EIDGENÖSSISCHE TECHNISCHE HOCHSCHULE LAUSANNE
POLITECNICO FEDERALE DI LOSANNA
SWISS FEDERAL INSTITUTE OF TECHNOLOGY LAUSANNE

PLASMA PHYSICS RESEARCH CENTRE
EURATOM - Swiss Confederation Association

ÉCOLE POLYTECHNIQUE
FÉDÉRALE DE LAUSANNE

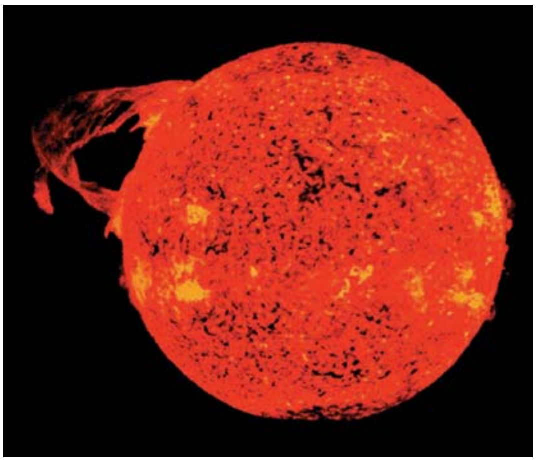
THE EPFL PLASMA PHYSICS RESEARCH CENTRE

The Plasma Physics Research Centre (CRPP) is a Non-Departmental Unit of the EPFL, and currently employs about 130 people, about 105 on the EPFL site and the rest at the Paul Scherrer Institute, PSI. The CRPP is a National Competence Centre in the field of Plasma Physics. In addition to plasma physics teaching, its missions are primarily the pursuit of scientific research in the field of controlled fusion within the framework of the EURATOM-Swiss Confederation Association and the development of its expertise as well as technology transfer in the field of materials research. As the body responsible for all scientific work on controlled fusion in Switzerland, the CRPP plays a national role of international significance.

The CRPP buildings can be seen in the foreground on the site of the Swiss Federal Institute of Technology at Lausanne

Fusion energy

There are two ways of releasing energy from the nucleus: firstly by the fission of heavy atoms such as uranium, the concept used in existing nuclear power plants and secondly by the fusion of light atoms into heavier atoms, a process which fuels the stars.



Fusion reactions take place at relatively low temperatures in the stars, due to the huge pressures: the temperature in the centre of the Sun is "only" 15 million degrees Celsius! There is no possibility of reproducing the extremely slow reactions which occur in the stars on Earth. However, other reactions which involve the heavy isotopes of hydrogen, namely deuterium (D) and tritium (T), take place when these nuclei are heated to temperatures in excess of 100 million degrees Celsius. At these extremely high temperatures, matter can only exist in the ionised state: this is the plasma state.

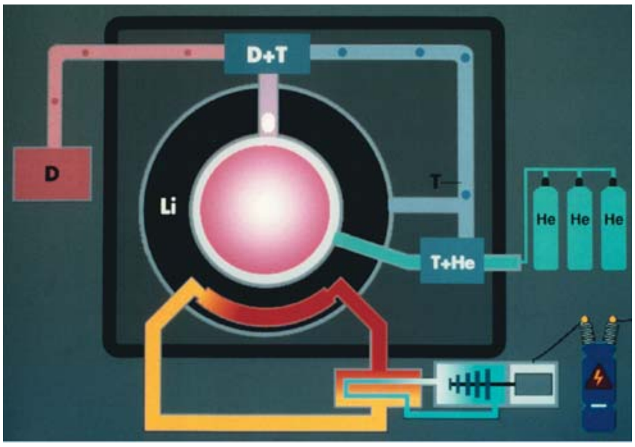
The sun, a natural fusion reactor…

There is enough deuterium in the water on Earth to last for millions of years…

The fusion of deuterium and tritium into helium and a neutron releases around 100,000 kWh per gram of fuel; by way of comparison, this is ten million times more than is released by burning a gram of oil. Deuterium exists in large quantities in water (34 g per cubic metre) and is well distributed over the surface of the globe. The volume of water in Lake Geneva could supply enough deuterium to cover the electricity requirements of Switzerland for tens of millennia. Tritium is an isotope which is not present naturally but which can be produced from lithium (Li), reserves of which are estimated at several hundred million tonnes. These characteristics alone are sufficient to explain the great potential of this practically inexhaustible source of energy.

