Attachment
List of Questions for Discussions at the APEX Meeting
May 10-12, 2000

1. Is there any innovative "Chamber Technology" concept or idea not being considered in APEX now that should be included in the APEX workshop (this year or next year)?

APEX team will explore lower power density (handling wall loading < 10 MW/m2) concepts if they provide dramatic improvement in efficiency or other parameters. This is based on S. Malang's suggestion that the figure of merit for attractiveness is proportional to the product of wall loading, energy multiplication, efficiency, and availability.

2. Do we have enough information to make a judgement on flibe as one of the liquid wall candidates? What conditions must exist for flibe to be successful as a LW?

   Examples of Possibilities
   a) Negative evaluation of flibe potential: eliminate flibe as a candidate
   b) There are good reasons to continue flibe at the current level
   c) Put flibe design exploration on hold but continue the two areas related to major uncertainties: plasma edge modeling and free-surface heat transfer

   Examples of favorable conditions?
   - Low recycling divertor required
   - edge plasma heating required
   - hot x-ray spectrum required
   - destruction of thermal boundary layer required
   - etc.

Option c) is adopted. Design exploration with Flibe is put on hold due to the narrow operating temperature window. No further engineering design effort would be spent on concepts with Flibe liquid wall. However, work will continue on items that impact the Flibe maximum allowable surface temperature. That includes vapor pressure measurement, modeling of plasma-liquid surface interaction, and free-surface heat transfer. The design work done on the CLIFF-Flibe concept will be documented this summer by the Task III group.

3. Given the limited resources in APEX, should we continue research exploration of both thin and thick liquid wall ideas?

   Examples of Possibilities
   a) For the near-term, focus only on THIN Liquid (CLIFF-Type) concepts.
      Possible Reasons: This is what is needed for near term plasma devices.
      Experience from thin liquid (if successful) will be a major input to thick liquid

research. Most of the benefits (except substantial neutron attenuation) are realized by thin liquids.

b) Continue both thin and thick liquid concepts (current situation).
c) Focus primarily on thin LW but keep some areas relevant to thick LW (e.g. waste management).
d) Focus on thin LW for tokamaks but keep thick liquid exploration for alternate confinement concepts plus limited areas (e.g. waste management).

Action c) and d) above were adopted. On a later stage, the findings from the thin liquid research in the near-term will benefit thick liquid concept exploration. Effort however will continue in exploring areas relevant to thick wall concepts which includes applicability in other confinement scheme, waste management and clearing issues, penetration issues and neutronics (attenuation, streaming through penetrations, back-walls lifetime and activation).

4. Do we need to address the stabilizing shell requirement in APEX? For the thin flibe liquid, is there anything about the stabilizing shell that is different from what has already been addressed in design studies? (When we move to liquid metals, the stabilizing effects will need to be considered.)

Yes. The stabilizing shell requirement in APEX needs to be addressed. In addition, the impact on plasma startup due to a conducting shell should be further studied. The presence of a conducting liquid wall near the plasma forms a situation different from previous solid wall designs. Participants emphasized the importance of coupling results from free-surface MHD codes with results from MHD codes used for the plasma stabilization (e.g. plasma simulation and modeling code TSC). This effort should be pursed. ARIES-AT was suggested to be a reference design for comparative purpose. Kink mode stabilization (direct effect) and plasma elongation (indirect effect) are best achieved by keeping stabilizing shell as close as possible to the plasma.

5. We need to hear (briefly) on the status of two items in the scope of work but not on the agenda:
   A) Assessment of impact of LW on waste management (McCarthy/Sawan/Youssef)
   B) Exploration of Liquid Wall in alternate confinement concepts, FRC and RFP (Moir). Do we need to increase the effort in this area?

A) This effort is currently in progress and preliminary results will be discussed in the next electronic meeting (August 15).

B) At present, the effort in this area is limited. The alternate confinement concepts encompass many concepts such as Stellarator, RFP, FRC, spheromak, etc. The work done so far in exploring liquid wall concept in FRC was pursued because this confinement concept is most adaptable to thick-liquid concept. It was pointed out by Morley (Task II) that modeling for thick-liquid wall can be extended to include FRC's. There was a concern that it is difficult to explore using LW in several of these concepts because of current physics and configuration uncertainties. It was agreed to

form a group (Kaita, Kotschenreuther, Clement, Morley, Ying, Moir, and Wooley) to decide on which alternate confinement concept to examine within the context of liquid-wall concept in the next year. The committee should give their recommendation in the next E-meeting.

