Summary of the Fifth APEX Meeting
Nov. 2-4, 1998
UCLA

Content

I. Introduction

The fifth APEX meeting was held at University of California, Los Angeles, during the period November 2-4, 1998. The objectives of the meeting were to review technical progress made since last meeting on the several concepts under investigation, discuss scientific criteria to be used in the evaluation process of these concepts, set plan for the next six month that focuses on the critical issues pertaining to each concept, and review deadlines and future direction of the study. Dr. C. Baker attended the second day of the meeting and gave a presentation on the current status of the Virtual Laboratory for Technology (VTL) and its future direction and responsibilities. The presentations given can be viewed from the APEX Web Page http://www.fusion.ucla.edu (including the VLT presentation). The meeting agenda, attendees, contact information and announcements are given in Appendices I-IV. A summary of the working sessions is given in Section II. Section III lists the action items agreed upon during the meeting.

II. Summary of Working Sessions

Summary of Session I: Status and Direction
Session Chair: Sam Berk, OFES

S. Berk (OFES) reviewed the status of several review activities. The report of the SEAB review is due to DOE by March, 1999, which will include an extensive review of all fusion energy concepts (magnetic and non-magnetic) and recommendations on the role of each concept in national fusion energy program and the adequacy of current funding for each concepts. The national Academy of Science (NAS/NRC) review report is due to DOE by December of 1999 on the opportunities and the requirements of a fusion energy sciences program, including technical requirements for fusion energy for near- to long-term. Berk described the upcoming Technology Working Group Meeting planned to be held in Snowmass, CO during July 11-23, 1999, organized by community (key person in technology: M. Abdou) in style of other Office of Science programs. This meeting will gather consensus of the fusion technology community on key scientific and technical issues for fusion energy development and associated plasma science and technology and on opportunities and potential contributions of existing and possible future facilities and programs to reduce fusion development costs and achieve attractive fusion product.

The procedures of phasing out the U.S. activities for ITER werw also discussed. About $12.2M is provided by Congress in FY 1999 to complete ITER-related activities. Following Congressional directions, US is withdrawing from all ITER design work while completing magnet and divertor cassette R&D tasks. The US secondees and visiting HT personnel are returning to home institutions. The newly structured Virtual Laboratory for Technology (VLT) was described by Berk. More detailed discussion on VLT was led by C. Baker on the second day of the meeting (see the web site.) This new activities officially started October 1, 1998, under the Direction of C. Baker and Deputy Director M. Saltmarsh. It has the vision of simulation of a traditional single-laboratory setting with central leadership and with interconnection of people and facilities through strong communication linkages, data and hardware sharing, and cross-institutional teaming to fully integrate tasks conducted at many performing institutions.

As for APEX study, the acticipated budget for FY99 ($2300K) was actually reduced to $2170K but this new budget is ~140% increase from FY98 budget ($900K). The allocations to organizations is based on task-performer-effort matrix developed at the last APEX meeting in Albuquerque. The plasma interface tasks ($180K) is currently funded under ALPS project. In related effort, Berk discussed the planning of competitive awards for APEX-related research. The special solicitaion and announcement for grant application and national lab proposals will start around February, 1999. As for the Small Business Innovative Research (SBIR) Program, similar solicitation procedures will start late this year (around December) for the same purpose of encouraging other participants in contributing to the APEX research project.

Regarding the competitive, peer-reviewed activities, Berk emphasized the importance of the APEX and ALPS team input to merit review through evaluation processes and criteria for scientific and technical merit and quality of ideas and concepts. The FY99 funding is devoted to merit review of grant applications and national laboratories proposals received *prior* to special solicitation and announcement. The FY2000 funding *after* announcement for competition will follow similar procedure, namely: proposal application, merit review, and final selection based on established criteria. In addition, Berk announced that another route for competition for new ideas and concepts for advanced technology will be followed through Small Business Innovative Research (SBIR) Program. Grant applications for this program will close around March, 1999, merit review and selection processes will be during the April-June, 1999 time frame , and funding can start around October, 1999.

The status of APEX study was presented next by M. Abdou. He announced that several new ideas already emerging among which the liquid rotation in fast moving FW jets, FRC, surface turbulence, heat transfer enhancement, low vapor pressure Li-Sn coolant, high temperature refractory alloy applications, etc. Abdou also announced that simple and effective Evaluation Criteria have been prepared by M. Sawan (UW) who now leads the Evaluation Criteria Group. Among other changes is that Dai-Kai Sze will lead the “Tritium and Liquid Coolants/Breeders Data Base” group and that the scope of the Flibe group is expanded to address Li, Flibe, Li-Sn, and other options. Other announcements made by Abdou are:

(1) Forming a new group (Led by McCarthy) that examines the issues associated with low activation goals and the role of high temperature refractory alloys in the context of APEX,
(2) The outlines of the Interim report has been developed. The reports will include 18 Chapters, including an introduction, overview, and study approach Chapters. The other Chapters cover all the concepts under investigation as well as the APEX groups (Plasma Interface, Material, Safety, Activation Consideration, Tritium, Power Conversion, and Evaluation Criteria,) findings. The report will also include a dedicated Chapter on key issues and near- and intermediate-term R&D. The lead author for each Chapter has been assigned. The deadlines of issuing the report are:

    - February 15, 1999: finalize report outline (Draft of outlines written by lead author is due by Mid january, 1999
    - June 1, 1999: Draft assembly
    - July 1, 1999: Draft report
    - July 30, 1999: Final Interim Report
    - August 15, 1999: mail report by UCLA.

(3) Submission of abstract to the upcoming ISFNT-5 is encouraged. Abstracts due January 19, 1999. Titles of abstracts and list of authors are due to M. Abdou by December 15.
(4) Next APEX meeting will be during February, 1999, either 9-12 or 16-19. Final date will be announced soon.
(5) There is a plan to hold an APEX workshop for the community to report progress, new ideas, and results of analysis and to receive feedback from the community. The date of the workshop will be after the issuance of the Interim Report (suggested dates: September 8-10, October 19-21, 1999). The final date will be announced soon.

Abdou also discussed briefly the Scientific Evaluation Process (more details is in the summary of Session VIII). The Evaluation Group will convene after the community workshop to evaluate the concepts based on information from the interim report and feedback from community. Experts from outside the APEX team might be added to the evaluation group during the concept evaluation. The APEX schedule and modified organizational chart are given in Appendix V and VI, respectively.

Several announcement were next given by M. Youssef (APEX Secretary, see Appendix IV). The APEX web site is fully operational with new design to facilitate searching and view any presentation given in previous APEX meeting. This web site is now linked to DOE home page.

Summary Session II: APPLE and EVOLVE Concepts
Session Chair: Richard Mattas

Mark Tillack described his work on modeling the particle flow dynamics for the solid breeder pebbles. The principal issues for the pebble flow are:

- Packing fraction and flow control through the exposed region (bridging, acceleration)
- Particle ejection (scattering)
- Multi-zone flows (mixing, shear flows)
- Heat transfer
- Heat exchanger optimization

The PFC2D code was used for simulating flow in APPLE. The code is available commercially, and it has been tested and applied to a wide variety of applications in soil mechanics, seismic response, mechanics of materials, and material mixing. An example problem was described. A vertical chute, 10 cm in width was modeled in 2D. A total of 10,000 individual pebbles, 1 mm in diameter were followed by the program over a period of 5s. Key observations include:

- No observed tendency for particles to be ejected.
- Tight packing is difficult to maintain in a free fall zone.
- Need to explore baffle arrangements and/or curved walls
- The code is very easy to use- scoping of new geometry and multi-layer flows will be done in the near future.
- The addition of heat transfer will be a major undertaking.

Siegfried Malang raised a question concerning the operating temperatures of the baffles in APPLE. He indicated that radiation cooling alone will not keep the baffle temperatures at a reasonable level. There is a need to address the heat transfer issue for the baffles to determine if lower temperatures can be obtained.

Rich Mattas presented the status of the EVOLVE design. Heat transfer is accomplished via Li vapor formation and transport. The operating point for the concept is 1200 C and the Li vapor velocity is ~1000 m/s. At this temperature, the size of the manifolds can be kept to a volume of <20 % of the blanket. The pressure of the Li vapor is very low at 0.035 MPa, and the estimated pressure drop is only 0.005 MPa. Materials selection at 1200 C was addressed. Important considerations at high temperatures are loss of strength, thermal creep, fatigue and crack growth, helium embrittlement, compatibility, and tritium containment. A comparison of tungsten and tantalum indicated a preference for tungsten. Finally, design code criteria for high temperature operation were reviewed. These criteria will be updated to include He embrittlement considerations and then applied to establish the operating limits of the structure. Also shown was an idea of E. Mogahed to use heat pipes behind the first breeding zone to help transport the power.

