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Plasma and fusion research in Switzerland – some milestones
## Plasma and fusion research in Switzerland – some milestones

<table>
<thead>
<tr>
<th>Year</th>
<th>Event</th>
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<tbody>
<tr>
<td>1961</td>
<td>Creation of Plasma Physics Laboratory by ‘Special Committee for Atomic Science’ formed by Federal Council and National Science Foundation</td>
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<td>1968</td>
<td>PPL becomes the Center for Research in Plasma Physics (CRPP)</td>
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<td>1973</td>
<td>CRPP joins EPFL</td>
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<td>1978</td>
<td>Agreement between Confederation and Euratom - CRPP is the Association EURATOM-Swiss Confederation</td>
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<td>1980</td>
<td>Tokamak à Chauffage d’Alfvén - TCA</td>
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<td>1989</td>
<td>Industrial Plasmas group</td>
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<td>1992</td>
<td>Superconductors test facility SULTAN (at PSI – Villigen)</td>
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<td>1995</td>
<td>First massively parallel HPC for fusion</td>
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<td>2000</td>
<td>First EC heating system on TCV</td>
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<td>2002</td>
<td>CRPP becomes a center in EPFL School of Basic Sciences</td>
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<td>2003</td>
<td>Basic plasma device TORPEX</td>
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<td>2014</td>
<td>CRPP-EPFL joins EUROfusion Consortium</td>
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<td>2015</td>
<td>First NB heating system on TCV</td>
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Today, CRPP becomes the Swiss Plasma Center

## CRPP becomes the Swiss Plasma Center

Capitalizing on the success of CRPP, the Swiss Plasma Center will use:
- Ad hoc investment funds from the Swiss Confederation
- Nation wide synergies in academia and industry

in order to:
- Reinforce the impact of Switzerland in fusion research for ITER and the R&D towards commercial reactors
- Expand research activities in space plasmas and astrophysics, environmental and industrial applications of plasmas
The TCV tokamak and its unique capabilities

- Development of the physics basis for ITER, DEMO and tokamak concept improvements
- Upgrades to heating systems under way to approach reactor relevant plasma conditions

TCV heating upgrades

- 1MW 30keV Neutral Beam and two dual-frequency 1MW gyrotrons: high plasma pressure, \( T_e \sim T_i \)
- Later: second 1MW 50keV Neutral Beam system: plasma rotation and fast ion physics

Upgraded TCV is one of three national tokamak facilities in EU Fusion Roadmap
Example of TCV contribution to ITER - control of plasma instabilities

Challenge
Remove the plasma instabilities before they affect the confinement significantly or lead to the termination of the plasma.

Example of TCV contribution to ITER - control of plasma instabilities

Method based on using microwave beams was proven on TCV.
Microwave launcher to cure instabilities – from TCV to ITER

TCV 0.5m, 15kg, 1MW beams at 82.7GHz

ITER 4.5m, 20'000kg, 8x1MW beams at 170GHz

The Swiss Plasma Center is in the EGYC consortium that develops the EU ITER gyrotron in collaboration with Thalès TED and hosts the relevant test stand.

It may also host the test facility for all ITER EC technologies.

Example of TCV contribution to DEMO – innovative edge configurations

Challenge

Exhaust heat and particles from plasma periphery

Conventional divertor configuration

- ITER heat heat fluxes, ~10MW/m², are at the limit of present materials
- DEMO heat fluxes will exceed this limit

Alternative advanced solutions for plasma periphery must be found for DEMO and reactors
Example of TCV contribution to DEMO – innovative edge configurations

Development of *snowflake divertor*
From a proof-of-principle to an assessment of these innovative configurations in reactor relevant conditions

Key issue: raise pressure to allow edge plasma to
- be detached from the wall
- radiate most of its power
- form a hot boundary surrounding a pure core

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Example of TCV contribution to DEMO – innovative edge configurations

TCV in vessel upgrade
Exhaust chamber of variable closure, with different length baffles for systematic investigations and optimization of magnetic configurations

