Summary of APEX Session Covering Tasks B and II on August 17, 2000

The following five presentations were given summarizing the work performed in Tasks B and II:

1) Update on Liquid Wall-Bulk Plasma Interactions (Kaita)
2) Updates on Intense Lithium Streams in tokamaks
3) Recent Plasma MHD Results (Kotschenreuther)
4) Liquid MHD Modeling and Experiments (Morley)
5) Radwaste Volume and Hazard in LW and Conventional SW Concepts (Youssef)

Bob Kaita gave a status report on work performed in Task B. Simulations of flow characteristics of liquid lithium along the center stack and inboard divertor in NSTX are being refined at UCLA, with boundary magnetic field strengths provided by PPPL. Support is also continuing for the toroidal liquid metal MHD facility at UCLA (MTorr), including plans for preventing coil damage through overheating of electrical insulation. An NSTX Liquid Surface Workshop was held on Aug. 10 at PPPL to explore the potential attractiveness of using lithium in NSTX for improving plasma confinement, aiding long pulse operation, and improving MHD stability. This is part of the process to identify key issues for implementing liquid walls in NSTX. Progress has also been made in MHD analysis and the use of intense lithium streams in tokamaks. They were discussed in separate presentations by Kotschenreuther and Zakharov. A new experimental test of magnetic propulsion is under development at the University of Illinois (UI). The "Toroidally Symmetric Flowing Liquid Metal Test Facility" at UI will have liquid gallium flowing down a centerpost in an "NSTX" geometry. The DEGAS2 code has been upgraded to handle more complex geometries (e. g., the Alcator C-Mod divertor region), and it has an improved ability to treat neutral-elastic collisions.

Leonid E. Zakharov gave an update on the impact of using intense lithium streams in tokamaks. The theory of stabilizing the tokamak plasma by lithium streams has been formulated (PPPL Report 3483 August 2000). A new stream-locked mode, found in the theory, determines the limits of the flow stabilization. Power extraction by the jets of Li, LiSn, Ga, crossing the X-point region in the tokamak, has been analyzed. It was shown that liquid metals in divertors have a very limited power extraction capabilities compared to lithium walls. MHD expulsion of the liquid metal has been shown in a simple magnetic propulsion experiment with a cylindrical propulsion cell. A combination of plasma facing lithium streams and Flibe blanket (proposed by S.Zinkle and B.Nelson) has been analyzed as a new fusion power extraction scheme. It was shown that Flibe can provide less than 5% energy losses through the side wall of channels at the high working temperature of about 800 C.

Mike Kotschenreuther summarized the recent plasma MHD results. PPPL MHD equilibrium and stability tools have been used to examine unexplored territory in plasma parameter space to find plasmas which meet the goals of APEX. Results indicate that plasma shaping with a close shell and liquid walls could potentially eliminate the need for current drive and neutral beams, while keeping feedback loops behind the shield. Elongated plasma kink stability results were obtained using the PPPL codes JSOLVER and PEST. $\kappa = 3 – 4$ plasmas with high beta have requirements for wall stabilization which are less stringent than $\kappa = 2$. For cases which are suitable for feedback stabilization using active coils behind the shield, $\kappa = 3 –4$ have beta ~ 11-25 %, vs ~ 4% for $\kappa = 2$. Such cases are also likely to have lower velocity requirements for liquid metal flow stabilization. The qualitative characteristics of the instabilities found in PEST indicate higher elongation is more suitable for feedback and liquid metal flow stabilization. It appears that current drive requirements for MHD stability can be reduced to very low levels using strong plasma shaping and liquid walls. With liquid walls, there is the potential to control the thermal instability using controlled losses of alpha particles from ripple. Vertical stabilization of cases up to $\kappa = 4$ with acceptable feedback power is possible with conducting shells very close to the first wall and with many feedback loops. The equivalent of 2 cm thick Li layer is adequate. Start-up of elongated tokamaks with Sn-Li and Li streams appears possible with some auxiliary heating (i.e. RF). Abdou emphasized during the discussion the need to explore the benefits of implementing liquid walls on improving the plasma performance.

The work on MHD related issues for APEX task II was summarized by Neil Morley. Work in this area has continued to progress. New models developed for axi-symmetric liquid metal flows are able to predict the effects of multi-component magnetic fields and magnetic field gradients on divertor and first wall flows. Magnetic pumping has also been analyzed with these codes and shown to be effective in simplified geometries. New direct numerical simulation models have been developed in collaboration with Japanese scientists that predict from first principles the effect of magnetic fields on turbulence in Flibe shear flows. This new data will be used to help tune k-e model predictions of free surface turbulence and heat transfer for Flibe. Experiments are also being developed to provide data for verification of simplified models. The MTOR facility at UCLA will soon be online and provide a tokamak simulation environment for a variety of free surface tests. Small-scale experiments at UIUC in collaboration with PPPL also aim to explore MHD flow with toroidal symmetry and deviations from toroidal symmetry. For Flibe, the FLIHY facility at UCLA will soon begin investigating free surface heat and mass transfer in high Prandtl number liquids. First experiments will focus on characterizing the surface turbulent Prandtl number for smooth and wavy flows. Upcoming work will emphasize continuation of these projects until the November meeting.

Mahmoud Youssef summarized the work performed with UW and INEEL comparing the waste volume and hazard for LW and conventional SW concepts. In both cases Li is the breeder/coolant and V is the structural material. Peak wall loadings of 5 and 10 MW/m^2 are used in the conventional and LW blankets, respectively. Two options were considered to get the high wall load for the LW. In one option, the plasma and FW radii are fixed with fusion power doubled. In the other option, the fusion power is fixed and radii reduced. A small structure content (2%) is used in the thick LW blanket. The same VV and magnet shielding requirements were used in the different designs. The lifetime of each component, and hence the required number of replacements, was estimated based on reaching the same damage limit. The LW option with Fixed Radii generates total waste that is ~10% less than the conventional option for comparable machine size and twice as much thermal power. The FW/B waste volume of the conventional option is ~4 times larger than LW fixed radii option. Total structure waste volume/GWth in the conventional option is ~ 2.14 larger than in both LW options. Total structure waste volume/GWth of the conventional FW/B is larger than the blanket waste in both LW options by nearly a factor of seven. All components are classified as LLW. Activity and decay heat values in the FW/blanket zone are much higher in the conventional blanket option resulting in safety improvement for LW. The impact of using Flibe in the LW with better shielding performance will be assessed.