Progress in Fusion Research
30 Years of TEXTOR

- TEXTOR as part of a multi-machine progress in fusion research
- Major results from TEXTOR
- Physics and engineering hand in hand
- Accumulation of large data bases
- Plasma-wall interactions and the question of wall materials
- The last day
- Publications
- Partners
70 Years of Fusion Research
from the idea to 500 MW Fusion Power and Steady State

TEXTOR as part of a multi-machine progress in fusion research


Geneva Confer. Tokamak success H-mode discovered 16 MW Fusion Power 500 MW Fusion Power

key milestones in fusion research
Major Results from TEXTOR

a plasma physics discovery

q(r) < 1
central plasma current density can be higher than predicted by theory

DPG Physikpreis
Soltwisch 1989

polari-interferometer
Major Results from TEXTOR

Clean plasmas by: carbonization, boronization, siliconization of the wall

...and improved energy confinement with clean plasmas

... reduced heat load densities by radiation cooling
Major Results from TEXTOR

Boronization became a world wide standard
Major Results from TEXTOR

ALTII Pumped Limiter

$\tau_a / \tau_E < 10$

efficient He-exhaust first demonstrated with ALTII
Major Results from TEXTOR

Application of Resonant Magnetic Perturbations
For a better control of plasma-wall interactions

Edge plasma instabilities are reduced (DIII-D, JET)
Will be applied on ITER

Dynamic Ergodic Divertor in TEXTOR
Major Results from TEXTOR

Anomalous transport due to turbulence?

Measurement of fluctuating edge plasma
Huber 1996

Understanding turbulence
Computational modeling

Calculation of density fluctuations in TEXTOR
Reiser 2014
A huge increase of data in 30 years

Data acquisition on TEXTOR
GB / shot

1983 2013
Accumulation of knowhow leads to new data bases

## New Hydride Collision Databases for Technical Plasmas and Fusion Plasmas

<table>
<thead>
<tr>
<th>Methane (CH\textsubscript{y})</th>
<th>C\textsubscript{2}H\textsubscript{y}</th>
<th>C\textsubscript{3}H\textsubscript{y}</th>
<th>Silane (SiH\textsubscript{y})</th>
<th>p,H,H\textsuperscript{-},H\textsubscript{2},H\textsuperscript{+},H\textsubscript{3}\textsuperscript{+}</th>
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Reiter et al.
Physics and Engineering – Hand in Hand

Competence in Fusion Engineering

1976 - 1980

TEXTOR construction
Physics and Engineering – Hand in Hand

Competence in Fusion Engineering

1980 - 1983
TEXTOR construction and inauguration
Physics and Engineering – Hand in Hand
Competence in Fusion Engineering

1984
ICRH heating
ERM/KMS
Physics and Engineering – Hand in Hand

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1987
ALT II
pumped limiter
Physics and Engineering – Hand in Hand
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1989
Neutral Beam Heating
Physics and Engineering – Hand in Hand
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1994
New transformer for 10 s pulse length
Physics and Engineering – Hand in Hand

Competence in Fusion Engineering

2003 Dynamic Ergodic Divertor
Physics and Engineering – Hand in Hand
Competence in Fusion Engineering

2003
Dynamic Ergodic Divertor
Physics and Engineering – Hand in Hand

Competence in Fusion Engineering

2003 Dynamic Ergodic Divertor
Physics and Engineering – Hand in Hand

Competence in Fusion Engineering

Supraleitende Stromverbinder

2010
Superconducting bus bar for Wendelstein 7-X
2012
Massive tungsten divertor plates for the JET ITER-like wall
Physics and Engineering – Hand in Hand

Competence in Fusion Engineering

2014 - 2020
ITER Port Plug for Charge Exchange Recombination Spectroscopy

Consortium
FZJ, ITER-NL, CCFE, HAS
Physics and Engineering – Hand in Hand

Competence in Fusion Engineering

Bild der Wissenschaft 2012
„deutscher preis für wissenschaftsfotografie“

Christian Lünig
Plasma wall interactions and the question of wall materials

Start with an all-metal wall
Plasma wall interactions and the question of wall materials

... and disruptions

9.11.1982, shot 1433, first discharge > 3 s
Plasma wall interactions and the question of wall materials

Stable plasmas with low-Z wall (graphite limiters, wall coatings)
Plasma wall interactions and the question of wall materials

Stable plasmas with low-Z wall (graphite limiters, wall coatings)

MARMAR and Wolfe, MIT

Jim Strachan, PPPL
Plasma wall interactions and the question of wall materials

- Neon gas puff
- Neon line radiation
- Feed back

Concept of high power radiation cooling with seeded impurities
Plasma wall interactions and the question of wall materials

Concept of high power radiation cooling with seeded impurities

Radiative Divertor in ASDEX Upgrade

... a scenario for ITER
Plasma wall interactions and the question of wall materials

A Thorough Study on Graphite for Plasma Facing Components

Experiments and Modeling
- Erosion mechanisms
- Transport and deposition
- Lifetime
- Robustness
- Deuterium/Tritium retention in layers

TEXTOR
ALT II limiter

deposition zone
erosion zone
Plasma wall interactions and the question of wall materials

A Thorough Study on Graphite for Plasma Facing Components

Experiments and Modeling

Erosion mechanisms
Transport and deposition
Lifetime
Robustness
Deuterium / Tritium retention in layers

Critical issue
Plasma wall interactions and the question of wall materials

Can we replace graphite by heavy metals (W, Mo, ..) ?

tests with limiters in TEXTOR

Massive W  W for melt studies  W, Mo, Ta, doped W

Start of a joint effort for replacing C by W
Detailed studies in TEXTOR and in special test devices
Integrated large scale tests in AUG and JET
Plasma wall interactions and the question of wall materials

Going beyond the limits: melt experiments in TEXTOR

ITER-like W macrobrush structure
Plasma wall interactions and the question of wall materials

ITER-like wall experiment (W divertor, Be wall)

21.11.2013; The ITER Council approved the IO proposal and decided to commence operations with a full tungsten divertor...

massive tungsten lamellae tested in TEXTOR
Plasma wall interactions and the question of wall materials

Higher Demands for Fusion Power Plant

- Power and particle exhaust
- Erosion and deposition
- Steady-state operation
- Neutron damage

TEXTOR was not ready to face these new challenges

Decision:
Switch from pulsed TEXTOR operations to a new research program for advanced materials for steady state
4 December 2013 – last day of TEXTOR operation after 30 successful years

last TEXTOR shot
publications in refereed journals

- **2 200** papers 1983 – 2014 on fusion
- **1 360** papers 1976 - 2013 explicitly mentioning TEXTOR
Partners

Worldwide (IEA…)

Europe (EURATOM)

Euregio (B, NL)

Germany (Helmholtz, …)

Universities
Partners

1996 Foundation of the TEC Trilateral Euregio Cluster

FZJ ERM/KMS FOM

role model for clustering of EURATOM associations and joint operation of large facilities