Thermonuclear fusion could become a new and substantial source of energy with several intrinsic advantages:

- the basic fuels (D, Li) are non-radioactive, abundantly available and are distributed fairly uniformly in the oceans and the Earth's crust;
- no runaway explosion of the reactor is possible because the quantity of fuel present in the reactor at any given time is very small;
- the problems of radioactive waste are limited: there is no radioactive ash, tritium is regenerated in the plant itself; assuming continued development of the materials used to construct the reactor, the storage of the components activated by neutrons could be limited to less than one hundred years;
- there is no atmospheric pollution giving rise to acid rain or greenhouse effects.

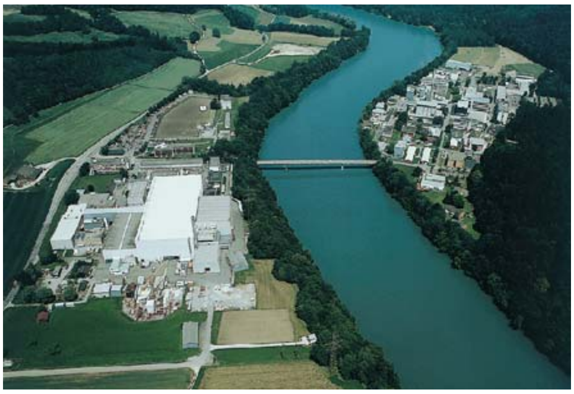


Block diagram of a D-T fusion power plant. The helium particles, confined in the plasma, maintain the high plasma temperature. The neutrons created by the fusion reactions traverse the first solid wall and are then slowed down in the surrounding blanket which contains lithium, thereby generating more tritium fuel. The fusion energy is recovered by a heat exchanger and in the final stage a conventional steam turbine generates electricity.

It is still much too early to evaluate the economics of a fusion power plant with any accuracy. The capital cost will certainly be higher than that of a coal-fired or fission power plant, but the fuel costs and indirect costs will be insignificant.

The EURATOM - Swiss Confederation Association

Since 1979, Switzerland has been associated with the European thermonuclear fusion research program whose aim is to develop a thermonuclear reactor. The Swiss part of this programme is handled by the CRPP. The CRPP was engaged in plasma physics research since 1961 and from 1979 became more specifically involved in controlled thermonuclear fusion research with its experimental tokamak(s) facilities. In October 1994, the fusion technology groups of the PSI were attached to the CRPP while remaining sited at the PSI. All the fusion activities of the EURATOM - Swiss Confederation Association then became the responsibility of the CRPP.



Site of the PSI in Villigen, on the banks of the River Aare

The Swiss contribution, calculated prorata with the Gross Domestic Product, amounts to around 3.5% of the EURATOM budget. Part of the overall budget is invested in the core activities, namely the exploitation of the European JET tokamak in the UK and the development of ITER, a large tokamak to be built together with Russia and Japan. Another part is redistributed among the associated centres throughout Europe. EURATOM contributes to the budgets of these associated centres by covering 25 % of their basic expenditure and 45 % of selected capital investments on a "priority support" basis. At the CRPP this support has been given to the TCV tokamak and its plasma heating systems, as well as to the SULTAN and PIREX installations at the PSI.

The CRPP: research in Lausanne and Villigen

Since plasma consists of electrically charged particles, it can be affected by electrical and magnetic fields. To keep the hot plasma away from contact with the surrounding walls, one solution is to create the plasma in a magnetic field. The tokamak uses this concept of magnetic confinement, with a large current flowing in the plasma, induced according to the principle of a transformer. The plasma current takes up the shape of a torus, like a car tyre. The current in the plasma heats it and also provides a force equilibrium by interacting with the magnetic field created by electrical currents in coils parallel to the plasma current. These coils also determine the shape of the plasma cross-section.

