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FUSION RESEARCH IN THE CZECH REPUBLIC – CONTRIBUTION TO FUTURE ENERGY PROSPECTS

Abstract: Fusion has been the main energy mechanism in the sun and the stars where hydrogen nuclei fuse releasing large amounts of energy. On earth, the most efficient process is a deuterium – tritium reaction which requires a plasma at about 150.000.000 K. Although extremely technologically complicated it represents a large source of energy with basic fuels broadely available which is environmentally friendly not only because it is immensely more energetic than the burning of any fossil fuel. Moreover, fusion has very low impact on the environment: no greenhouse gas emissions, no radioactive vaste, no danger of massive accident.

In order to demonstrate the technical feasibility of fusion it will be necessary to develop a facility of the size comparable to a 500 MW power station which could be able to operate for about 20 years. This is the ITER tokamak project, world's biggest fusion energy research project & world's largest S&T cooperation endeavor, being built in Cadarache, France.

The Czech tokamak COMPASS D (first plasma 2008) though smallest in the family of European tokamaks (ITER Cadarache, JET Culham, ASDEX-U Garching) is a flexible and adaptible facility having ITER-like geometry aims to fulfill the EU RaD program of European Fusion Research accompanying the ITER project. The installation of COMPASS D in Prague has strengthened the collaboration with EURATOM Associations, opened many new possibilities of participation of researchers both national and foreign and broadened the chances of Czech industry in the fusion research.

The facility COMPASS D has been included in the Czech Roadmap of Large Rresearch Infrastructures which was issued by the Czech government recently.

WHAT IS FUSION?

Fusion is the process at the core of our Sun. What we see as light and feel as warmth is the result of a fusion reaction: Hydrogen nuclei collide, *fuse* into heavier Helium atoms and release tremendous amounts of energy in the process.

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Fig. 1. Fusion is the energy source of the Universe, occuring in the core of the Sun and stars.

In the stars of our universe, gravitational forces have created the necessary conditions for fusion. Over billions of years, gravity gathered the Hydrogen clouds of the early Universe into massive stellar bodies. In the extreme density and temperature of their cores, fusion occurs.

HOW DOES FUSION PRODUCE ENERGY?

Atoms never rest: the hotter they are, the faster they move. In the core of our Sun, temperatures reach 15.000.000° Celsius. Hydrogen atoms are in a constant state of agitation, colliding at very great speeds. The natural electrostatic repulsion that exists between the positive charges of their nuclei is overcome, and the atoms fuse. The fusion of two light Hydrogen atoms (H-H) produces a heavier element, Helium.

The mass of the resulting Helium atom is not the exact sum of the two initial atoms, however: some mass has been lost and great amounts of energy have been gained. This is what Einstein's formula $E=mc^2$ describes: the tiny bit of lost mass (m), multiplied by the square of the speed of light (c^2), results in a very large figure (E) which is the amount of energy created by a fusion reaction.

Every second, our Sun turns 600 million tons of Hydrogen into Helium, releasing an enormous amount of energy. But without the benefit of gravitational forces at work in our Universe, achieving fusion on Earth has required a different approach.

WHY FUSION?

Over the last hundred years the world's commercial output and population have increased more rapidly than ever before and overall annual energy consumption has risen more than 10-fold. Most of the growth in commercial output and energy consumption has been in the industrialized nations, whereas most of the growth in populations has been in the developing world.

If the people in the developing world are to achieve prosperity, their energy needs will have to be met. Findings ways of reducing our demands for energy and making more efficient use of it are important steps to reduce the overall demand – indeed just as important as finding new sources of energy. However, even if we assume that people in the industrialized world will drastically reduce the amount of energy they use, say, to one-half the present level, brining the rest of the world up to this same level and coping with the expected growth in population will still require a big increase in world energy supply.

Burning fossil fuel cause different forms of damage to the environment, including global warming and acid rain, which is already affecting many rivers, lakes and forests, and pollution which damages people's health.

A short-term response to these problems in western Europe has been to switch some electricity generation form coal to gas. But this is not a long-term solution; there is still pollution, gas supplies are limited, and at best it merely puts these problems on hold for a few more years. Burning oil and gas on a massive scale to generate electricity is also a waste of valuable resources that should be conserved for other purposes.

