Vision/Innovative Directions Workshop Summary

The panel consisted of Yasushi Ono, John Slough and Michael Schaffer. Slough and Ono-san presented several prepared slides each. This was followed by general discussion. Finally, Schaffer presented a few prepared slides, and there was more discussion. All the discussion was lively.

Slough began by showing a typical T vs. $n\tau$ plot with tokamak and FRC progress marked on it. He highlighted that tokamaks made large advances toward fusion breakeven with increases in size and heating power, but that increased FRC size has yielded much more modest gains. Therefore, simply increasing the size of FRC experiments does not look productive. He said that the high density approach, somewhere between PHD (~10^{23} m^{-3}) and MTF (~10^{26} m^{-3}), would most likely be able to achieve D-T fusion. However, the high β FRC is uniquely qualified among fusion concepts to burn D-He^3, if the confinement and large poloidal flux can be achieved at low (10^{20} m^{-3}) density. Slough noted that the present empirical FRC confinement scaling is at least an order of magnitude below that required. There is recent encouraging news about confinement improvement, though. The FIX experiment at Osaka University yielded enhanced FRC lifetime in translated FRCs that were injected with a neutral beam. Increasing the poloidal flux of the FRC appears to be a bigger problem. It was noted that while the RMF experiments at the University of Washington have sustained the FRC configuration, an essential requirement for steady state, significant increases have yet to be achieved. Currently ~1 mWb of poloidal flux is driven, but at least several Wb would be required for even a D-T reactor. The confinement observed in the RMF experiments showed strong improvement with increasing density, but this scaling would not help much in the low density, steady-state approach. It was suggested that understanding the current transport mechanisms that limit confinement at low density is essential, and that new diagnostics are needed to realize this goal. The large poloidal flux requirement may require retrying old approaches such as coaxial formation, or investigating new ones such as merging spheromaks, or helicity injection.

Ono-san began by noting that CTs have returned after almost been eliminated from consideration in the 1990s. He emphasized that CT researchers need a strategy to survive for the next 10 years. Drawing a parallel to winning an Olympic competition, he said that the CT team strategy must be to be a finalist in the fusion competition. In order not to be eliminated early, the FRC team must explain its basic stability and show that it might extrapolate to fusion, while the spheromak team must suppress the dynamo or, at least, its associated losses. If they can stay in the game, CTs will have to move up to reactor relevance. For all CTs this means overcoming startup and current drive limitations. Even though CTs have valuable connections with solar, space and magnetospheric physics, Ono-san adamantly insisted that we must not be distracted by them and “escape from fusion to physics”. He thinks that STs appear to offer the best combination of advantages vs. disadvantages for fusion. Whether STs are “pure” CTs or not, “ST is our son,” he stressed. Recent experiments in which one kind of CT plasma is transitioned into another in the course of a single discharge have been very productive.

Schaffer showed two plasma technology concepts as examples of ways to make progress with FRC experiments. First, he showed his concept of injecting large amounts of magnetic flux in a single pulse via a Taylor-relaxed double helix plasma. Since the poloidal flux content scales with the length of the double helix rather than with source radius, the flux can be large. Second, he showed how an RMF magnetic field from external coils can be made to penetrate a metal vessel through just a narrow toroidal cut. A metal vessel might be needed for long-lived, high-energy plasma experiments, plus it would make FRCs devices amenable to high temperature bakeout. George Vlases had a related idea for multiple toroidal cuts. Finally, Schaffer briefly pointed out that the diamagnetic nature of the FRC can supply almost all of its current. It is only necessary to supply power (eventually by fusion products), particles (refueling) and a seed current near the internal null. The process is much more efficient than bootstrap current and wave or beam current drive in tokamaks.

The audience participation was long and lively. Regrettably, neither the session chair person nor the other panelists took notes of the discussion from which to prepare a summary.