The CRPP TCV tokamak

The TCV tokamak (Tokamak à Configuration Variable) is the largest experimental facility at the Swiss Federal Institute of Technology in Lausanne. Its purpose is to push back the frontiers of tokamak operation, searching for new operating regimes with improved performance, in terms of the energy confinement time and the ratio of the plasma energy to the required magnetic energy. Scenarios to create a wide variety of plasma shapes are being systematically evaluated. Theoretical studies model the behaviour of the plasma and a strong interaction between CRPP experimentalists and theorists is crucial to the success of the whole project.

Interior of the TCV

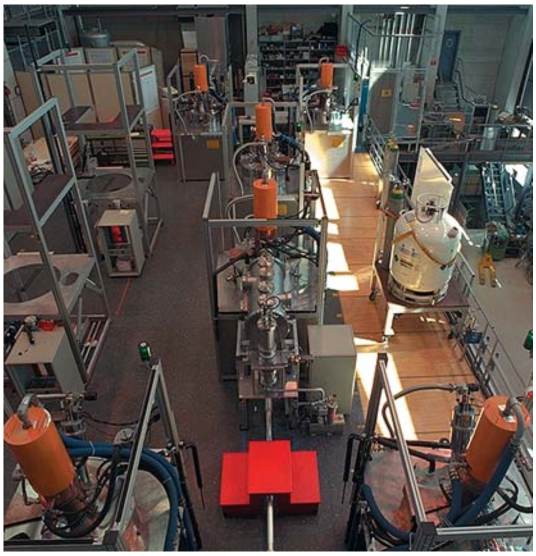
The TCV installation was commissioned in November 1992. Since then, plasmas currents over 1,000,000 amperes have been obtained in pulses lasting one to two seconds. The pulses are typically repeated at fifteen minute intervals. The installation is completed by a multitude of diagnostics installed around the tokamak to measure the plasma parameters.

Varying the shape of the plasma cross-section is one of the major features of the TCV research program. The shape and position of the plasma in the torus must be actively controlled in order to avoid contact with the wall. The different plasma shapes already obtained in TCV demonstrate the versatility of the facility.

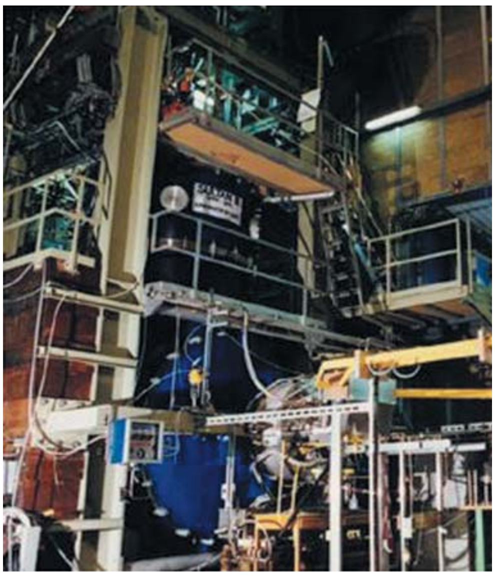
TCV is a complex experimental facility in which several thousand variables must be monitored and a huge volume of experimental data has to be recorded during the plasma pulses; this requires a multitude of automatic computer-controlled tasks.

A TCV plasma pulse, including the auxiliary heating, requires 200 MJoules of energy over about three seconds. The necessary electrical energy is supplied by a motor generator which separates the experiment from the local electricity grid.

An ambitious research programme into plasma heating, in addition to that produced by the plasma current itself, is underway on TCV. Hyperfrequency tubes, known as gyrotrons, are used. The frequencies generated are 83 GHz (6 tubes) and 118 GHz (3 tubes). These nine gyrotrons will deliver a total power of 4.5 MW. Wave-guides transfer the microwave power from the gyrotrons to the TCV plasma.