Electricity is an important and flexible form of energy because it is clean to use and power a wide range of sophisticated devices like computers. About 13% of the world's energy is used in the form of electricity, but it has to be generated from a more basic form of energy. Worldwide, about 65% of electricity is generated by burning fossil fuels, about 17% from nuclear fission, and the rest mainly by hydroelectric plants. Nuclear energy is clean and produces no global warming.

However, public concern over nuclear energy and relatively low oil prices have combined to slow dramatically the construction of nuclear power plants.

Hydroelectricity is seen a clean source of energy – though it is not without risks or damage to the environment. However, most of the suitable rivers are already dammed, and there is no possibility that this source can be expanded sufficiently to meet future demands. All other forms of renewable energy – wind, tidal, and solar – taken together presently contribute less than 2% of the electricity that is generated worldwide. Although the energy in sunshine, wind, waves and tides is enormous, there are many difficulties in harnessing these sources economically and integrating them into a reliable supply network. Those living in northern climes are very much aware that there are many days when the Sun does not shine and even those when the wind does not blow. Electricity is very difficult and expensive to store – indeed at the moment the only cost-effective method of storing it is to run a hydro plant in reverse, pumping water from reservoir to one at higher level.

Even though these sources will be developed to meet a much greater proportion of the world's future energy requirements than they do at present, they will never be able to satisfy the total demand. New energy options must be developed – systems that are optimally safe, environmentally friendly, and economical.

ADVANTAGES OF FUSION ENERGY

One of the most perspective energy source is thermonuclear fusion.

The prospect of using fusion energy on earth has a number of important advantages, which are briefly mentioned here.

First of all, fusion has an almost limitless fuel supply. The basic fuels are distributed widely around the globe. Deuterium is abundant and can be extracted easily from sea water. Lithium, from which tritium can be produced, is a readily available light metal in the Earth´s crust. Moreover, these raw materials widely distributed, making it impossible for any country to corner the market. More advanced types of fusion may be developed in the very long term to burn only deuterium.

Energy density of fusion fuel is hardly comparable to energy density of the traditional ones. For instance 1 GWe coal power plant need 2,7 Mt coal per year and the same fusion power plant makes do with 250 kg of DT mixture per year.

Fusion produces no greenhouse gas emissions. Fusion power plants will not generate gases such as carbon dioxide that cause global warming and climate change, nor other gases that have damaging effects on the environment.

Fusion is suitable for the large-scale electricity production required for the increasing energy needs of large cities. A single fusion power station can generate electricity for two million households.

Fusion power plant is intrinsically safe; it cannot explode or "run away". Unlike a fission powerplant, which contains a large quantity of uranium or plutonium fuel, enough to keep it going for many years, a fusion power plant contains only very small amount of deuterium and tritium fuel. Typically there is about 1 gram – enough to keep the reaction going for only a few seconds. If fuel is not continually replaced, the fusion reaction goes out and stays out.

A second safety consideration is radioactive waste.

The fusion fuel cycle produces none of these radioactive waste products – the waste product is helium gas, which is not toxic or radioactive. The tritium fuel itself is radioactive, but decays relatively quickly (the half-life is 12,3 years). And in any case all tritium fuel that is produced will be recycled quickly and burned in power plant. An important safety feature is that there need be no shipments of radioactive fuels into or out of the fusion plant. The raw materials necessary for the fusion fuel, lithium and water, are completely nonradioactive.

The second source of waste from a nuclear power plant is the structure of the reactor – this made radioactive by the neutrons emitted during the nuclear reactions.

However the life time of these structural wastes is much shorter than that of fission fuel waste products. Moreover this radioactivity can be reduced by careful choice of the construction materials – research is already under way to developed advanced steels and other materials.

With careful design and choice of materials, the level of radioactivity left by a fusion power plant after it has been closed down for about 100 years could be comparable with that left by coal-fired power plant!