Mohamed Sawan presented the results of tritium breeding calculations for EVOLVE. The results indicate that the first breeding zone with high temperature Li vapor will achieve a TBR of 0.637 to 0.87 depending on the thickness of the zone and the choice of structure. Tungsten as the structure yielded a higher TBR than tantalum. A secondary breeding zone behind the first breeding zone is needed to increase the TBR. The overall TBR increases to 1.120 for tungsten structure and natural enrichment of Li. If the Li is enriched to ~30% ^{6}Li, then the TBR increases to ~1.28. These values reflect the coverage of the Li cups in the first breeding zone and the IB and OB coverage. Nuclear heating calculations show that ~2/3 of the power is deposited in the first breeding zone and ~1/3 is deposited in the second breeding zone. Additional neutronics issues to be addressed include nuclear heating profiles, structure damage profiles, impact of streaming between cups, VV and magnet shielding, and activation and decay heat in candidate structural materials.

Summary Session III: Liquid Wall Concepts
Session Chairs: Neil Morley and Brad Nelson

Work was reported on the current concepts for high power density liquid walls. These include the Convective Liquid Flow First Wall (CLiFF), the Gravity and Momentum Driven (GMD), the thick Electromagnetically Restrained (EMR) concepts. Presentations were also made on heat transfer issues, penetration requirements, and shielding performance. Finally, reports were presented on the work of the Flibe assessment group and on a new liquid metal, Sn-Li.

Neil Morley presented "Recent Analysis And Design Implementation For The Convective Liquid Flow First Wall (CLIFF) Concept" and an overview of its' potential and critical issues. Hydrodynamics, LM-MHD drag, effect of spatially and temporally varying fields on liquid metal surface stability, and heat transfer at the liquid surface were emphasized as critical issues. Using the results of CFD simulation of 15 ^{o} arc for CLiFF, Morley observed no large surface waves, and the surface waves due to boundary layer relaxation had wavelengths less than 3-4 mm, with similar scales compared to the FMIT and IFMIF results. CFD results also pointed that the turbulent boundary layer size was comparable (turbulent boundary layer size was ~1/3 of the film depth) to the film depth at 50 cm away from the nozzle exit. This situation suggested that the heat transfer at the liquid surface might increase due to enhancement of the turbulence in the liquid film. He also explained that the flow appeared to be stable and adhered to the back wall by centripetal acceleration. Morley emphasized the effect of MHD on the turbulent suppression and therefore the decrease in the heat transfer coefficient of the film by using previously performed experimental results. Dai Kai Sze disputed a quotation from Brannover that the change in heat transfer rate is similar to the friction factor. The enhancement of turbulence in the flow by promoting eddy formations such as wall surface modification, using obstruction on back wall surface was suggested to enhance the heat transfer at the liquid surface. The heat transfer regime for Flibe, lithium and tin-lithium were investigated for Cliff concept using 10 m/s operation velocity. Morley determined that Flibe flow regime was turbulent, lithium flow regime was laminar and the tin-lithium flow regime is at transition to turbulence region. The velocity profile of Flibe was expected to be turbulent while velocity profiles of lithium and tin-lithium was expected to be MHD-slug. Morley mentioned MHD modeling and incorporating it into a CFD/casting code (Telluride) that is currently under development at LANL. There was also a question about the pressures on conducting liquids from plasma motion.

Alice Ying presented the progress on thick liquid wall concepts. She outlined the advantages of the concept (high wall loading capability, attainability of high power densities, simplified maintenance, etc.). She also outlined the critical issues such as temperature management (keeping the liquid surface at a specific temperature), forming and maintaining the thick liquid walls with minimum pumping power requirements and plasma-liquid interface stability. She presented the required pumping power, calculated bulk temperature rise and required volumetric flow rate for different fusion reactor configurations when the Flibe is considered as a working fluid. The required pumping power and calculated temperature rise in the bulk fluid were compared for high power density ARIES-RS , ARIES-ST and FRC configurations. FRC and Aries-ST configurations required lower pumping power and resulted in higher temperature rise in the bulk fluid as compared to Aries-RS configuration. The pumping power and bulk temperature rise results for high power Aries-RS made it clear that using two coolant streams was needed to overcome this difficulty for Aries-RS. The surface temperature rise of liquid walls was also presented when tin-lithium is used as an operating fluid. Ying mentioned that tin-lithium relaxes the temperature management requirement due to its low vapor pressure but pointed out that high density counteracts this benefit if a thick liquid wall is favored.
Also, recent progress on liquid pocket design was presented. The size, curvature of the inner walls of the pockets and the outlet section (size, dimension and location in the pocket) was optimized. The results showed that the first wall surface temperature could be maintained within the maximum allowable value while achieving a high exit temperature for high power conversion efficiency and without using continuos curvature. Three-dimensional analysis and various outlet design options will also be investigated. The compatibility of Flibe and HT-9 were questioned with respect to the low thermal stress limit of HT-9. The stress distribution in the pockets and the effects of swelling need to be investigated.

Gao presented the heat transfer modeling for liquid walls when a high Prandtl number liquid (such as Flibe) is used. Laminar model solution for heat transfer using Flibe was presented and several numerical models for wavy surface and turbulence were explored. Gao compared the numerical heat transfer results with the analytical results and compared the surface temperatures and bulk temperatures for contracted and uncontracted liquid walls. The contraction of the liquid wall did not have much impact on the bulk temperature but had a great effect on the surface temperature since the contractions caused convection of heat transfer across the liquid blanket. The importance of this effect in enhancing the heat transfer for liquids with low thermal conductivity coefficients such as Flibe was mentioned. Various turbulent flow models (eddy diffusivity, K-e, etc) were explained briefly and numerical methods of boundary fitted grid method, Marker-and-Cell and VOF methods were under consideration in implementing the free surface with wavy flow for the turbulent flows.

Nelson presented considerations for heating and diagnostic penetrations. Penetrations are a significant issue for any of the liquid wall concepts, and guidance was needed as to the type, size, and locations of typical penetrations. ITER was used as a model for diagnostic and heating penetrations, since ITER is the first fusion design to integrate these features in a detailed manner. For heating, ITER has three systems that each deliver 50 MW. The only systems thought to be applicable for APEX are the ICRF and ECRF systems, and the ECRF is probably better suited. Wooley suggested that NBI could be used for startup, before the liquid walls were formed, and then shut down as the plasma reached steady state. The ICRF system would need to use a folded waveguide launcher with a power density of around 10 MW/m^2, and could operate near the top of the machine, but not completely vertical. It must also be very close to the plasma for good coupling efficiency. The ECRF system needs smaller openings, and has much more flexibility as to location, but cannot operate in the vertical orientation either. The diagnostics for proposed for ITER are very complex, with at least 40 separate systems. APEX should only need a limited set for machine protection, plasma stability and control. These diagnostics would include magnetic loops, impurity monitors, bolometers, IR cameras, neutron flux monitors, pressure gauges, RGAs, X-ray monitors and interferometers. In addition to the plasma related diagnostics are a viewing system for inspection and maintenance and component instrumentation (coolant flowrate and temperature, structure temperature, deflection, vibration, etc). Nelson recommended that the diagnostics be restricted to small openings (e.g., 20-30 mm clear holes or slots through first wall) and located in a standard location (such as near the top, in a “diagnostic cassette”). The designs must include radiation and debris protection of mirrors and windows.

Wooley presented the axisymmetric simulation of the EM restrained lithium blanket. He explained the principle of the EMR concept, where a thick blanket of lithium is flowing vertically in a toroidal device, but is forced to stay against the walls of the torus by the interaction of the toroidal field and a small poloidal current flowing in the lithium. The major issues associated with this concept are related to whether there are steady flow fields of sufficient stability for this application, and whether the flow can satisfy the power density requirements without exceeding the surface temperature limits. To investigate these problems, Wooley proposed to develop a free surface flow simulation model that includes MHD effects. The simulation code is for an axisymmetric system and is nearly complete. The code uses a novel “adaptive unstructured grid” approach defined by a list of arbitrary points that are repositioned between time steps. This approach allows very small features to be resolved. A grid geometry has been created and the code should be running soon.

