Response to Question 2) from FESAC Panel Feedback to the ST Community
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Question 2: "What features make the ST preferable for this goal; what challenges need to be overcome to achieve it?"

## ST strengths

The ST has several features that make this concept preferable for producing a high heat flux, high neutron fluence environment as specified in the ST goal. These features are enumerated below:

**1) Common physics basis with the Tokamak:**
The broad scientific knowledge of the Tokamak has enabled the rapid advance of ST towards its high-β operational state at low-A due to a strong commonality of the underlying physics of these two concepts. This commonality allows projection to future ST designs with minimized physics risk.

**2) Increased margins to known stability boundaries and pressure driven currents:**
ST experiments have transiently demonstrated macroscopically stable operation at high-β (with central local β ~ 1), representing an increase of a factor of 4 or more relative to standard A. This is aided by the naturally increased plasma shaping, high toroidal rotation under NBI due to low moment of inertia, and increased ion banana width at low-A. These properties should scale favorably when going to the ST goal, including the ρ* scaling which is estimated to require at most a factor of 2 scale-up. Near-fully bootstrapped non-inductive equilibria are accessible at high $q_{cyl}$ with realistic profiles.

**3) Favorable ion transport scalings:**
Strong rotation and ExB shear lead to stabilization of ion scale instabilities and turbulence. The ion thermal diffusivity approaches the neoclassical ion level, indicating different mechanisms from the observed electron turbulence and transport. Since neoclassical ion thermal diffusivity decreases as field and current increase, the ST goal will likely tolerate higher levels of ion thermal diffusivity than the neoclassical while still remaining substantially below the anticipated electron thermal diffusivity. It is estimated that < factor of 2 scale up in normalized plasma size (1/ρ*) is required from MA-level ST experiments today (~50) to that required for the ST goal (<100).

**4) Strongly shaped plasma edge and SOL:**
Increased stability limits at low-A and elevated q(0) to ballooning-peeling modes is expected near the ST plasma edge, leading to larger margins in pedestal pressure gradients for ELMs and the associated edge collapse. Increased fraction (~90%) of toroidally trapped particles in the outboard SOL increases the prospect for trapped particle instabilities and the possible cross field transport, potentially affecting the heat flux SOL thickness. Closer proximity of the SOL to the higher order x-point located on the machine vertical axis naturally leads to increased SOL flux expansion at the divertor. This potentially enables use of advanced divertor configuration to reduce peak divertor heat flux by a further factor of 5-6.

**5) Compact configuration & simplified engineering:**
The compact nature of the ST goal leads to Demo-relevant heat and neutron flux at the wall at modest field and size to test divertor materials and technology. The ST has a more efficient use of poloidal field coil stored energy at high κ, limiting the poloidal field coil current ampere-turns including divertor coils to the same order as the plasma current. It also has more efficient use of TF stored energy due to small gap between plasma and center TF Coil leg. This, together with stable operation at high-β, leads to a high utilization of the TF stored energy. These combined then enable realization of the ST Goal with reduced size, fusion power, tritium inventory, and potentially also capital cost. These further allow full remote maintainability of modular divertors, chamber components, slender TF and MIC solenoid coil center post, etc.

## ST challenges

The following challenges must be overcome to allow the ST Goal to be achieved:

**1) Start-up and steady state operation:**
Techniques for full start-up, such as, helicity injection, merging-compression, RF, NBI, and their combinations exist, but full non-inductive operation for the ST goal has not been adequately tested and understood.

**2) Electron turbulence and transport:**
Electron turbulence and transport, similar to tokamaks, is not yet adequately tested and understood.

**3) Macroscopic stability:**
Demonstration and understanding of sustained high-β operation beyond conventional tokamak levels with high reliability and maintenance of stabilizing plasma rotation is required to avoid disruptions.

**4) Disruption mitigation and divertor design:**
Large uncertainties remain regarding disruption mitigation, similar to those faced by the tokamak. The high heat and neutron fluxes in the compact ST goal necessitate solving divertor challenges far beyond those faced by ITER.

**5) Energetic particle instabilities and impact:**
ST NBI experiments show increased ratio of fast-ion speed to Alfvén speed, and of fast-ion beta to total beta, potentially exciting increased Alfvén instabilities leading to additional fast-ion redistribution and loss.

**6) Extrapolation to the very low collisionality regime:**
Large (~2 orders of magnitude) scale down in plasma collisionality ($\nu^*$) for plasma core and edge is anticipated from MA-level ST experiments to the goal relevant ST. Effective particle control for sufficient pulse lengths (~5s) at increased temperatures will be required to reduce $\nu^*$ by an order of magnitude to establish the needed understanding for the ST goal.