About 3,5 milion tons of coal have to be burned to produce 1 gigawatt-year of electricity (the requirement of a typical industrial city), and this contains over 5 tons of uranium. This is in the fact more uranium that would be used to supply the electricity from a nuclear fission power plant. Some of the uranium escapes into air, but most is left in the ash, which is buried in landfill sites.

FUSION ON EARTH – TOKAMAK

20th century fusion science has identified the most efficient fusion reaction to accomplish in the laboratory setting: the reaction between two Hydrogen (H) isotopes Deuterium (D) and Tritium (T). The D-T fusion reaction produces the highest energy gain at the 'lowest' temperatures. It requires nonetheless temperatures of 150.000.000° Celsius to take place – ten times higher that the H-H reaction occurring at the Sun's core.

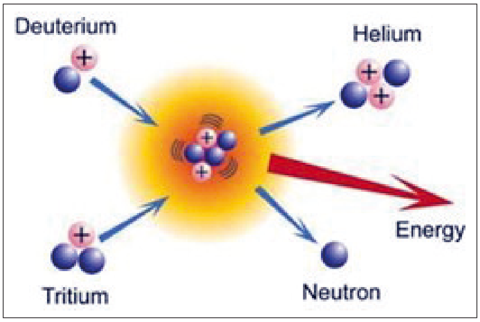

Fig. 2.

At extreme temperatures, electrons are separated from nuclei and a gas becomes a *plasma* – a hot, electrically charged gas. In a star as in a fusion device, plasmas provide the environment in which light elements can fuse and yield energy.

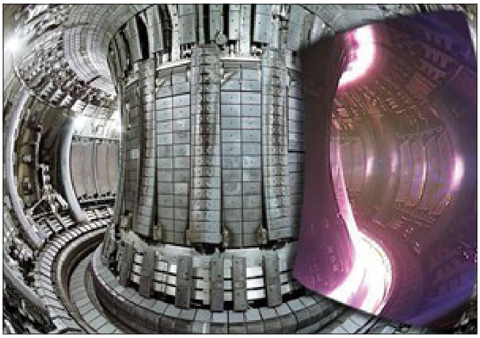

Fig. 3. Three, two, one … We have plasma! Inside the European JET Tokamak, both before and during operation. Photo: EFDA, JET.

The fusion reaction will be achieved in a *tokamak* device that uses magnetic fields to contain and control the hot plasma. The fusion between Deuterium and Tritium (D-T) will produce one Helium nuclei, one neutron and energy.

The Helium nucleus carries an electric charge which will respond to the magnetic fields of the tokamak, and remain confined within the plasma. However some 80% of the energy produced is carried away from the plasma by the neutron which has no electrical charge and is therefore unaffected by magnetic fields. The neutrons will be absorbed by the surrounding walls of the tokamak, transferring their energy to the walls as heat.

THE INTERNATIONAL ITER PROJECT FOR FUSION: WHY?

ITER tokamak is a large-scale scientific experiment that aims to demonstrate that it is possible to produce commercial energy from fusion.

$Q \geq 10$

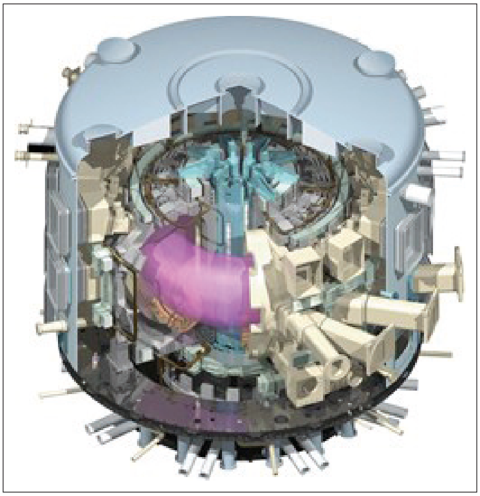

Fig. 4. A cut-away view of the ITER Tokamak, revealing the donut-shaped plasma inside of the vacuum vessel

The Q in the formula above symbolizes the ratio of fusion power to input power. *$Q \geq 10$ represents the scientific goal of the ITER project: to deliver ten times the power it consumes.* From 50 MW of input power, the ITER machine is designed to produce 500 MW of fusion power – the first of all fusion experiments to produce net energy.