Task-Specific Questions

Task I

6. Should we consider other plasma devices besides NSTX?

Yes. Other plasma devices can be considered in task I in addition to NSTX. Possible devices include C-mod and D-III-D. However, it is argued that a working group should be formed within the institute to facilitate the execution including identification of the issues and layout of the schedule. In addition, APEX plan to visit and discuss with these institutions to convey interest and benefits of implementation of flowing liquid wall in these devices.

7. What are the main findings on exploring LW experiments on NSTX?

Various possibilities and options for liquid wall in NSTX are being carefully studied. Key issues in each possible option are explored. For example, the questions of CHI and diagnostics are being addressed for the liquid wall in the center stack. Implementation of a liquid divertor is one of the initial objectives. There was a question raised about the NSTX schedule and whether CHI was in the plan at all.

Progress made so far is listed below:

(a) To assist in the characterization of NSTX operating conditions, predicted NSTX high beta equilibrium and magnetic field components have been provided by PPPL to UCLA for determining an operating window for non-insulated lithium flow. Information on the design and heat loads for NSTX plasma facing components has also been supplied.

(b) For LMMHD facility set up at UCLA, a power supply was sent by PPPL to UCLA. Reports were also prepared on possibilities with TARA field coils, LN2 enhancement of coil performance, and LMMHD toroidal facility forces and torque.

(c) To identify key issues and development of an R&D plan for implementing Flowing liquid walls (FLW) in NSTX, a draft systems requirements document was prepared to describe issues which need to be addressed if NSTX decides to implement FLW. The integration of CDX-U project and other ALPS/APEX programs for concept development to explore NSTX liquid wall issues has also begun.

8. Can lithium flows be handled safely in plasma physics devices? Will the physicists accept the risk?

For the development of environmentally safe liquid wall systems, handling procedures and accident prevention techniques, failure mode analysis for liquid lithium use in CDX-U will address concerns (loss of vacuum, constraints on in-vessel cooling, etc.) common to ST's and other magnetic confinement devices. This work is now in progress.

9. Are there more issues to be addressed next year?

Develop and provide liquid wall technology systems that satisfy a set of operational conditions before installation in NSTX. NSTX could become a device to implement FLW capabilities that satisfy the operational conditions and contribute to the 10-year objective identified by FESAC of demonstrating spherical torus attractiveness over long pulse duration. The technical and programmatic issues that need resolution prior to implementation of FLW capabilities in NSTX are beginning to be addressed in new experiments. Other plasma devices can be considered in task I in addition to NSTX. Possible devices include C-mod and D-III-D.

It was recommended to begin with resolving issues pertaining to flowing liquid in the divertor through experiments on CDX-U and also focus next year on plasma control and instability control issues.

Task II

10. Is the scope of work in Task II (design exploration, scientific issue, modeling experiments, etc.) too much to cover with current resources? How to reduce the scope of work for next year?

Possibilities

a) The answer to Questions 2 and 3 are important. If the focus is only on thin liquid for now this reduces the scope. Also if flibe is put on hold, then the scope will be focused enough
b) Move the design exploration to another Task (e.g. to Task III). Keep the task focused only on scientific issues and necessary tools (modeling and experiments).
c) Others?

The answers to questions 2 and 3 above result in focusing the scope of Task II. The focus will be only on thin liquid. However, effort will continue in exploring areas relevant to thick wall concepts which includes applicability in other confinement schemes, waste management and clearing issues, penetration issues, and neutronics. Work on Flibe in Task II will be focused on understanding in more detail the surface heat transfer and edge plasma transport of Flibe systems.

11. What is the impact of the decision on flibe (answer to Question 2) on FLiHy experiment?

The FLiHy experiment is the subject of U.S./Monbusho collaboration and it will continue as planned for exploring the hydrodynamics and heat transfer issues associated with Flibe flow. Some parameters may need to be scaled back. Nozzle studies will continue. The

experiment itself may be extended to include conducting fluids in addition to Flibe. Data collected on Flibe (temperature rise, etc.) will be valuable to this experiment.