Mahmoud Youssef presented the neutronics analysis related to shielding performance and magnet protection in thick liquid wall concepts. He compared the damage parameters at the V.V. and the SCM as a function of the shield thickness for two types of thick liquid FW (2cm) and Blanket (40 cm) of Flibe and Li-Sn. The shield is made of Flibe (or Li-Sn) and structural material (ferritic steel) with ratio of 40:60. Th Li-6 enrichment is natural in the case of Flibe and 90%Li-6 in the case of Li-Sn. In the case of Flibe and for 50 cm thick shield. The DPA rate is ~0.01 DPA/year (for 10 MW/m2 wall load) which is below the 200 dpa limit for the V.V. to be a lifetime component. The He-production rate in the V.V. in this case is ~0.02 appm/year (i.e. 0.6 appm after 30 years) which is below the He-appm (of 1 appm) for the V.V. to be reweldable. He showed that the DPA rate in the V.V., TF coil, and the copper stabilizer are larger in the Li-Sn case than in the Flibe case. The attenuation length for DPA rate in the V.V. for Li-Sn is ~30 cm (i.e. an order of magnitude reduction in DPA rate for every 30 cm of the shield) while it is ~20 cm in the case of Flibe (Sn-Li is not as effective as Flibe for shielding.) Youssef also showed that the TBR with Flibe is larger at natural Li-6 enrichment as compared to 90% Li-6 enrichment. This is true in the case of GMD concept where thick liquid layer is facing the plasma. The TBR with Flibe (1.21) is however low and raises a concern of achieving tritium self-sufficiency unless a separate neutron multiplier is used. The TBR with Li-Sn breeder increases rapidly with Li-6 enrichment. At 90% Li6, TBR is ~ 1.35 (better than Flibe). It appears that this breeder could offer sufficient breeding if cleverly used with structure that has less neutron absorption. The Li-Sn breeder also offer larger power multiplication factor (~1.33) as compared to natural Flibe (1.12) which could improve the thermal cycle.

Dai Kai Sze presented the status of the Flibe assessment group and reported on the meeting at ORNL. The preliminary conclusions were 1) Tritium breeding is marginal, so we must add Be to the blanket. 2) We can add Be to the Flibe to capture free fluorine and TF. 3) Adding Be will reduce all the fluorides, and thus the corrosion, but it is not known if the Be will react with F fast enough. 4) MHD has a small effect on pressure drop. He reported that ORNL has 2400 kg of Flibe. He estimates that Flibe costs somewhere between $45 and $125 per kg, while lithium costs $30-$40 per kg. The biggest concern is reduction of heat transfer in a magnetic field, since magnetic field suppresses turbulence, and heat transfer is limited to conduction only. Flibe has the big advantage of chemical compatibility compared to lithium.

Dai Kai Sze also presented an overview of Sn-Li, potentially a very attractive new material for APEX and ALPS. Sn-Li has a low vapor pressure, 0.7 torr at 1200C, and only 1 mPa at 650C. These are actually lithium partial pressures, since the partial pressure from tin is essentially zero. From a safety standpoint, Sn126 is the only long-term activation product, and the short-term activation should not be a concern. The chemical reaction kinetics of Sn-Li are low, and chemical reactivity of Sn-Li with, for example, water should be similar to Pb-Li.. However, there was some controversy over Sn-Li / water compatibility. Tritium solubility is low, but higher than Pb-Li. With respect to structural materials, Sn alone is compatible with most refractory metals up to 850C. Vanadium may be compatible to 700C. Sn-Li is compatible with Ta up to 1200C.
The group met with Jack DeVan, ORNL (retired), and he had some interesting comments. The strongest advantage Sn-Li may be that it is probably easier to develop an insulating coating for Sn-Li than for pure lithium. Nickel based alloys are probably not compatible, and Fe-based alloys may be limited to <500C. Refractory metals and SiC may be compatible, but there is a difficulty with oxygen potential with a Sn / refractory metals combination. (This raised the issue that there needed to be a source of oxygen for this problem to crop up) A natural convection test loop may generate some very useful information. The material properties appear better than Pb-Li. The thermal conductivity is better than Pb, and the volumetric specific heat is better than lithium. Proposed R&D activities were presented, and the group thought that the vapor pressure measurements should be the top priority, followed by the corrosion studies.

Mohamed Sawan presented the breeding potential of Sn-Li relative to Flibe. For Flibe, a vanadium structure has the least impact on TBR, while Ta and W have the largest impact. Flibe, with 90% 6Li and W structure had the best TBR, at about 1.2. Ta with natural Li had the lowest TBR at .39. Adding Be to the front structure can increase the TBR by 40%. The conclusion is that Flibe needs a multiplier to achieve the required TBR, and in this case natural lithium is acceptable. The TBR for 75%Sn-25%Li is better than Flibe, but the net TBR is not much better than Flibe when the structure is included. In all cases the Sn-Li is not as good as Pb-Li, even though the (n,2n) cross section is comparable for Sn and Pb. Enriching the lithium can increase the TBR, and lower Sn percentage also helps. The amount of structure affects the TBR, (less is better), but the material type has a small effect. In any event, a TBR > 1.3 can be achieved.

Kathy McCarthy made a few remarks about safety considerations of Sn-Li and Flibe, and mentioned that Be is a toxic hazard, with a limit of .002 mg per m^3. This is a very significant limit, and fairly difficult to achieve. Kathy distributed two new documents of general interest. The first is by Dave Petti, entitled “Safety and Environmental Guidance for Fusion Conceptual Design Studies”, draft 10/28/98. The second is by Lee Cadwallader, “Preliminary Assessment of Personnel Safety Issues with Flibe Coolant”, October 23, 1998.

Summary Session IV: He-Cooled Refractory Metal FW/Blanket/Divertor Concept
Session Chair: Mahmoud Youssef

This session included three presentations given by Nelson, Nygren, and Youssef on results pertaining to the He-Cooled Refractory FW/Blanket/Divertor Concept.

Nelson review He-cooled concepts proposed previously in the BCSS study (1983), in ITER project (1993) in the last evolutionary concept proposed by Wong for APEX (1998). The APEX baseline concept deals with coolant (He) at inlet and outlet T of 400 and 1100 C, respectively under 80 atm. Tungsten and Vanadium alloys are the leading candidates for the structure but other refractory alloys (T-111, TZM, Nb-1Zr, V-4Cr-4Ti) are also considered. The FW is made of formed tubes/sheet with toroidal flow. The blanket/shield is in the form of nested coolant shell in lithium bath with a toroidal flow. The major design tasks are the module segmentation, module configuration (including transition from nested shells to coolant headers), integration of piping to maximize reliability, and module fabrication concept. The major issues with this design are the resultant availability with pressure boundary containing 80 atm He at 1100 C, the fabrication and piping transitions for refractory metals, and the thermal stress/motion under APEX operating conditions. The Aries-RS configuration is used as a reference with some changes to accommodate enlarged vessel port for full sector maintenance and modified thickness distribution for blanket/structure. Nelson discussed the general availability consideration for this design, i.e., the design should be tolerant to a few failures while operation continues until next scheduled maintenance, potential problems should be predicted and prevented, and any failure that occurs must be diagnosed and corrected quickly. Helium leak to the plasma is considered the primary failure mode which is more serious than pipe rapture. Double containment for small leak will improve reliability. As for thermal stress, there is a potential for large temperature difference between the FW and blanket and large internal structure gradients. To mitigate these features, the design will let the inlet and outlet piping float relative to structure, let FW float relative to blanket and operate structure at uniform temperature. Brad presented two revision for a Strawman design in which the FW is cooled separately. In rev.1, there are 48 O.B modules and 24 I.B modules The total estimated pumping power is 118 MW. Assuming that Mean Time to Repair (MTTR) is 1 month for sector replacement (regardless of failure), the net availability is ~0.11 for a single-barrier blanket system. Assuming a factor of 10 improvement in failure rate for “guard piping”, the availability improves significantly to ~0.65. Further improvement is possible (~0.72) if all piping is double contained.