During its operational lifetime, ITER will test key technologies necessary for the next step: the demonstration fusion power plant that will prove that it is possible to capture fusion energy for commercial use.

In ITER, this heat will be dispersed through cooling towers. In the subsequent fusion plant prototype DEMO and in future industrial fusion installations, the heat will be used to produce steam and – by way of turbines and alternators – electricity.

The science going on at ITER – and all around the world in support of ITER – will benefit all of mankind.

SITE PREPARATION

The ITER project is situated on a total of 180 hectares of land in St-Paul-lez-Durance, a commune in the Provence-Alpes-Côte d'Azur region of Southern France that is already home to France's nuclear research centre, the CEA (Commissariat à l'Energie Atomique).

The most important feature of the ITER site will be a raised 42-hectare platform – the approximate size of 60 soccer fields – that will hold the scien-

Fig. 5. Ten years down the road: ITER in 2019.

tific buildings and facilities. As part of France's engagements as the host country, site work is carried out under the responsibility of the Agence ITER France, an entity of the CEA.

ON TO DEMO

ITER is not an end in itself: it is the bridge toward a first plant that will demonstrate the large-scale production of electrical power and Tritium fuel self-sufficiency. This is the next step after ITER: the Demonstration Power Plant, or DEMO for short. A conceptual design for such a machine could be complete by 2017. If all goes well, DEMO will lead fusion into its industrial era, beginning operations in the early 2030 s, and putting fusion power into the grid as early as 2040.

By the last quarter of this century, if ITER and DEMO are successful, our world will enter the Age of Fusion – an age when mankind covers a significant part of its energy needs with an inexhaustible, environmentally benign, and universally available resource.

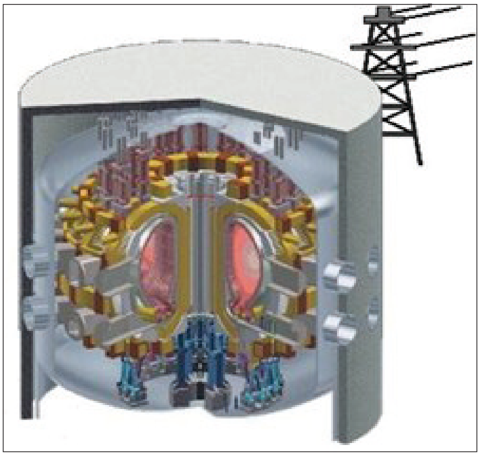

Fig. 6. The projected design for the next-step demonstration fusion power plant, or DEMO, designed to produce 2000–4000 MW of power

A GLOBAL COLLABORATION

The seven Members of the international ITER project (European Union, United States, Russia, China, Japan, Korea and India) have all created Domestic Agencies (DAs) to act as the liaison between national governments and the ITER Organization. In the case of the European Union, the European Domestic Agency serves as the link between the European Commission and the ITER Organization. Fusion for Energy (F4E) is the European DA based in Barcelona.

The Domestic Agencies' role is to handle the procurement of each Member's in-kind contributions to ITER.

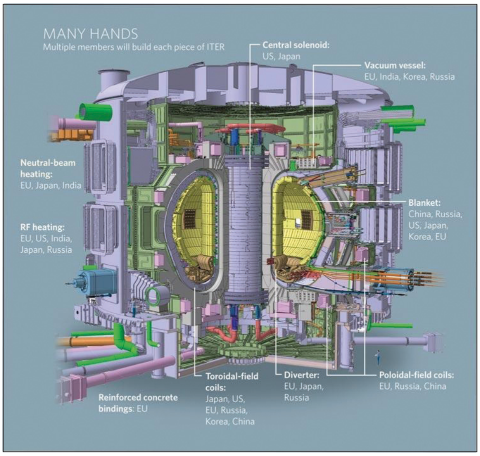

Fig. 7. The cut of the ITER tokamak with collaboration marked

The Domestic Agencies employ their own staff and have their own budget, and place contracts with suppliers. They are responsible for organising and carrying out the procurement for each ITER Member.