Task III

12. Are we adequately addressing the engineering issues related to CLIFF-flibe (e.g. nozzle design, configuration, and penetration accommodation)?

Design work on Flibe will be put on hold. Continue work on other data/modeling issues for Flibe such as modeling to improve heat transfer characteristics, evaporation and vapor pressure measurements.

13. Is the design being explored capable of pumping helium?

Yes, for Flibe case, but this may change for the lithium case due to the expected low recycling of DT.

14. When do we start work on CLIFF-LM (i.e. 1-2 cm Li or SnLi)? (This summer or next year?) Also should we start by Li or Sn-Li?

This summer. Li will be studied first followed by Sn-Li. Emphases should be placed on the design of the first wall and resolving design issues arising from the FLW. Second priority is given to the blanket design details, but the blanket is a critical feature of an integrated system and must be defined to the extent necessary to configure space envelopes for piping, supports, etc.

15. What are the favored options for integrating the divertor? Will these options change for liquid metals?

Experiments planned on using FLW for the divertor in CDX-U will be valuable in helping cast light on some of the PSI issues with Li at the edge and getting some experience in introducing an open Li surface into a Tokamak. However, its pulse length and field strength are not adequate to address divertor integration issues such as heating, plumbing and pumping details that are examined in Task III. Lithium may require a reconfiguration of the pumping scheme due to the low recycling of DT.

Task IV

16. Is it time to switch the EVOLVE effort to another cooling design variation (e.g. capillary cooling in trays versus boiling)? Or do we still need to investigate the boiling Li base design further?

We need to investigate the Li boiling base design further. In addition, the transpiration cooled FW design seems to be credible concept and should receive further evaluation.

Both cooling concepts (boiling and transpiration) are on table for further evaluation before a reference concept is chosen for design.

Other issues were raised during the meeting that will require further evaluation. They are:

(a) How large a leak at the FW can be tolerated and what are the mechanisms by which this leak may occur,
(b) Identification of stress concentration locations
(c) Evaluation of structural design impact from vibration caused by boiling Li trays,
(d) Evaluation of impacts from large oscillatory bubble growth effects,
(e) Passive afterheat removal.
(f) Need to initiate/plan experiments to support cooling mechanisms that are under investigation.

17. Should we consider other advanced solid wall concepts next year in addition to or instead of EVOLVE?

Other advanced solid wall concepts will be explored. Reduction of the power density capability requirement will open the door for more solid wall concepts. Rich Mattas will lead the search for alternate advanced solid wall concepts. Recommendations will be made in the November project meeting.

18. The reliability/maintainability/availability (RMA) for designs with solid walls has been addressed in the past to the extent that we know it is a critical issue (some think it is a fatal flow), but do we know what to do about it? Is there anything that we can do in APEX to address the issue? Should we recommend to VLT and DOE to initiate a study by a group (outside APEX) from the community and non-fusion experts to address the issue? (RMA may also be an issue for liquid walls but there are not enough details yet for meaningful assessment. But RMA for liquid walls can also be addressed sequential to the solid wall RMA assessment?)

RMA is a critical issue for designs with solid walls operating at high power densities that should seriously be addressed. It is not fully covered in APEX and may require an outside group evaluation. Steve Zinkle has identified a person whose expertise could be used to assist in addressing this issue. Christopher Piaszczyk of Advanced Energy Systems (formerly Grumman Aerospace) is well versed in RMA methodology, and might provide useful guidance on the reliability/availability of different APEX concepts.

Concluding Discussion:

At the end of the Friday's morning session, there was a discussion on the LW application for fusion power development. The discussion also included the roadmap for technology development. It was emphasized to improve communication with people outside APEX to keep them informed on progress and impact of the study on fusion science and technology development for future deployment in fusion reactors.

It was planned to prepare 4 presentations (1/2 hour each) before the upcoming VLT-PAC meeting, scheduled for last week of June at ORNL, to cover broad aspects of the APEX study.

Action Items

Please review the action items listed in the Steering Committee report.