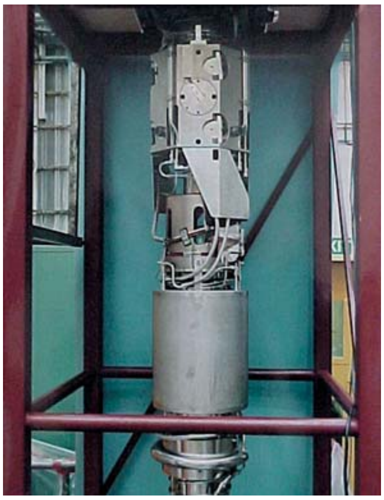
83GHz gyrotron installation in the TCV hall



SULTAN installation

Several features of the technology necessary for a fusion reactor are under study by the CRPP groups at the Paul Scherrer Institute (PSI). These Fusion Technology groups study the superconducting magnets and materials to be used in the construction of a future experimental reactor. The SULTAN (SupraLeiter Test Anlage in German) superconductor test facility located at the PSI is a tool which is unrivalled anywhere in the world for the study of low temperature superconducting cables for large fusion reactor magnets. SULTAN is the test facility for all the cables being developed for ITER. High temperature superconductivity is also being pursued for possible use in the ITER current leads. One spin-off from this work is the development of a prototype superconducting cable cooled to a temperature close to that of liquid neon, for transporting electrical energy, a project jointly financed by OFEN and PSEL (governmental agencies) and industry (UMS and KWB).

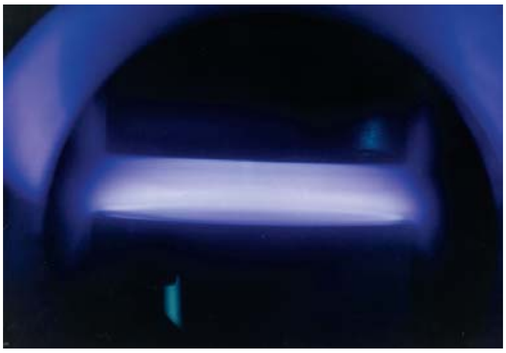
The structural materials in a fusion reactor will be activated by the neutrons from the fusion reactions. To enhance the environmental aspects of fusion energy, new structural materials will be needed. Their residual radioactivity after several decades must be low enough to permit recycling of the materials, thereby avoiding the need for long-term storage. The CRPP is working with a Swiss industry (Sulzer Innotec) and its European and world partners on two families of materials: martensitic ferritic steels and titanium alloys with low residual activation. In the absence of sufficiently intense sources of fusion neutrons, samples from laboratory or industrial castings are being irradiated in the 600 MeV proton beam of the PSI in the PIREX facility (Proton IRradiation EXperiment) as well as in various European reactors.



Sample irradiation head

The CRPP is also a centre of expertise in the development of gyrotrons at very high frequencies, over 100 GHz, with a high unit power up to1 MW. It collaborates with European partners in the development of these tubes for heating TCV and other European fusion experiments.

For the past ten years or so, the CRPP has been active in a diversification program using its expertise in plasma physics. This diversification covers the development of processes suitable for industrial use, their diagnosis and the understanding of the physical phenomena involved. These activities cover several fields: deposition of silicon films, formation of decorative coatings for the watch industry, deposition of diamond coatings on tools, packaging coatings, study of plasma torches for layer formation, and the manufacture of compact disks. These studies are performed in collaboration with industrial companies such as ASULAB, Balzers, Sulzer METCO, Tetrapak as well as other European laboratories.



Plasma study for an industrial process

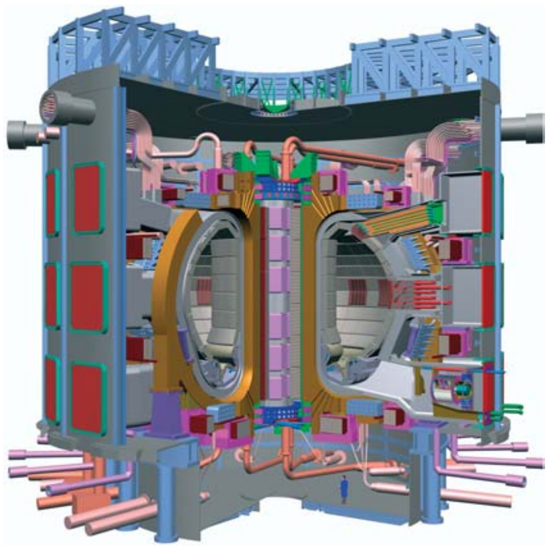
The CRPP is also involved in the undergraduate teaching of general physics, plasma physics and controlled fusion and in the training of young researchers during their PhD studies, which are carried out in the laboratory under the supervision of scientists working in the Centre.