TOKAMAKS IN PRAGUE – IPP ASCR V. V. I.

In 1963, one of the fathers of tokamak, Russian scientist L. A. Artsimovich, visited Prague and initiated the period of fruitful collaboration of Czech and Russian scientists, lasting almost thirty years. It is important to note that in the '50 s and '60 s, the world center of plasma physics was east of Prague. A promising collaboration with the Institute of Atomic Energy and the Institute of Physics in Moscow, the Institute of Nuclear Physics in Novosibirsk, plus institutes in Kharkov, Leningrad and Suchumi was started.

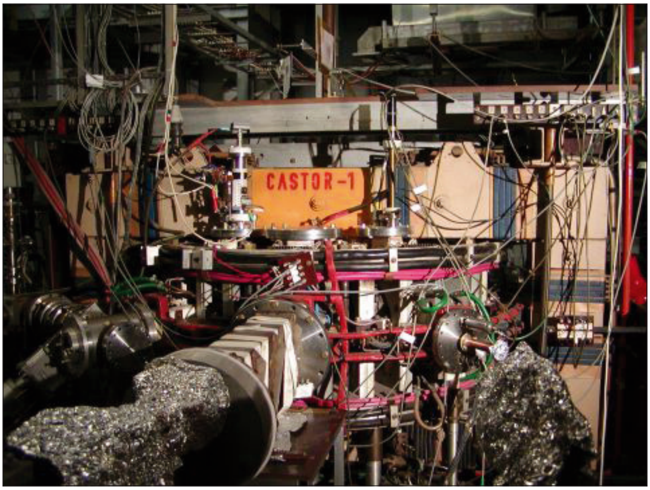

Fig. 8. The first tokamak in Czech Republic – CASTOR tokamak in IPP Prague

Successful work on the influence of the HF field on plasma continued by a waveguide structure, developed and built at IPP and installed at the T–7 superconducting tokamak in Moscow. In 1982, it generated a record noninductively generated current of 150–200 kA for 50 ms.

In 1977, IPP was lent one of the oldest tokamaks in the world, TM–1 MH, formerly used at the Kurchatov Institute in Moscow to study adiabatic heating of magnetically confined plasma and HF field heating, an area also intensely studied at IPP. In 1985, after a complete overhaul, this tokamak started operation as CASTOR (Czechoslovak Academy of Science Torus). On the other hand, in 1985–1990, IPP supplied 36 superconducting magnets for gyrotrons of the modern T–15 tokamak at the Kurchatov Institute, totaling 33 million CZK. Originally the property of the IPP, they were donated to the Russian party in 1995.

Gradually, intense international collaboration developed, especially with colleagues from the former Societ Union, East Germany, Romania and Hungary, but also from France, Italy and other countries. The CASTOR operation was closed in 2007 and the facility was transferred to the Faculty of Nuclear Sciences and Physical Engineering of Czech Technical University in Prague, where it is currently being prepared for educational purposes under the name GOLEM.

In connection with the domestic research program, the members of the Tokamak Department actively participate in experiments on other European tokamaks, including the largest ones – the JET, ASDEX Upgrade, Tore Supra – as well as the ITER project.

Fig. 9. The modern COMPASS tokamak fired the first plasma in the winter of 2008 year.

In 2007, IPP obtained tokamak COMPASS from the United Kingdom Atomic Energy Authority (UKAEA), with EURATOM approval, showing recognition of its outstanding results in the field of high temperature plasma, within the frame of European collaboration. On April 1, 2008, a ceremonial inauguration of COMPASS took place in the newly constructed building on the Mazanka campus in Prague, with the participation of the EC, EURATOM, UKAEA, the Czech Government and Parliament, President of the Academy, as well as the academic community. The construction of the building and the supporting systems were financially supported by the Czech Government, EURATOM and the Academy, in addition to a significant contribution of the Institute itself. In December 2008, complex technological tests were concluded by a successful ignition of high temperature plasma discharge. On February 19, 2009, COMPASS started officially the physics operation stage. This marks the beginning of a new – and we hope, successful – era in the Institute's research in high temperature plasma and thermonuclear fusion. The installation od two NBIs has begun on the end of 2010.

