Summary of Thrusts 16-18

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Theme 5: Optimizing the Magnetic Configuration

ReNeW
Research Needs Workshop

Theme 5 represents the fusion science and technology opportunities in toroidal alternates

- Five major toroidal alternates were examined by FESAC Toroidal Alternates Panel (TAP), with focus on goals for the ITER era
  - Stellarator
  - Spherical Torus (ST)
  - Reversed Field Pinch (RFP)
  - Compact Torus (CT):
    - Field Reversed Configuration (FRC)
    - Spheromak
- Each configuration offers particular strengths for fusion development. Each requires a self-consistent and unique set of solutions to general scientific issues, e.g., confinement, stability, sustainment, controlled boundary interface, etc.
- Research on multiple magnetic configurations collectively advances and validates our understanding of fusion plasma science and technology

Thrusts 16-18 advance configuration optimization

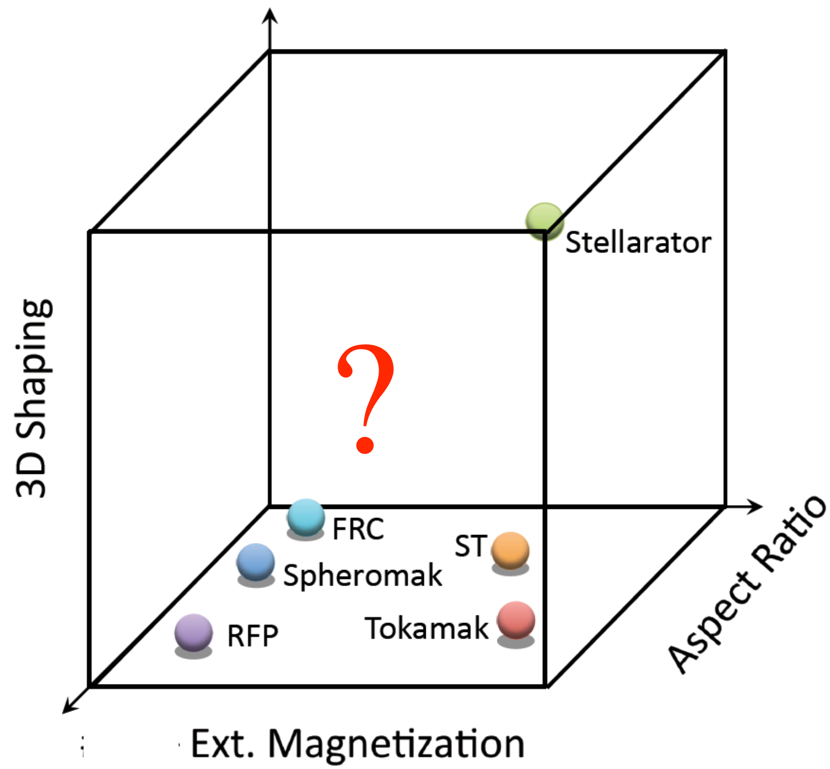
16. Developing the spherical torus to advance fusion nuclear science

17. Optimize steady-state, disruption-free plasma confinement using 3D magnetic shaping, emphasizing quasi-symmetry principles

18. Achieve high performance plasma confinement using minimal externally applied magnetic field

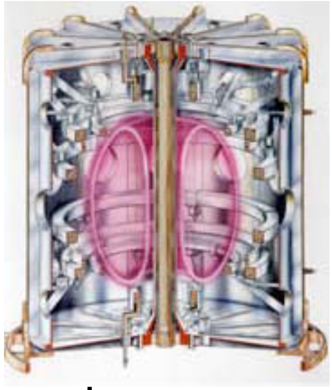
“spots” represent typical or historical view of the configurations

optimized configurations exist in this space



16. Developing the spherical torus to advance fusion nuclear science

- The ST (low aspect ratio tokamak) program is poised to generate the knowledge to construct a fusion nuclear science and technology component testing device, and to aggressively pursue improvements to advance the ST for energy production



- Thrust builds on recent advances
  - Non-solenoidal current initiation (25% of required value)
  - Favorable dependence of confinement on the magnetic field
  - Sustained stability at beta required for Component Test Facility
  - Test bed for liquid lithium walls, demonstrating improved confinement

Key issues

- The ST has little room for a central solenoid to produce and drive plasma current.
- The compact geometry increases the heat loading to the wall.
- ST energy confinement behaves differently than in a higher aspect ratio tokamak.
- Broad current profiles and near-spherical geometry strongly impact stability.
- The lower magnetic field and enhanced energetic particle drive of the ST may challenge the sustainment of high plasma current.
- The compact geometry precludes the use of shielded superconducting magnets.