Nygren presented the current status of the design process for the concept as a co-author with Wong (was unable to attend the meeting). The tasks planned and performers/dates are as follows (tasks marked with * are critical issues):

1. Next iteration of FW/B neutronics and Thermal-hydraulics design, including FW Thickness variation (Youssef/ Wong, November 98)
2. FW/B/HHF components CAD configuration (Nelson/Wong/ Nygren, November 98)
3. Coolant routing transition zone concept (Wong/Nelson November 98)
4. CCGT design review and identification of high temperature material options* (Wong, February 99)
5. HHF components thermal/hydraulics* (Nygren, February 99)
6. HHF refractory material test plan and analysis (Nygren, February 99)
7. HHF components review and selection of reference design (e.g. porous medium versus helical tape) (Nygren/Wong, April 99)
8. FW/B/HHF loops pressure drop estimate (Wong, April 99)
9. Power conversion options (Sze/Wong April 9)9
10. Materials compatibility & irradiated properties* (Zinkle/Ghoniem April 9)9
11. FW design, 2-D and 3-D analysis* (GA August 99)
12. Identify He impurity control system* (Ulrickson August 99)
13. Tritium migration (Sze/Willms August 99)
14. Safety, decay heat, LOCA and LOFA analysis (McCarthy/Mogahed August 99)
15. Preliminary understanding and solution approach to material/coolant loop/power conversion issues* (Nygren/Wong August 99)
16. Preliminary approach on FW/plasma interaction issues* (Wong August 99)

Youssef presented the neutronics calculations for the He-cooled refractory metal FW/blanket concept for three candidate structural materials (W, TZM, Nb-1Zr) with liquid lithium as the breeding material. The local TBR saturates around 1.43 with W structure at 35% Li-6 enrichment. Using TZM and Nb-1Zr alloys resulted in ~4% and ~15% reduction in the TBR respectively. tritium breeding from Li-6(T6) is the main contributor to TBR. T6 is larger in W case than in TZM and NB-1Zr cases. T7 in TZM case is the largest among the three structural materials. The profiles of tritium production rate across the FW/blanket were also presented. Youssef showed also the heating depositionrate (HDR) profiles in the three cases. The largest HDR is at the FW with ~ 90 w/cc (wall load 10 MW/m2) in the case of W. The max. HDR in the TZM and Nb-1Zr is ~ 40 w/cc, a factor of 2.2 lower than the W case. As for the blanket (breeder) zone, the max. HDR is ~50 w/cc. Youssef also showed a comparison of performance for three breeder, namely, Li, Li-Sn, and Flibe, in terms of total power multiplication (PM) and tritium breeding ratio (TBR), as a function of Li-6 enrichment. While TBR at ~35%Li-6 for Li, it keeps rising in Flibe and Li-Sn with Li-6 enrichment. At 90% enrichment, it is ~ 1.2 (Flibe) and ~1.15 (Li-Sn). The increase in TBR with Li-6 enrichment is specific for the blanket under consideration where metallic structure proceeds the breeder which also includes heterogeneous structural zones. In the GMD thick liquid concept, TBR decreases with Li-6 enrichment where no (or very little) structure is present in the liquid layer that directly faces the plasma. The low TBR in the Li-Sn breeder is a concern, even with high Li-6 enrichment of ~90%. This is partially due to the low Li atomic densities in Li-Sn and high neutron absorption in Sn. Power multiplication PM is the largest in the Li-Sn case (PM ~1.4 at natural Li-6 enrichment). At natural Li-6 enrichment PM is ~1.22 (Li), ~1.40 (Li-Sn) and ~1.07 (Flibe). It is larger by ~15% than Li case and by ~31% than Flibe case for natural Li-6. It is larger by ~12% than Li case and by ~27% than Flibe case for 90%Li-6. Gamma heating in tungsten is enhanced in the Li-Sn case. Gamma production rate vi Sn(n,g) is noticeably large and slightly decreases with Li-6 enrichment (Li-6(n,a) and Sn(n,g) are competing reactions). The large amount of gamma production in Sn tends to increase total power multiplication through large contribution from gamma heating in the breeder and the W structure.

Summary Session V: Materials and Data Base Evaluation
Session Chair: Steve Zinkle

Two presentations were made in this session. In the first talk, Nasr Ghoniem reviewed the high temperature oxidation behavior of tungsten and molybdenum. Both of these materials form volatile oxides at elevated temperatures, and the resulting erosion of material imposes an upper temperature limit for these materials in an oxygen-containing environment (helium, Pb-Li, etc.). The rate-limiting step for the oxidation is the adsorption of oxygen atoms on the surface. Using published free energy data for oxide formation and equilibration probabilities (oxygen atom “sticking” probabilities), the onset for rapid materials loss due to oxidation was shown to be ~1200°C at an oxygen partial pressure of 0.1 apm in 50 atm He) for both Mo and W. It was noted that the high pressure He may modify (retard) the diffusion of the gaseous oxide gas away from the solid interface, which could produce a slight increase in the maximum allowable temperature. Work is in progress (by Ghoniem) to examine this effect. Kathy McCarthy noted that safety concerns associated with the formation of volatile refractory oxides are not expected to be severe, based on tungsten analyses performed during the ITER EDA.

In the second presentation, Steve Zinkle reviewed some of the available thermomechanical property information on W-(5-25%)Re alloys. The addition of rhenium to tungsten significantly improves the fabricability. Most forming operations can be performed at temperatures as low as room temperature for W-Re alloys, versus the minimum temperature of 250°C or higher that is required for pure tungsten. To date, all of the tabulated data by the APEX materials group for refractory alloys has been for recrystallized material (as opposed to the stress-relieved condition, which is customary for refractory alloys). The lower-strength recrystallized condition has been adopted as a conservative reference case for APEX in order to account for welds and possible radiation-enhanced recrystallization processes. Unfortunately, no tensile data were found for recrystallized W-Re alloys. For a given stress-relieved condition, the tensile strength of W-Re alloys appear to be comparable to that of pure W up to ~1200°C. Therefore, for APEX design purposes, the tensile properties of pure W are recommended for W-Re alloys. The thermal conductivity of W-Re alloys decreases with increasing Re content, and amounts to an ~15% reduction in W-10 Re compared to pure tungsten.

Temperature limits based on mechanical property (fracture toughness at low temperatures and creep-rupture at high temperatures) and coolant compatibility (Li, Pb-Li, Flibe, Sn-Li) considerations were also summarized for the major candidate structural materials.

Session VI: FRC Configuration
Session Chair: Robrt Woolley

Ralph Moir’s vugraphs were presented by Karani Gulec. In his proposed FRC configuration, a fusioning FRC plasma is located inside a liquid vortex cavity in a thick, swirling, helical flow of FLiBe molten salt, in turn located inside a cylindrical chamber. Outside the chamber are solenoidal magnet coils serving to form, move, and contain the FRC plasma, and also other equipment for plasma fueling and heating. The proposed configuration departs from pure axisymmetry by orienting the cylinder's axis in the horizontal direction instead of aligning it with gravity. Proposed dimensions showed the FRC plasma as 8 m long and 1 m in radius, with the surrounding FLiBe layer extending radially from 1.2 m to 2.0 m and extending axially several meters past the ends of the FRC plasma. Ralph Moir also included some additional vugraphs describing a FLiBe thick liquid wall design concept for a tokamak, using purely vertical flows inboard of the plasma and flows with a strong azimuthal component outboard of the plasma.

Karani Gulec presented some preliminary analyses of FLiBe flows for the proposed FRC configuration and for an ST low aspect ratio tokamak configuration. Although there is a minimum velocity threshold which must be exceeded to maintain the proposed horizontal vortex flow against gravity collapse, a higher velocity magnitude is needed to limit variations between the top and bottom in the liquid wall thickness. He presented a computed flow field in which variations of the liquid layer thickness due to gravity appeared acceptable; approximate FLiBe velocity magnitudes were near 10 m/s. He suggested modifications of the cylindrical chamber's cross section which would help to maintain uniform liquid layer thickness, and showed their modified computed flows. He also examined a vertically oriented version of the FRC/FLiBe configuration. Although this reorientation restores complete axisymmetry, it also causes the fluid velocity to increase in the axial direction as the fluid descends vertically. The velocity magnitude increase reduces the thickness of the liquid layer towards the bottom of the configuration and tends to increase the separation distance from the FRC plasma to the free surface of the liquid. The separation distance can be held constant by tapering the chamber's cross section to contract at the bottom, but the liquid blanket thickness would still be reduced at the bottom. A computed flow was presented for this tapered vertical orientation. For the ST tokamak geometry, an initial computed flow featured an attempt to slow down the rapidly descending liquid blanket flow by placing a small bump in the solid backing surface on the horizontal midplane. The presentation also discussed general aspects of swirling flow and commented on the absence of (and need for) data on free surface heat transfer in FLiBe in conditions appropriate for the proposed configurations.

Summary of Session VII: Plasma Interface Issues
Session Chair: Richard Mattas

T. Uchimoto described work on modeling the Bremsstrahlung radiation spectrum from the plasma. This information is being used to examine the penetration depth of the surface power deposition, which is important for determining the temperature profiles and heat transfer requirements.

Tom Rognlien present recent UEDGE results for reflux and recycling of neon (florine) and beryllium at the plasma edge. These calculations are representative of a Flibe surface at the first wall. The calculations yield values of 53 MW to the outer divertor plate with 45 MW of power radiated by neon. The level of neon that entered the core gave a Zeff of 1.47. Radial profiles of neon in various charge states were calculated. It was shown that the inclusion of an ion absorbing boundary has little effect on the radial profiles except very near the plasma-liquid interface. Recycling of ions on the liquid wall would be important of the recyling coefficient is near unity. Too much reflux/recycling may a produce wide, low Te region in front of the wall, allowing deeper penetration.