*Project under development*

Use of High Temperature Superconductor for additional divertor coils to demonstrate a key technology for tokamak concept improvement
Superconducting magnets for ITER and DEMO

Challenge: Maintain the strand capability in cable

ITER cables (Nb3SN, NbTi): 200km, 1000t, 2500 strands

Two worldwide unique facilities at the PSI-Villigen site or testing high-current superconductors
Qualification of ITER cables

Development of DEMO conductors
Explore high temperature superconductors option

Example of Swiss contribution to enabling technology for ITER

Challenge: Keep first mirrors cleaned in ITER severe environment

Proposed technique: radio-frequency plasma in strong magnetic field

Courtesy of L. Marot
HPC simulation of ITER plasmas

Challenge
Limit the transport by turbulence for confinement optimization

Gyrokinetic simulation of ITER on PetaFlop HPC
$10^9$ particles, $10^9$ points, ~million CPU hours

Theory and numerical simulations at the Swiss Plasma Center

Challenge
From first principles to predictions and control tools for ITER and DEMO
- Global plasma equilibrium and stability
- Core and edge turbulence
- Fast ion dynamics

Forefront in theory of complex systems, development of numerical methods, HPC Validation on fusion devices and simple basic experiments
Challenge
Turbulent transport of fast ions, whose confinement is essential for plasma heating

Theory predicts that large fast ion orbits can average out the effect of turbulence

Example of theory validation – basic studies of fast ion turbulent transport

- Directly measure non-diffusive transport of fast ions in the presence of turbulence
- Confirm theory predictions on orbit averaging effect

Discover of non-diffusive transport of fast ions confirms that in ITER and future reactors turbulence effects on fast ions should be negligible
Expansion of basic and low temperature plasma physics

**Challenge**
Address basic plasma physics mechanisms for space and astrophysics in the laboratory

Particle acceleration by turbulence, momentum transport of interest in solar flares and accretion disks

Develop new multi-purpose basic plasma facility based on existing hardware and novel plasma sources

*Collaborations with ESA (mission THOR - Turbulence Heating ObserveR), Swiss Space Center, ISSI, Berkeley, ENS Lyon, …*

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Expansion of basic and low temperature plasma physics

**Challenge**
Develop plasma sources for high temperature chemistry on low temperature substrates, address open questions on plasma interaction with living matter

Dielectric barrier discharges
- Medicine: skin treatments, cancers, teeth, …
- Food: packaging, sterilization

*SEM images of untreated (l.) and N₂ plasma exposed starch*
Example of plasma synergies: from food to particle accelerators and fusion

Helicon (or whistler) waves

Helicon wave antennas produce plasmas at high density with high efficiency

Source for food packaging

Source for new high energy plasma wake-field accelerator

Source for high efficiency Neutral Beam for DEMO

Education and training are primary missions of the Swiss Plasma Center

The Swiss Plasma Center is one of the few EU fusion institutions embedded in an academic system

Complete curriculum offered on plasmas and fusion at Master and Graduate level (~30-35PhDs)

The first MOOC on Plasma Physics and Applications had 6’137 students enrolled
Plasma and fusion activities in Switzerland

In addition to its international network, the Swiss Plasma Center is expanding collaborations at Swiss level, including industries involved in ITER procurement and plasma spin-offs.

The mission of the Swiss Plasma Center

By catalyzing national efforts in academia and industry, developing state-of-the-art facilities, and taking advantage of the CRPP human capital, the Swiss Plasma Center will:

- Enable EPFL to fulfill, on behalf of the Swiss Confederation, its important role in the international fusion scene, in the context of ITER and DEMO
- Provide wide spectrum of education and training, and prepare ITER and DEMO generations
- Foster interdisciplinary aspects of plasma physics and fusion, in view of contributing to three main current societal challenges: clean energy, health and food

I look forward to facing the next challenges and adventures in plasmas and fusion together with many of you, in Switzerland, Europe and elsewhere

I am very grateful to all previous and present collaborators of CRPP for paving our way, and to the Institutions that understand and support our efforts!