Configuration Studies for an ST-based Fusion Nuclear Science Facility

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Overview

• Recent U.S. studies for ST-FNSF have focused on assessing achievable missions versus device size
• Possible missions:
  – Electricity break-even
  – Motivated 2010-12 analysis of R=2.2m ST Pilot Plant
  – Tritium self-sufficiency (trium breeding ratio TBR > 1)
  – Motivates present (2013-14) analysis of R=1m, 1.7m ST FNSF devices to address key questions:
    – How large must ST device be to achieve TBR > 1?
    – How much externally supplied T would be needed for smaller ST?
  – What are device and component lifetime?
• Fusion-relevant neutron wall loading and fluence
• STs studied here access 1MW/m2, 6MWy/m2 (surfacing values)
• PF coil set identified that supports combined Super-X + snowflake divertor for range of equilibria

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Components:
- All equilibrium PF coils outside vacuum vessel
- Increased strike-point radius reduces B, q
- Strike-point PFCs also shielded by blankets
- 2nd X-point/snowflake increases SOL line-length
- PF coil set supports wide range of q = 0.4 – 0.8
- Breaching and strike points change with q
- 3D strike point R, controllable strike point angle of incidence (0-14°)
- Diverter coils in TF coil ends for equilibrium, high q
- Breeding in CS ends important for maximizing TBR

R=1.7m configuration with Super-X divertor

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Two sizes (R=1.7m, 1m) assessed for shielding, TBR

Parameter:
- Major Radius 1.68m 1.0m
- Minor Radius 1.7m 0.8m
- Fusion Power 1632MW 623MW
- Wall loading (avg) 1MW/m2 1MW/m2
- TF coils 12 10
- TBM ports 4 4
- MTM ports 1 1
- NBI ports 3 3
- Plant Lifetime >30 years
- Availability 10-50%
- Neutron source distribution

Mapping of dpa and FW/blanket lifetime (R=1.7 m Device)

0.5 MeV NNBI favorable for heating and current drive (CR) for R=1.7m ST-FNSF

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Impact of TBM, MTB, NBI ports on TBR

No partial or penetrations, breeding blanket

Approx. ΔTBR per port:
- TBM: -0.25%
- MTB: -2.0%
- NBI: -0.75%

TBR contributions by blanket region

Breeding at CS ends important: ΔTBR = +0.07

Options to increase TBR > 1

- Add to PF coil shield a thin seeding blanket (ΔTBR = +13%)
- Smaller opening to divertor to reduce neutron backscattering
- Uniform OB blanket (1m thick; nothing thinner)
- Reduce cooling channels and FCI's within blanket (used thermal noise analysis to cutoffs)
- Thicker IB VV with breeding

Potential for TBR > 1 at R=1.7m

R2 = 1m ST-FNSF achieves TBR = 0.88

Summary: R = 1m and 1.7m STs with R2 = 1MW/m2 and Dn2 = 1.2 assessed for FNS mission

- Ex-vessel PF coil set identified to support range of equilibria and Super-X/snowflake divertor to mitigate high heat flux
- 0.5MeV NNBI optimal for heating & current drive for R=1.7m
- Vertical maintenance approach, NBI & test-cell layouts identified
- Shielding adequate for MgO insulated inboard Cu PF coils
- Outboard PF coils (heated outboard blanket) can be superconducting
- Calculated full 3D TBR: reduction from TBM, MTB, NBI
- Threshold major radius for TBR = 1 is R2 = 1.7m
- R=1m TBR = 0.88 = 0.4-0.55kg of FFPPY → $12.5MM/FPPY
- R=1m device will have lower electricity and capital cost future work could assess size/cost trade-offs in more detail

ST-FNSF shielding and TBR analyzed with sophisticated 3-D neutronics codes

• CAD coupled with MCNP using UW DAGMC code
• Fully accurate representation of entire torus
• No approximation/simplification involved at any step:
  – All neutrons considered
  – 3-D neutronics codes: MCNP + DAGMC
  – Effects of all shielding materials modeled in detail, including:
    – FW, side, top/bottom, and back walls, cooling channels, SIC FCI
    – All walls accurately modeled
  – Cooling channels, FCI's, etc.
  – All OB blanket modeled
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  – Tritium breeding
  – Electricity break-even
  – Tritium self-sufficiency
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• Supporting Systems
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  – Tritium consumption
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0.0004
0.0064
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