Tom Rognlien also presented a short summary for Jeff Brooks of the status of work for the ALPS/APEX Plasma Task Group. The near term goal is to define the surface temperature limits for candidate ALPS/APEX surface materials. Seven tasks have been identified.

1. Erosion/Redeposition and Sheath analysis of surface materials
2. 2-D fluid code analysis of the scrape-off layer with UEDGE coupled with 1D analysis of kinetic effects.
3. Systems code study of the benefits of Li, e.g. low recycle 300 eV edge temperature regime, reduced current drive power.
4. Coupling of core impurity transport with SOL analysis.
5. DiMES experiment using Li.
6. Atomic data coordination. Assess existing data particularly for Flibe.
7. Plasma related parameters during disruptions such as runaway electron effects.

Rich Mattas made a presentation for Ahmed Hassanein on the capabilities of models for disruption analysis and surface stability analysis. Ahmed has developed a suite of codes that can be integrated to examine a variety of off normal conditions for APEX. The next steps in performing analyses for APEX are to define the off normal conditions and to define the specific tasks to be performed.

Richard Nygren summarized the recent US-Japan Workshop on HHF Components and Plasma Surface Interactions, which took place at NIFS on October 25-28. The Japanese presented recent results for a falling pebble divertor concept, and also results of work on liquid metal flow. One interesting study is the use of a boiling liquid metal for divertor cooling. This appears to be similar to the approach used in the EVOLVE concept. Experiments have been performed on boiling heat transfer of mercury in the presence of a magnetic field. The Japanese are actively studying Flibe as a coolant/breeder, and this area is being considered for future a US-Japan collaboration.

Summary Session VIII: Evaluation Criteria and Discussion on Concepts
Session Chairs: Mohamed Abdou and Mohamed Sawan

In this session, Sawan presented the plan for APEX evaluation. The schedule for the evaluation process was presented. Upon completion of the interim report in July 1999, a community workshop will be held to obtain feedback from the community on the proposed concepts. The scientific evaluation will immediately follow this workshop. The scientific evaluation is aimed at determine if a concept can proceed into a more detailed level of analysis beyond the initial exploration phase. The community workshop was initially planned for August 1999. However, Mohamed Abdou pointed out that there will be conflicts because of the Snowmass and ISFNT-5 meetings. Moving the workshop and the evaluation towards the end of September or the beginning of October is an option to be considered.

Sawan presented the information required for the scientific evaluation. These represent the minimum information that should be included in the interim report for each concept. The scientific evaluation criteria were presented. They fall into four categories as follows:

1. Does the concept meet the minimum functional requirements?
   - Tritium breeding
   - Tritium extraction
   - Vacuum
   - Plasma exhaust
   - Power extraction
2. Does the concept have potential for improved attractiveness?
   - High power density and heat flux handling
   - High power conversion efficiency
   - High availability (low failure rate and short maintenance time)
   - High safety & environmental attributes
   - Low cost
3. What are the design margins and uncertainties?
   (e.g., in temperatures, stresses, and TBR)
4. Were major critical issues addressed and R&D needs identified?

Mohamed Abdou suggested that the 4th category be modified to address the amount of risk associated with resolving the critical issues and the time and cost associated with the identified R&D needs. Sawan indicated that members of the group will work on giving details for different areas with some quantitative requirements if possible. This will essentially involve adding detailed description of the items in the 2nd category to identify the parameters that affect the potential attractiveness for each area. This will provide guidance for the group when evaluating the concepts. A lead person will be assigned for each area.

In addition to utilizing the evaluation criteria in the scientific evaluation of the proposed concepts, Sawan pointed out that the evaluation criteria will be utilized to compare different options in the same concept (e.g., compare performance of different breeders in liquid wall concepts). Experts from outside the team might be added to the evaluation group during the concept evaluation.

Summary of Session IX: Key Issues and Plans

Chairmen: Mahmoud Youssef and Mohamed Sawan

In this session, the lead person for each concept presented the key issues and urgent R&D needs. Mohamed Abdou requested that the top two issues to be resolved in the next few months should be identified for each concept. In addition, each concept leader should address the question whether there are urgent R&D needs that have to be done soon either within the APEX project or by encouraging other programs (e.g. material program) to do it.

CLiFF (Morley):

The CliFF research plan was presented that includes the following:

- Heat transfer at unsteady surfaces (Ying)
- Laminar LM-MHD modeling (Morley)
- Modeling of spreading in FLOW3D for Flibe (Gulec)
- Thermal Hydraulics (Morley)
- Tritium and plasma edge
- Design

The first two items of the research plan were identified as the issues to be given the most attention in the next few months.

The immediate R&D needs were identified as:

- Develop free surface heat transfer experiment
- Develop benchmark experiment in MeGA

Comments from the group addressed the following questions:
Can we get the tritium out of Li?
Is there any fundamental reason requiring that the plasma sees a smooth rather than wavy surface? Mattas indicated that ITER allows +- 1 cm for FW and +- 1 mm in divertor.
Fluid mechanics for nozzles and fast replacement of nozzles and exposed areas (Tillack)

GMG (Ying):

The issues and key tasks to be performed over the next 4 months were presented. These are:

Heat transfer tasks (UCLA)
Hydrodynamics tasks (UCLA)
Mechanical task (Nelson)
Thermomechanical task (UCLA)
Material task (Zinkle)
Plasma interface issues (UCLA integrated with others)

During the discussion several concerns were raised about the concept with compartments. Sawan indicated that the amount structure needs to be realistically estimated to look at impact on tritium breeding. The option of using Be in the compartment walls might be addressed. There was a concern about the fast replacement of the compartments. Malang indicated that replacing the compartments separately will take half a year and we should replace everything at the same time.

After a long discussion the consensus of the group was that we should look more at the rotation rather than the compartment approach.

FRC (Gulec):

The critical issues were listed. These are:

- Friction losses might be high and the turbulence generated at the wall may become important due to helical motion and confined vortex geometry friction losses.

- Special attention will be given to design of inlet section for FRC since it affects the velocity profile in the cylindrical region.

The tasks to be performed are:
- Estimation of evaporation rate along the liquid wall, definition of on axis field profile with/without plasma, location of current in steady and pulsed coils, Bremsstrahlung radiation, and Plasma parameters.
- Effect of using Flibe with various thicknesses and reactor radii on the FRC reactor system parameters by using system code utilizing scaling laws on general FRC physics parameters.
- FRC design details, port details, manifold designs, etc.

EM restrained Thick LM blanket (Woolley):

The top two issues are:
- Is there a steady flow configuration with sufficient stability?
- Can a sufficiently low evaporation system be defined, either by 2 layer/ 2 temperature or LiSn?

Other important issues are:
- Can excessive pumping power be avoided?
- Interactions with plasma magnetics must be acceptable
- There must be a feasible scenario for plasma ignition and EMR wall generation

The R&D needs in the order of urgency are:
- Computational modeling
- LM experiments
- LM/plasma experiments

Sn-Li (Sze):

The issues and R&D needs related to assessing the potential of Sn-Li as a coolant/breeder are:
- Material preparation
- Li and Sn vapor pressure measurement
- Structural material screen tests (pot, natural convection loop)
- Tritium solubility measurement
- Thermal properties measurement
- Sputtering coefficient calculation/measurement
- Sn-Li / water and air reactivity
- Sn cross section confirmation

Sze pointed out these issues can be addressed within the APEX activities, material/safety/tritium programs, IFE interaction, and international collaboration.

Concerns about the breeding potential of Sn-Li were raised particularly if large structure content is used. Sawan showed that the local TBR increases significantly if the Li content is increased beyond 50 at.%. Mattas suggested that we look at compositions with higher Li content and investigate whether the attractive features are preserved.

APPLE (Sze):

The key issues are:
- Tritium breeding and recovery
- Requirements for lifetime structure
- Heat transfer to secondary system
- Mechanical design with possible elimination of baffles
- Penetration cooling
- Power conversion

The effort in the next few months will be concentrated on the following tasks:
- Hydrodynamics with 2D and possibly 3D modeling of the particulate flow

- Baffle cooling with possible elimination of baffles or solution of heat transfer problems for baffles
- Accommodation and cooling of penetrations

EVOLVE (Mattas):

The areas to be addressed are:

- Design layout (ORNL/FZK/All)
- Power conversion design/analysis (ORNL/UW)
- Neutronics analysis (UW)
- Liquid/vapor analysis (ANL/ORNL)
- Secondary blanket design/comparison (ANL/FZK/All)
- Structure lifetime analysis (ANL)
- MHD analysis (ANL)
- Tritium recovery (ANL)
- Safety assessment (INEEL)

Among these, two tasks were given the highest priority. These are power conversion and liquid/vapor analysis.