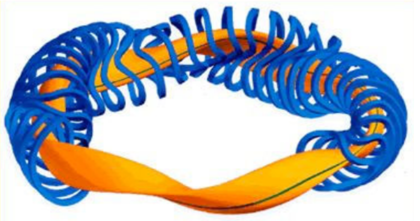
16. Developing the spherical torus to advance fusion nuclear science

Proposed actions in thrust:

- Exploit and understand magnetic turbulence, electromagnetic waves, and energetic particles for MA plasma current formation and ramp-up.
- Develop innovative magnetic geometries and first wall solutions such as liquid metals to accommodate multi-MW/m^2 head loads.
- Utilize upgraded facilities to increase plasma temperature and magnetic field to understand ST confinement and stability to fusion-relevant parameters.
- Implement and understand active and passive control techniques to enable long-pulse disruption-free operation in plasmas with very broad current profiles.
- Employ energetic particle beams, plasma waves, particle control, and core fueling techniques to maintain the current, and control the plasma profiles.
- Develop normally-conducting radiation-tolerant magnets for low aspect ratio applications.
- Extend ST experiments to near burning-plasma conditions in a new or upgraded device.

17. Optimize steady-state, disruption-free toroidal confinement using 3D magnetic shaping, emphasizing quasi-symmetry principles

- The stellarator concept, and more generally 3D flux surface shaping, provides the only validated means of disruption free, sustained high plasma pressure with tokamak-like confinement.



  - Intrinsically steady-state
  - No disruptions in routine operation
  - Fusion-relevant performance: good confinement, high plasma pressure, densities above the empirical tokamak limits, and long sustainment.
  - Understanding 3D shaping physics is a core competence for mag. fusion
- Thrust builds on U.S. leadership in the development of quasi-symmetry

Key issues

- How much 3D shaping is required to attain simultaneous sustained good confinement at high pressure and temperature without disruptions.
- 3D shaping requires magnets that are more complex than planar coils.
- Divertor designs for 3D magnetic fields are geometrically more complicated, but offer lower plasma edge temperatures and higher density which eases power handling.

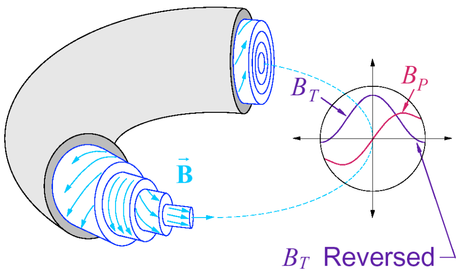
17. Optimize steady-state, disruption-free toroidal confinement using 3D magnetic shaping, emphasizing quasi-symmetry principles

Proposed actions in thrust:

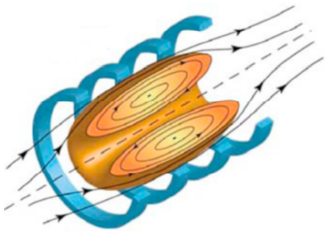
- Build quasi-symmetric configurations with plasma parameters sufficient to demonstrate low collisionality, disruption-free operation at high plasma pressure. Will extend understanding of plasma flow, turbulent transport, divertors, energetic particle confinement, and impurity transport to quasi-symmetric fields
- Expand efforts in non-axisymmetric theory and modeling, which is crucial to the full range of applications of 3D magnetic fields
- Design quasi-symmetric configurations with simpler and maintainable magnet systems
- Increase participation on the large stellarator experiments in Japan and Germany, particularly to understand 3D divertor physics and design, and impurity transport
- Determine the level of 3D shaping needed to eliminate disruptions in tokamaks
- Explore the additional application of 3D shaping to other magnetic configurations, such as RFPs, and CTs.
- Building on actions above, conduct an integrated quasi-symmetric experiment which will validate extrapolation of 3D shaping to burning plasma applications

18. Achieve high performance toroidal confinement using minimal externally applied magnetic field

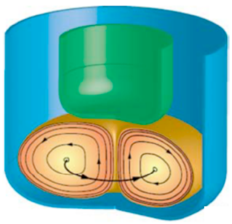
- By requiring less external magnetization, the RFP, spheromak, and FRC represent potentially high payoff options for the fusion energy program.
  - Modest magnets reduce engineering challenges
  - High beta 10-80%, and large Ohmic heating
  - FRC and spheromak approach cylindrical geometry



- Thrust builds on recent advances, especially the use of control techniques to improve confinement and stability



- Broad scientific impact
  - Physics connections to space and astrophysical plasmas
  - Versatile laboratories for fusion, basic science, and education



Key issues

- Understanding confinement and stability in reactor-relevant conditions.
- Configurations must be formed and sustained efficiently.
- The compatibility of confinement, sustainment, and plasma-boundary control must be demonstrated.

18. Achieve high performance toroidal confinement using minimal externally applied magnetic field

Proposed actions in thrust:

- Develop and deploy plasma diagnostics to understand transport and stability
- Apply theoretical and computational models to analyze nonlinear effects. Validate models through comparison with improved measurements.
- Study FRC stability at small ion gyro-radius in a new or upgraded facility with energetic ion sources. Success will enable integrated tests of stability, confinement, and sustainment.
- Develop improved current sustainment methods for the spheromak. Small experiments will feed transformational ideas to a larger facility to test integrated confinement and sustainment.
- Extend confinement scaling and demonstrate current sustainment at high temperature in a new large current RFP. A staged, upgradeable facility would eventually demonstrate near-burning plasma conditions with integrated plasma-boundary and MHD stability control.
- Quantify the benefits of low-field, steady-state or pulsed reactors using system studies.