdom
- United States

Funding

As of 2016, the total price of constructing the experiment is expected to be in excess of €20 billion,[52] an increase of €4.6 billion of its 2010 estimate,[53] and of €9.6 billion from the 2009 estimate.[54] Prior to that, the proposed costs for ITER were €5 billion for the construction and €5 billion for maintenance and the research connected with it during its 35-year lifetime. At the June 2005 conference in Moscow the participating members of the ITER cooperation agreed on the following division of funding contributions: 45% by the hosting member, the European Union, and the rest split between the non-hosting members – China, India, Japan, South Korea, the Russian Federation and the USA. During the operation and deactivation phases, Euratom will contribute to 34% of the total costs.[55]

Although Japan's financial contribution as a non-hosting member is one-eleventh of the total, the EU agreed to grant it a special status so that Japan will provide for two-elevenths of the research staff at Cadarache and be awarded two-elevenths of the construction contracts, while the European Union's staff and construction components contributions will be cut from five-elevenths to four-elevenths.

It was reported in December 2010 that the European Parliament had refused to approve a plan by member states to reallocate €1.4 billion from the budget to cover a shortfall in ITER building costs in 2012–13. The closure of the 2010 budget required this financing plan to be revised, and the European Commission (EC) was forced to put forward an ITER budgetary resolution proposal in 2011.[56]

The U.S. withdrew from the ITER consortium in 2000. In 2006, Congress voted to rejoin, and again contribute financially. In June 2015, it appeared that the U.S. Senate might vote to stop the scheduled U.S. contribution of $150 million in the 2015–2016 fiscal year.[57]

Criticism

A technical concern is that the 14 MeV neutrons produced by the fusion reactions will damage the materials from which the reactor is built.[59] Research is in progress to determine whether and how reactor walls can be designed to last long enough to make a commercial power station economically viable in the presence of the intense neutron bombardment. The damage is primarily caused by high energy neutrons knocking atoms out of their normal position in the crystal lattice. A related problem for a future commercial fusion power station is that the neutron bombardment will induce radioactivity in the reactor material itself.[60] Maintaining and decommissioning a commercial reactor may thus be difficult and expensive. Another problem is that superconducting magnets are damaged by neutron fluxes. A new special research facility, IFMIF, is planned to investigate this problem.

Protest against ITER in France, 2009. Construction of the ITER facility began in 2007, but the project has run into many delays and budget overruns.[8] The World Nuclear Association says that fusion "presents so far insurmountable scientific and engineering challenges".[58]

Another source of concern comes from the recent tokamak parameters database interpolation which says that power load on tokamak divertors will be five times the expected value for ITER and much more for actual electricity-generating reactors. Given that the projected power load on the ITER divertor is already very high, these new findings mean that new divertor designs should be urgently tested.[61] However, the corresponding test facility (ADX) still has not received any funding.

A number of fusion researchers working on non-tokamak systems, such as Robert Bussard and Eric Lerner, have been critical of ITER for diverting funding from what they believe could be a potentially more viable and/or cost-effective path to fusion power, such as the polywell reactor.[62][63] Many critics accuse ITER researchers of being unwilling to face up to the technical and economic potential problems posed by Tokamak fusion schemes.[62] The expected cost of ITER has risen from $5 billion USD to $20 billion USD, and the timeline for operation at full power was moved from the original estimate of 2016 to 2027.

A French association including about 700 anti-nuclear groups, Sortir du nucléaire (Get Out of Nuclear Energy), claimed that ITER was a hazard because scientists did not yet know how to manipulate the high-energy deuterium and tritium hydrogen isotopes used in the fusion process.[64]

Rebecca Harms, Green/EFA member of the European Parliament's Committee on Industry, Research and Energy, said: "In the next 50 years, nuclear fusion will neither tackle climate change nor guarantee the security of our energy supply." Arguing that the EU's energy research should be focused elsewhere, she said: "The Green/EFA group demands that these funds be spent instead on energy research that is relevant to the future. A major focus should now be put on renewable sources of energy." French Green party lawmaker Noël Mamère claims that more concrete efforts to fight present-day global warming will be neglected as a result of ITER: "This is not good news for the fight against the greenhouse effect because we're going to put ten billion euros towards a project that has a term of 30–50 years when we're not even sure it will be effective."[65]

ITER is not designed to produce electricity, but made as a proof of concept reactor for the later DEMO project.[66]