Mattas announced that a monthly conference call will be planned to discuss developments in analysis of the EVOLVE concept.

Plasma Modeling (Rognlien):

The major concern here is impurity contamination of the plasma core. Two issues/analyses were identified for impurity sources. These are:

1) Define limits on evaporation rate of wall liquid (Flibe, Li). Tokamaks will be initially addressed with FRC and other confinement concepts considered later.
2) High heat flux strike-point (divertor). The sputtering source will be assessed.

The R&D needs are:

1. Properties of dissociated molecules to give Tgas
2. Recycling properties of liquids (Flibe, Sn-Li, Li)
3. Sputtering coefficients- hydrogen & self-sputtering

He-Cooled Refractory Alloys HHF Concept (Nygren):

The detailed outline of tasks for FY99 from the July meeting was presented. Three high priority issues were identified to be addressed in the next few months. These are:

1) Compatibility: Oxygen in V/W system
    a. Oxygen source term and passivation of V
    b. Helium cleanup in bimetallic system

    Primary task: Credible O-management scheme
2) Piping design: Simplify
    a. Reexamine reliability data (APT info)
    b. Limit secondary containment if possible
    c. Reduce number of pipes and welds
    d. Identify feasible W-V transition
3) FW heat management: Thermal stresses
    a. Heat transfer analysis (stress/constraint)
    b. Fabrication (credible path)

Mechanical Design Group (Nelson):

The mechanical design group will assist the varius concept groups with mechanical design including 3-D layouts, maintenance approach, fabrication ideas, etc. The designs will be based on the ARIES-RS, generic FRC, and ST configurations. The group will use the ARIES-RS configuration for analysis of the GMD, CliFF, EM restrained, He cooled, and EVOLVE concepts. The FRC and ST configurations will be used for the rotating thick liquid breeder without structure and the ST configuration will be used for the APPLE concept.

Materials Group (Zinkle):

The key issues to be addressed by the materials group are:

1) Chemical compatibility of structural materials with coolants (He, Li, Pb-Li, Sn-Li, Flibe)
   - Will complete analysis of temperature limits (5 μm/yr erosion) and prepare written report by 5/99.
   - Additional experimental data are needed for several cases (e.g. Flibe/V, Sn-Li/V, Sn-Li/Ta, Flibe/Ta, etc.). It is not clear where resources will come from.
2) Need experimental data on radiation embrittlement of refractory alloys at high temperatures (focus on 500-800 C)
   - Will document all known published studies on mechanical properties of irradiated refractory alloys by 5/99.
   - Further work is needed to develop the design methodology for brittle structural materials
   - Consider possibility of a few focussed irradiation studies. Need prioritized materials.
3) Transition joints between dissimilar materials (e.g. V/W)
   - Summarize possible joining methods for high temperature dissimilar materials by 5/99.
   - Make recommendations for prioritized experimental studies.
4) Providing input on fabrication of refractory alloys (Mo,W) as requested

Safety Group (McCarthy):

The issues to be addressed in the next 6 months are:

1) Generate Sv/TBq tables for relevant materials using MACCS
2) Complete parametric study of decay heat/mobilization
3) Continue investigation of failure rate issues
4) Prepare for TZM mobilization tests
5) Continue working on Flibe white paper (safety issues, test preparations)
6) Look into Sn-Li safety issues (activation, effect on disruptions, chemical reactivity with air and water)
7) Begin preliminary safety assessments as designs are ready
8) Complete white paper on safety and environment guidelines
9) Continue preparation for analysis of LM/liquid systems

After the presentations of plans from each group leader, Charlie Baker presented the current status of the newly structured Virtual laboratory for Technology (VTL). The activity of the newly structured body officially started October 1, 1998, under the Direction of C. Baker and Deputy Director M. Saltmarsh. It has the vision of simulation of a traditional single-laboratory setting with central leadership and with interconnection of people and facilities through strong communication linkages, data and hardware sharing, and cross-institutional teaming to fully integrate tasks conducted at many performing institutions (see the web site for details).

III: Action Items

(1) M. Sawan (UW) now leads the Evaluation Criteria Group.
(2) Dai-Kai Sze will lead the "Tritium and Liquid Coolants/Breeders Data Base" group and that the scope of the Flibe group is expanded to address Li, Flibe, Li-Sn, and other options.
(3) Forming a new group (Led by McCarthy) that examines the issues associated with low activation goals and the role of high temperature refractory alloys in the context of APEX,
(4) The outlines of the Interim report has been developed. The reports will include 18 Chapters, including an introduction, overview, and study approach Chapters. The other Chapters cover all the concepts under investigation as well as the APEX groups (Plasma Interface, Material, Safety, Activation Consideration, Tritium, Power Conversion, and Evaluation Criteria,) findings. The report will also include a dedicated Chapter on key issues and near- and intermediate-term R&D. The lead author for each Chapter has been assigned. The deadlines of issuing the report are:
    - February 15, 1999: finalize report outline (Draft of outlines written by lead author is due by Mid January, 1999
    - June 1, 1999: Draft assembly
    - July 1, 1999: Draft report

- July 30, 1999: Final Interim Report
- August 15, 1999: mail report by UCLA.

(5) Submission of abstract to the upcoming ISFNT-5 is encouraged. Abstracts due January 19, 1999. Titles of abstracts and list of authors are due to M. Abdou by December 15.

(6) Next APEX meeting will be during February, 1999, either 9-12 or 16-19. Final date will be announced soon.

(7) There is a plan to hold an APEX workshop for the community to report progress, new ideas, and results of analysis and to receive feedback from the community. The date of the workshop will be after the issuance of the Interim Report (suggested dates: September 8-10, October 19-21, 1999). The final date will be announced soon.

(8) The Evaluation Group will convene after the community workshop to evaluate the concepts based on information from the interim report and feedback from community. Experts from outside the APEX team might be added to the evaluation group during the concept evaluation.

(9) The APEX schedule and modified organizational chart are given in Appendix V and VI, respectively.

(10) Conference calls are to be established for each concept at least once a month.

(11) Project conference calls will also be established. The first project conference call is scheduled after Thanksgiving (between December 5-10). Final date will be announced soon.

Appendix I
Agenda for APEX Study Meeting
University Of California-Los Angeles
Faculty Center, California Room

November 2-4, 1998

Monday, November 2

8:30 a.m.	Coffee/Muffins	
Session I: Study Status and Direction (Chair: Sam Berk)		
9:00 a.m.	OFES Remarks	Berk
9:15 a.m.	Status	Abdou
9:50 a.m.	Secretary's Announcements	Youssef
Session II: APPLE and EVOLVE Concepts (Chair: Richard Mattas)		
10:00 a.m.	APPLE Concept:	
	• Progress	Sze
	• Particulate Flow Dynamics	Tillack
	• Configuration and Engineering	Igor
11:00 a.m.	EVOLVE Concept:	
	• Status of EVOLVE	Mattas/Malang
	• Neutronics of EVOLVE	Sawan
12:00 noon	Group Discussion	
12:30 p.m.	Lunch	
Session III: Liquid Wall Concepts (Chairs: Neil Morley and Brad Nelson)		
1:30 p.m.	Recent Analysis and Design Implementation for the Convective Liquid Flow First Wall (CLiFF) Concept	Morley
1:50 p.m.	Progress on the GMD Thick Liquid Wall Design for Advanced Tokamak Configuration	Ying
2:20 p.m.	Heat Transfer Issues for Liquid FW Concepts:	Gao/Ying
	• Turbulent Heat Transfer Enhancement	
	• Impact of Temperature Distribution on Flow Stability	
2:40 p.m.	Mechanical Design for Piping and Penetrations in Liquid Concepts	Nelson
3:10 p.m.	Coffee Break	
3:25 p.m.	Axisymmetric Simulation of EM Restrained Lithium Blankets	Woolley
3:55 p.m.	Shield Performance and Magnet Protection in Thick Liquid Wall Concepts	Youssef
4:10 p.m.	Summary of the Flibe Assessment Group and Report on the ORNL Flibe Meeting	Sze
5:00 p.m.	Sn-Li, A Coolant/Breeder Material Developed for APEX/ALPS Applications	Sze
	• Breeding Potential Relative to Other Liquid Breeder	Sawan
	• Safety Issues Of Li-Sn and Flibe	McCarthy
5:50 p.m.	Group Discussion	
6:15 p.m.	Adjourn	