International relations

JET

Through its participation in the European fusion programme, the CRPP contributes to experiments in progress on the largest tokamak in the world, the European tokamak JET (Joint European Torus). Staff are seconded to take part in experiments on-site and through theoretical and computational work performed in Lausanne.

In the context of the EURATOM – Swiss Confederation Association, Swiss industry is involved in the construction of several European experiments and in



the development of new equipment. It has proved both competent and competitive in these high technology fields.

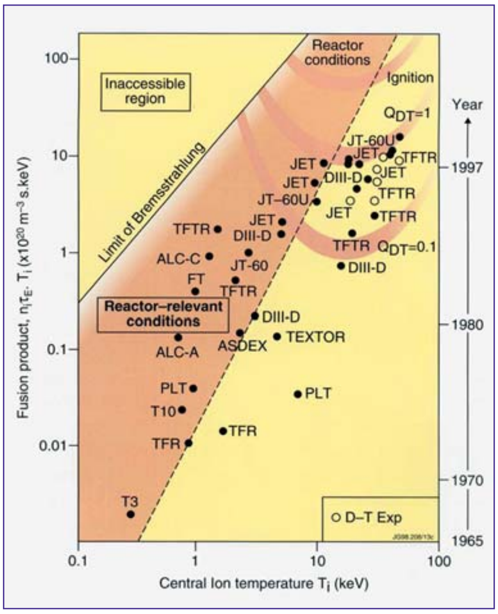
The EURATOM - Swiss Confederation Association participates in the design and engineering work for the ITER project (International Thermonuclear Experimental Reactor) which unites the Russian Federation, Japan and the European Union, plus Switzerland and Canada. In the development strategy for fusion as an energy source, ITER is regarded worldwide as a single intermediate phase between the present installations and an industrial demonstration reactor. The present design, known as ITER-FEAT, is ready for a political decision to go ahead.

The CRPP collaborates with many institutes both in Switzerland and abroad. These include KFA (Julich), FZK (Karlsruhe) and IPP (Garching) in Germany, CEA (Cadarache) in France, IST (Lisbon) in Portugal, the University of Cork in Ireland, the Royal Institute of Technology (Stockholm) in Sweden, JAERI (Naka) in Japan, MIT (Boston) and UCLA (Los Angeles) in the USA, Kurchatov, Triniti and Keldysch Insitutes (Moscow) in Russia, Imperial College (London) in the UK, the CREATE Consortium (Naples) in Italy and the Academy of Sciences (Prague) in the Czech Republic.

How far have we come with fusion?

Enormous progress has been made in the field of fusion research over a few decades, underlined by the following facts:

- a substantial deuterium-tritium fusion power has been obtained in tokamaks: 10.7 MW for 0.4 s in TFTR (USA) in 1996, 16.1 MW for 0.8s and 4.5 MW for 5 s (stopped only to limit the number of neutrons!) in the JET European tokamak in 1997. The CRPP was involved in these experiments.
- an amplification factor Q (fusion power divided by the heating power needed to maintain the plasma at the high temperature) close to 1 on JET and an equivalent Q value (achieved with pure deuterium plasma and converted for a 50:50 mix of deuterium and tritium) of around 1.25 on the Japanese JT-60U tokamak in 1998.



Improvement of tokamak performance

These results are the fruit of a sustained research program with a long-term vision of fusion as an energy source. They allow the scientific and technological goals of the ITER tokamak to be confidently defined, opening up promising and encouraging perspectives for fusion as an inexhaustible source of energy compatible with the environment.

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