WHAT PROGRESS WILL BRING THE TOKAMAK COMPASS IN PRAGUE?

– COMPASS has been a flexible and adaptable tokamak with ITER–like plasma geometry.

– The facility is enough simple to be installed quickly and with relatively low expenditures and operated by a relatively small team, which has already experience with a tokamak operation.

– The project of transporting, installation, operation and research on COMPASS has been broadly supported by EURATOM.

– The aims of scientific and technological programme proposed for COMPASS in collaboration with large tokamaks are in line with prepared R&D programme of European fusion research accompanying the ITER project.

Fig. 10. The press conference during tokamak COMPASS oficial start of operation

– The installation of tokamak COMPASS in Prague brings the fusion research in the Czech republic to qualitatively higher level.

– The collaboration of ASSOCIATION EURATOM/IPP. CR with other European Associations and with Czech Universities has been strengthened.

– Czech Act Nr. 130/2009 Sb defines special access to the support of Large research infrastructures (LRI). The COMPASS tokamak belongs to Large infrastructures in the Research Area Energy.

WHAT IS ROADMAP FOR LARGE RESEARCH, DEVELOPMENT AND INNOVATION INFRASTRUCTURES IN THE CZECH REPUBLIC

Czech Act Nr. 130/2009 Sb. defines special access to the support of large research infrastructures. Based on this, the Roadmap for Large Research, Development and Innovation Infrastructures in the Czech Republic was approved by Government Decree No. 207 of 15 March 2010 as a strategic document for development of large infrastructures for research, development and innovation. This document was drafted with participation of leading researchers from the Czech Republic in cooperation with state administration officials and key players in the research and development process. The document aims to describe the situation and significance of large research, development and innovation infrastructures within the Czech Republic, as well as the European Research Area, opportunities arising from financing of these types of facilities from the Structural Funds, and participation of the Czech Republic in projects under the so-called ESFRI Roadmap. Furthermore, the document provides an overview of major projects from 6 areas – social science and humanities, environmental sciences, materials physics and space, energy, biomedicine and informatics/e-infrastructure. Each of these areas includes a description of the current status, a SWOT analysis and high-priority and promising projects. The Roadmap for Large Research, Development and Innovation Infrastructures in the Czech Republic will be updated at intervals depending on the development and dynamics of implementation of this first version. Criteria used when selecting the infrastructures:

– excellence and importance on both national and european level
– connection to or membership in ESFRI projects
– expensive and/or unique set of facilities
– open access
– critical mass
– knowledge transfer
– connection to R&D Operational Programmes

CZECH ROADMAP OF LARGE RESEARCH INFRASTRUCTURES – HIGH PRIORITY PROJECTS IN THE AREA ENERGY

LVR–15, LR–0

The largest local infrastructure in reactor physics with a significant share of cooperation with the industry and international activities. Continued operation and further development of this infrastructure need to be ensured for the purposes of research in the CR (in particular MIT, ČEZ, ÚJV). The infrastructure is a part of the premises of Centrum výzkumu Řež, s r. o.

JHR

JHR – Jules Horowitz Reactor is a European project (with major participation of CEA, EDF and AREVA – 80% in total), in which CR has a 2% share. The total reference project costs are EUR 500 million. The CR is represented in the JHR by Centrum výzkumu Řež, s r. o.

COMPASS and ITER

The COMPASS tokamak is a local large infrastructure. It is a facility for experimental study of hot plasma physics in magnetic fields. COMPASS is a facility with geometry similar to that of the ITER tokamak and additional two large European facilities (ASDEX Upgrade in Garching near Munich and the joint European tokamak JET). The ITER project is a planned international project with European participation relating to thermonuclear fusion. The CR is represented by the Institute of Plasma Physics, Academy of Sciences of the Czech Republic, v. v. i.

HiPER

HiPER is a European project. The facility if in its preparatory phase and its construction is planned in Great Britain (operation is to commence in 2018). It is a laser-controlled fusion demonstrator. The CR is represented by the Institute of Physics, Academy of Sciences of the Czech Republic, v. v. i.

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