Tuesday, November 3

8:00 a.m.	Coffee/Muffins	
Session IV: He-Cooled Refractory Metal FW/Blanket/Divertor Concept (Chair: Mahmoud Youssef)		
8:30 a.m.	The Helium-Refractory First Wall Blanket CAD	Nelson
8:50 a.m.	Design Model for Dual Channel He Cooled Heat Sink	Nygren
9:05 a.m.	Profiles of Heating Rates and Damage in the He-Cooled Refractory Metals Concept	Youssef
Session V: Materials and Data Base Evaluation (Chair: Steve Zinkle)		
9:15 a.m.	Updated Data on Corrosion of Structural Materials (including volatile oxidation of Mo, W, oxygen partial pressure vs. temperature limits)	Ghoniem

9:40 a.m.	Thermomechanical Properties of W-Re Alloys	Zinkle
10:05 a.m.	Coffee Break	

Session VI: FRC Configuration (Chair: Robert Woolley)

10:20 a.m.	FRC Design Status	Gulec/Moir/ Santarus
10:30 a.m.	Liquid Blanket Configurations for FRC	Gulec
11:20 a.m.	Group Discussion	

Session VII: Plasma Interface Issues (Chair: Richard Mattas)

11:30 a.m.	Bremsstrahlung Radiation Spectrum	Uchimoto
11:50 a.m.	Impurity Ion Penetration into the Edge Plasma Region	Rognlien
12:20 p.m.	Lunch	
1:30 p.m.	Summary of Work of ALPS/APEX Plasma Modeling Group	Rognlien/Brooks
2:00 p.m.	Disruption/Surface Stability	Hassanein
2:20 p.m.	Summary of Japanese Activities on Liquid Metal Studies	Nygren
2:50 p.m.	Group Discussion	
3:15 p.m.	Coffee Break	

Session VIII: Evaluation Criteria and Discussion on Concepts (Chairs: M. Abdou and M. Sawan)

3:30 p.m.	Evaluation Criteria	Sawan
3:45 p.m.	Discussion on Evaluation Criteria	
4:15 p.m.	Discussion by Participants on all Concepts and Options for Concepts (Key Issues, suggestions, etc. from APEX team point of view)	
6:00 p.m.	Adjourn	

Evening: Group may wish to meet for dinner. Wendy can help with reservations.

Wednesday, November 4

8:00 a.m.	Coffee/Muffins	

Session IX: Key Issues and Plans (Chairs: Mahmoud Youssef and Mohamed Sawan)

8:30 a.m.	Each speaker is to summarize key technical issues, planned tasks (what will be done and who will do it) for the next 6 months, and schedule other open technical and management issues.	
	CLIFF (15 min)	Morley
	GMD and FRC (15 min)	Ying/Gulec
	APPLE (15 min)	Sze
	EVOLVE (15 min)	Mattas/Malang
	He-cooled Refractory (15 min)	Nygren
	Mechanical Design (15 min)	Nelson
	Materials (10 min)	Zinkle
	Safety (10 min)	McCarthy
	Plasma Disruption (10 min)	Hassanein
10:30 a.m.	Coffee Break	
10:45 a.m.	Virtual Laboratory for Technology	Baker

Session X: Study Direction (Session Chair: Mohamed Abdou)

11:00 a.m.

- Comments and Suggestions on Future Directions
- Interim Report Outline and Schedule
- Solicitation of New Ideas
- Competitive Proposals Process
- Next Meeting Plans
- Plans for US-Japan Workshops

12:30 p.m. Adjourn

Appendix II

ATTENDEES

Mohamed Abdou (UCLA)
Charles Baker (UCSD)
Sam Berk (Monitor, OFES)
Ralph J. Carbone (TSI)
Mohamad Dagher (UCLA)
Brent Freeze (UCLA)
Nasr Ghoniem (UCLA)
Karani Gulec (UCLA)
Dong-Hong Guo (UCLA)
Siegfried Malang (FZK)
Rich Mattas (ANL)
Kathy McCarthy (INEL)
Neil Morley (UCLA)
Evgeni Muravier (ITER)
Brad Nelson (ORNL)
Richard Nygren (SNL)
Tom Rognlien (LLNL)
Mohamed Sawan (U.WIS)
Sergey Smolentsev (UCLA)
Dai-Kai Sze (ANL)
Mark Tillack (UCSD)
Tetsuya Uchimoto (UCLA)
Scott Willms (LANL)
Robert Woolley (PPPL)
Alice Ying (UCLA)
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Appendix III

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Appendix IV

SECRETARY'S ANNOUNCEMENTS
APEX 5th Meeting
UCLA, November 2-4, 1998

SUMMARY OF LAST MEETING

- Distributed to participants. Summaries from Session Chairs arrived late to UCLA.

- We need to have the summary ready for distribution at most 1 week after the conclusion of this meeting. Please, if you are assigned as a Session Chair, provide Secretary with your summary within this time frame. (preferably, you can finish the summary before you leave UCLA). Let Secretary knows if you can't meet this deadline.

APEX WEB SITE:

  - Fully operational with new design to facilitate access to presentations Please visit frequently for updates. *(*http://www.fusion.ucla.edu*)*

  - The web site is now linked to DOE web site. Thanks to Al Opdenaker

- Please provide Secretary with copy of your presentation before you leave UCLA. On the other hand, forward electronically your presentation in pdf form or postscript form. This way we can post your presentation on the web site as soon as possible.
  -

ACTION ITEMS FROM LAST MEETING (ATTACHED)

APEX Secretary
M. Youssef, November 2, 1998

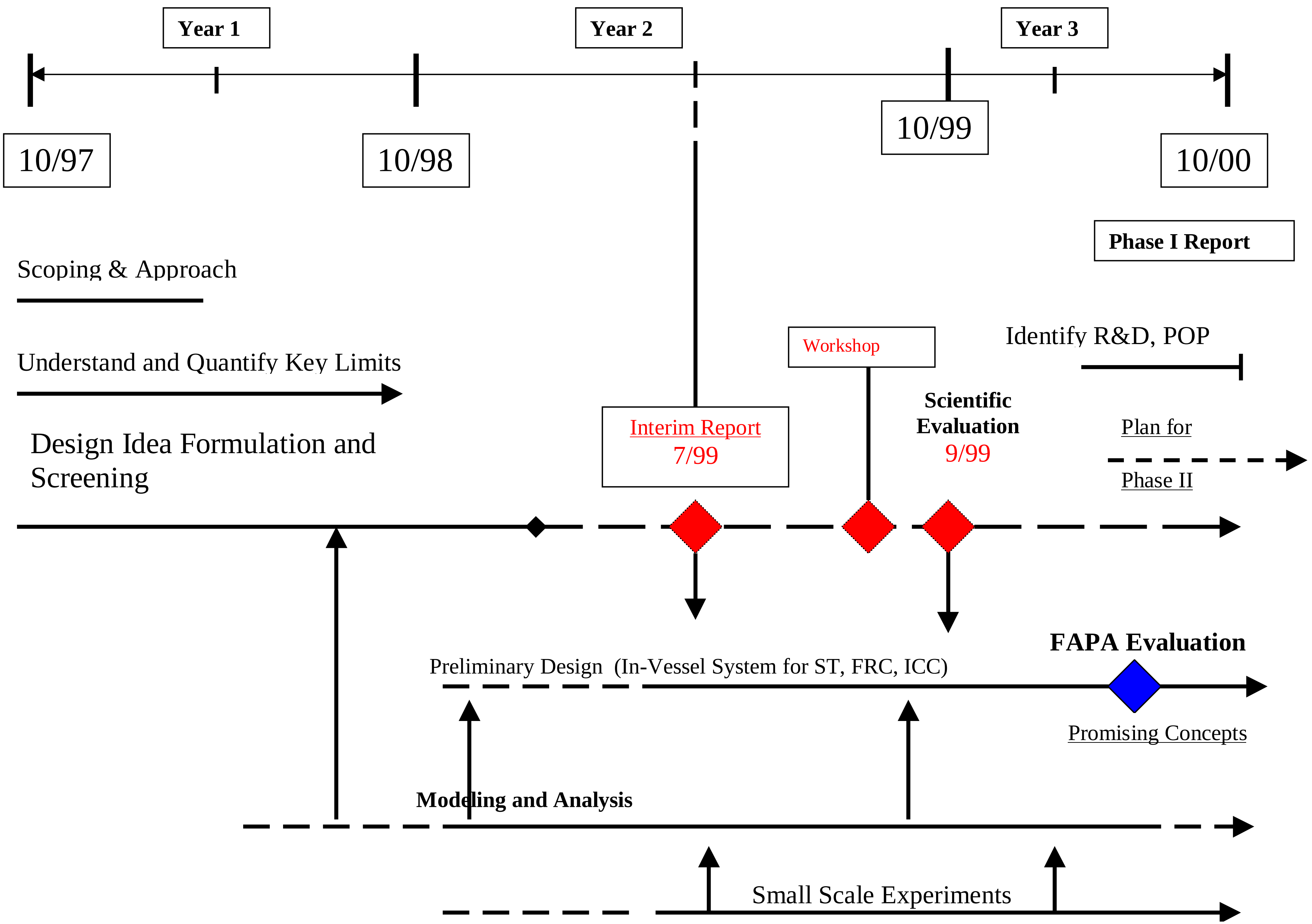
Action Items from July 27-29, 1998 APEX Meeting

