Spheromak questions and issues for the FESAC Toroidal Alternates Concept Community Input Meeting in Dallas:

1. The ITER-era goal for the spheromak should be more specific, and there are concerns that it may be too ambitious. We know from experiments on other concepts (tokamak and stellarator) that, following long-pulse current drive development and achievement of good confinement, extensive studies were required to resolve physics issues before experiments at the PE level. Given the present lack of a spheromak current drive that is demonstrated to be compatible with good confinement, can you craft a goal that recognizes this need? The result might be something like: "Conduct experiments and simulations that demonstrate current drive compatible with stability and good energy confinement, enabling successful fusion-plasma experiments at the PoP level followed by construction and initial operation of a PE-level experiment within 20 years."

2. Your §4.3.5 calls for the PE in 7-10 years, which appears too ambitious and inconsistent with your goal. Did you mean PoP on the shorter time scale?

3. Is it true that confinement-compatible and efficient current drive requires success in at least one of three scenarios: a) Achievement of helicity current drive at sufficiently low magnetic fluctuation levels that energy is well confined; b) Development of non-helicity current drive techniques; or c) Demonstration that a pulsed technique such as "refluxing" works well enough to be of interest for an eventual reactor? If so, experiments on these at a CE level should identified as the highest priority. To what extent can these be explored via simulations? What and how much can be learnt from the results of RFP research? How will you examine the validity, efficiency, and compatibility of such methods?

4. The scientific goals should stress measurement of basic stability and confinement properties in quasi-steady discharges (that is, pulse length >> all characteristic times for MHD, transport, current profile relaxation, etc. and of course many transit times or Alfvén times). The required dimensionless parameters should be based on the best current assessment of relevant physics not arbitrary dimensioned quantities.

5. Scientific Roadmap: You have done an excellent job of describing the scientific goals, although more discussion of their physics basis would be useful to make them clearer. Less "sharp" is a scientific roadmap for reaching these goals, although much of the information is available, e.g. in Table 4-1. A scientific roadmap is recommended to pull these together and probably should have decision points (e.g. among the opportunities in §3-§4). What experimental and simulation work is needed in the near term?

There are numerous additional scientific goals which need to be met in the long term; these should be prioritized and worked into the scientific road map. Specifically:

6. Panel members were particularly complementary about Table 3.1. However, in general, the physics basis for reaching goals is not explained, nor are techniques outlined. A short table of desired target parameters would be useful.

7. The basic spheromak equilibrium is force-free with $\beta=0$ and nearby MHD stable, finite pressure equilibria have been achieved with the use of close fitting conducting walls. What is required for achieving high β? When and how should it be addressed?

8. Electrode-Wall interactions: With formation via electrodes, what is the situation on plasma impurity content? Is this formation method relevant for a fusion reactor? Will a technology development program be required?

9. What issues will require a larger device, and when will it be appropriate to move to it? What should be done differently from SSPX for a next step experiment, aside from the addition of auxiliary heating and current drive for sustainment on the transport time scale? It is stated that a larger device at higher current and current amplification is needed, but little discussion of what this implies. At what point does efficiency become the leading issue?

10. There is interest in generating similar parameter tables for all the concepts. This may be difficult for the spheromak given its stage of development, but it would be useful to fill out the attached table.

Concept Key Parameters

Parameter	Present value†	ITER-era goal	Reactor Target
Confining Field[a] (T)			
Plasma current[b] (MA)			
Pulse length Δt (sec) and $\Delta t/\tau_E$			
External sustainment/current drive type			
External sustainment/current drive power[‡] (MW)			
Current drive efficiency (η)			
Major Radius[c] (m)			
Minor Radius[c] (m)			
Elongation (κ)			
Central density n_e or $\langle n_e \rangle$ (m^{-3})			
Central T_e or $\langle T_e \rangle$ (keV)			
Central T_i or $\langle T_i \rangle$ (keV)			
Central beta (% and β_N)			
Energy confinement time[d] (s)			
Fusion power density $B\tau_E$ (T-s)			
Core electron transport[d] (χ_e m^2/s)			
Core ion transport[d] (χ_i m^2/s)			
$\rho_* = \rho_D / a$ or $S_D = L^*/\rho_D$			
$S_\alpha = L^*/\rho_\alpha$			
Collisionality (ν_*)			
Normalized pulse length (τ/τ_r)[#]			
Normalized pulse length $(\tau/\tau_{Ti=Te})$[#]			
Estimated Fusion Power (MW)			
Estimated wall loading (MW/m^2)			
Estimated plasma exhaust power (MW/m^2)			

[a] peak on axis [b] ohmic or driven or diamagnetic [c] mean values if not axisymmetric

[‡] power to plasma needed to maintain configuration, magnetic field, or plasma current

[d] measured or estimated from power balance, size, beta, or ne, Te, and Ti

[#] τ_r ($\tau_{Ti=Te}$) is relevant time scale for configuration redistribution (temperature equilibration)

[*] use either a or R as appropriate [†] indicate if not simultaneous

Table values based upon known or estimated values from present experiments, possible ITER-era targets based on extrapolation from present experiments, and estimated reactor conditions based on previous reactor studies or back-of-envelope style spreadsheet calculations.

Please provide definitions, formulary, or assumptions on a separate sheet.