Responses to criticism

Proponents believe that much of the ITER criticism is misleading and inaccurate, in particular the allegations of the experiment's "inherent danger." The stated goals for a commercial fusion power station design are that the amount of radioactive waste produced should be hundreds of times less than that of a fission reactor, and that it should produce no long-lived radioactive waste, and that it is impossible for any such reactor to undergo a large-scale runaway chain reaction.[67] A direct contact of the plasma with ITER inner walls would contaminate it, causing it to cool immediately and stop the fusion process. In addition, the amount of fuel contained in a fusion reactor chamber (one half gram of deuterium/tritium fuel[14]) is only sufficient to sustain the fusion burn pulse from minutes up to an hour at most, whereas a fission reactor usually contains several years' worth of fuel.[68] Moreover, some detritiation systems will be implemented, so that at a fuel cycle inventory level of about 2 kg, ITER will eventually need to recycle large amounts of tritium and at turnovers orders of magnitude higher than any preceding tritium facility worldwide.[69]

In the case of an accident (or sabotage), it is expected that a fusion reactor might release far less radioactive pollution than would an ordinary fission nuclear station. Furthermore, ITER's type of fusion power has little in common with nuclear weapons technology, and does not produce the fissile materials necessary for the construction of a weapon. Proponents note that large-scale fusion power would be able to produce reliable electricity on demand, and with virtually zero pollution (no gaseous CO_2, SO_2, or NO_x by-products are produced).

According to researchers at a demonstration reactor in Japan, a fusion generator should be feasible in the 2030s and no later than the 2050s. Japan is pursuing its own research program with several operational facilities that are exploring several fusion paths.[70]

In the United States alone, electricity accounts for US$210 billion in annual sales.[71] Asia's electricity sector attracted US$93 billion in private investment between 1990 and 1999.[72] These figures take into account only current prices. Proponents of ITER contend that an investment in research now should be viewed as an attempt to earn a far greater future return. Also, worldwide investment of less than US$1 billion per year into ITER is not incompatible with concurrent research into other methods of power generation, which in 2007 totaled US$16.9 billion.[73]

Supporters of ITER emphasize that the only way to test ideas for withstanding the intense neutron flux is to experimentally subject materials to that flux, which is one of the primary missions of ITER and the IFMIF,[14] and both facilities will be vitally important to that effort.[74] The purpose of ITER is to explore the scientific and engineering questions that surround potential fusion power stations. It is nearly impossible to acquire satisfactory data for the properties of materials expected to be subject to an intense neutron flux, and burning plasmas are expected to have quite different properties from externally heated plasmas. Supporters contend that the answer to these questions requires the ITER experiment, especially in the light of the monumental potential benefits.

Furthermore, the main line of research via tokamaks has been developed to the point that it is now possible to undertake the penultimate step in magnetic confinement plasma physics research with a self-sustained reaction. In the tokamak research program, recent advances devoted to controlling the configuration of the plasma have led to the achievement of substantially improved energy and pressure confinement, which reduces the projected cost of electricity from such reactors by a factor of two to a value only about 50% more than the projected cost of electricity from advanced light-water reactors. In addition, progress in the development of advanced, low activation structural materials supports the promise of environmentally benign fusion reactors and research into alternate confinement concepts is yielding the promise of future improvements in confinement.[75] Finally, supporters contend that other potential replacements to the fossil fuels have environmental issues of their own. Solar, wind, and hydroelectric power all have a relatively low power output per square kilometer compared to ITER's successor DEMO which, at 2,000 MW,[76] would have an energy density that exceeds even large fission power stations.[77]

Similar projects

Precursors to ITER were KSTAR, JET,[78] and Tore Supra.[79] Other planned and proposed fusion reactors include DEMO,[80] Wendelstein 7-X,[81] NIF,[82] HiPER,[83] and MAST,[84] as well as CFETR (China Fusion Engineering Test Reactor), a 200 MW tokamak.[85][86][87][88]

See also

- Tokamak
- ITER Neutral Beam Test Facility, the facility dedicated to the development of the ITER neutral beam injector prototype
- Fusion for Energy, the Domestic Agency in charge of managing EU contributions to the ITER project
- International Fusion Materials Irradiation Facility, proposed, construction not started
- JT-60/JT-60SA
- EAST (Experimental Advanced Superconducting Tokamak)
- National Ignition Facility, inertial confinement using lasers
- Nuclear power in France
- Wendelstein 7-X (German experimental fusion reactor) - a stellarator
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