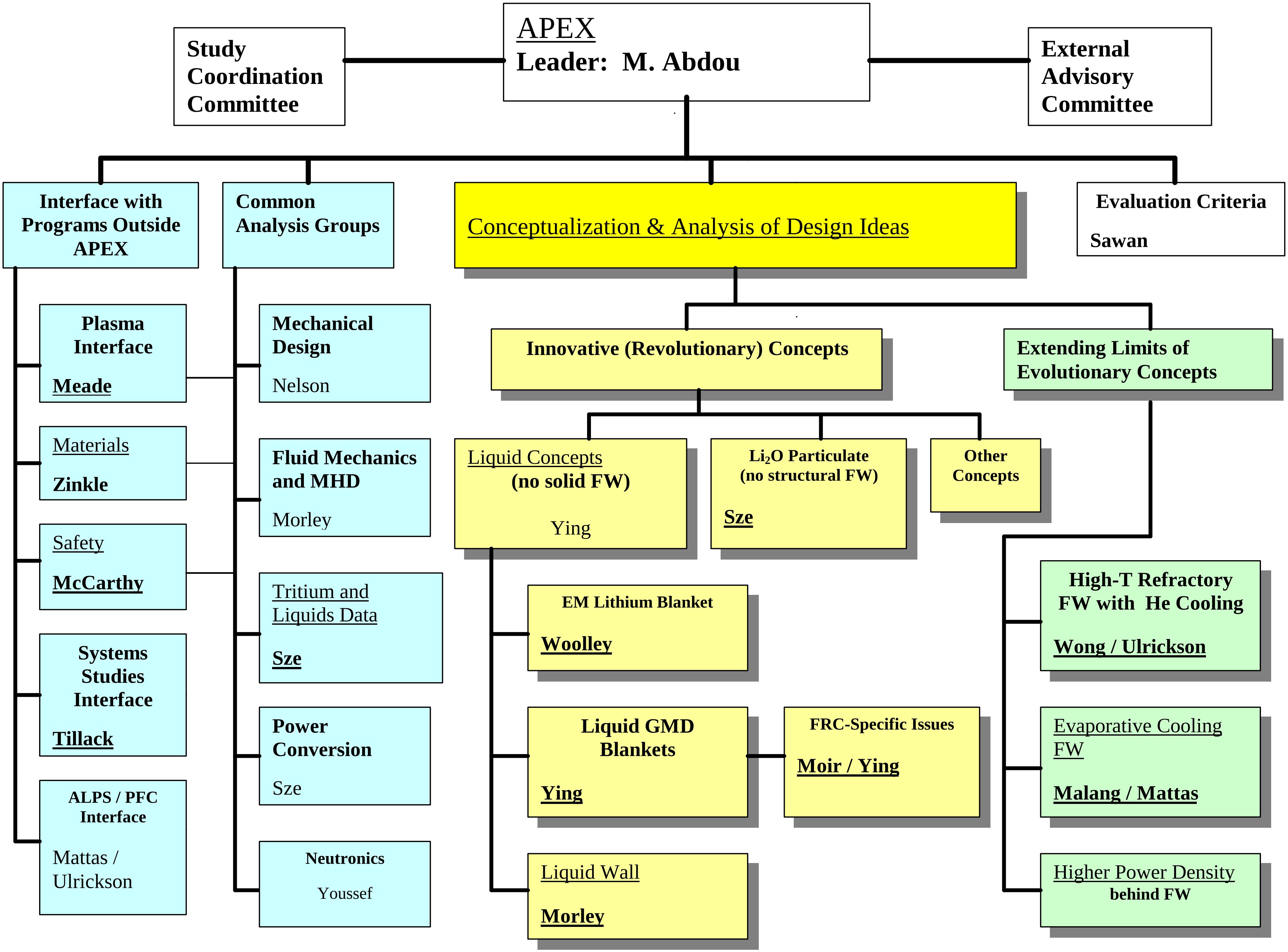
(1) The next APEX meeting will be held during the period November 2-4, 1998, at UCLA.
(2) No complete and detailed conceptual design is expected during Phase I of the APEX study but rather, effort should be focused on ideas and scientific basis for each proposed concept.
(3) The key issues for each concept be identified and added to the Basic Information needed for each concept
(4) The interim report on the scientific bases and preliminary analyses of the concepts under consideration is due March, 1999. Adequate analyses on each concept should be completed as early as of January, 1999. The Scientific Evaluation process is also scheduled March 1999.) It was raised that this date is too early. It was also suggested that the Evaluation Group include those individuals who will undertake the Scientific Evaluation. . *Abdou suggested that a community workshop could be held just after the Interim Report is issued and before the Scientific Evaluation is performed. One suggestion was to have the Interim Report out for distribution by July 1, 1999, and hold the community workshop after that date and have the Scientific Evaluation be performed by September-August, 1999. This is under discussion and will be finalized before or on the next APEX meeting.*
(5) People should be prepared to submit abstracts to the upcoming ISFNT-5 Symposium (headline July, 1999).
(6) Changing the Spray Cooling FW concept to Evaporation Cooling FW concept. This concept is now termed Name the concept "EVOLVE" (EVaporation Of Lithium and Vapor Extraction).,
(7) Abdou indicated that the current Evaluation Group should develop the criteria for the Scientific Evaluation. *He suggested that we start developing these criteria and send them to people for comments. He specifically indicated that the Scientific Evaluation should be based on:*
(8) Potential of the concept in
(9) *handling high power density,*
(10) *having high power conversion efficiency*
 (a) *Potential of concept with regard to (a) failure rate, (b) maintainability,*
 (b) *Defining the design margin for each concept,*
 (c) *Defining major technical issues and uncertainties.*
(11) Extensive failure analysis is not needed at this point but rather a qualitative guideline to mitigate failure is needed. Abdou suggested that INEL to help in developing these guidelines.
(12) Add start-up as an issue under hydrodynamics issues
(13) We should look into how the FW liquid responds to plasma changes and instabilities.
(14) Analysis of dynamics and heat transfer properties of particulate flow in a vacuum and in heat exchangers should be emphasized in the Li2O particulate concept (couple of pages on this is needed – Mark will get a code that deal with this issue).
(15) Dust generation from particulate and distribution is an issue that should be added to the Li2O particulate concept.
(16) For the Materials Group, the following was decided:
(17) Add fracture toughness to the list of issues
(18) Add effect of transmutation on material properties
(19) Include SS304 to material data bases
(20) Add property data base for a preferred W allot
(21) Look into making cost prediction based on "typical blanket" rather than $/kg
(22) Add costs of coolants to database.

(23) We need a reference FRC design. APEX will not develop a design. We have little funds to get from the FRC community a reference design (Abdou).
(24) The level of effort and task distribution by organization shown in Table I and II (see also Appendix IX) received acceptance from the APEX study participants. However, it was emphasized that some changes in tasks/resources may take place subjected to the final funding level to the APEX study.

APPENDIX V

APEX Schedule and Milestones for Phase I





Study Coordination Committee
APEX
Leader: M. Abdou
External Advisory Committee
Interface with Programs Outside APEX
Common Analysis Groups
Conceptualization & Analysis of Design Ideas
Evaluation Criteria
Sawan
Plasma Interface
Meade
Materials
Zinkle
Safety
McCarthy
Systems Studies Interface
Tillack
ALPS / PFC Interface
Mattas / Ulrickson
Mechanical Design
Nelson
Fluid Mechanics and MHD
Morley
Tritium and Liquids Data
Sze
Power Conversion
Sze
Neutronics
Youssef
Innovative (Revolutionary) Concepts
Extending Limits of Evolutionary Concepts
Liquid Concepts
(no solid FW)
Ying
Li_2O Particulate
(no structural FW)
Sze
Other Concepts
EM Lithium Blanket
Woolley
Liquid GMD Blankets
Ying
FRC-Specific Issues
Moir / Ying
Liquid Wall
Morley
High-T Refractory FW with He Cooling
Wong / Ulrickson
Evaporative Cooling FW
Malang / Mattas
Higher Power Density behind FW