Summary of the Kick-Off Meeting of the APEX Study
October 15-17, 1997
UCLA

I. Introduction

The first meeting on APEX research study was held at UCLA during the period October 15 - 17, 1997. This kick-off meeting was attended by the Planning Group of this multi-organization study to discuss the near- and long-term objectives of the study and set the most effective paths to achieve these objectives. The ultimate long-term goal is to make significant contributions to making fusion energy more competitive through exploring and developing more attractive concepts for Fusion Power Technology (FPT). The near-term objective of the study is to explore new (and possibly revolutionary) concepts that can provide the capability of efficiently extract heat from systems with high neutron and surface heat loads while satisfying all the FPT functional requirements and maximizing reliability, safety and environmental attractiveness. During the meeting, several concepts were discussed that have the potential of high density power removal. The study is open for other revolutionary concepts that are anticipated to be developed during the course of the study.

The Agenda of the meeting is given in Appendix I. The list of the Planning Group members and attendees is given in Appendix II. Summary of the presentations and discussions that took place during the meeting is given in Section II. Section III lists the action items that were developed during the meeting. It was agreed that the next meeting will be held at UCLA during the period January 12-14, 1998.

II. Summary of Presentations and Discussions:

II.1 Summary of Session I:
Study Scope and Objectives
(Chairperson: Sam Berk)

OFES vision of the APEX study was outlined by Sam Berk. The study is led by UCLA with participation from other organizations. He indicated that the study consists of three phases, namely, the Planning Phase (~4 months), the Evaluation and Supporting R&D Phase (~ 3 years), and the R & D Phase that begins after the Evaluation Phase (beginning FY 2001). He pointed out that the funding for the next year depends on the outcomes from the activities this year. OFES sent an official letter of charge to Mohamed Abdou asking him to lead the APEX study.

Mohamed Abdou discussed in details the motivation, scope and the preliminary approach of the APEX study. The long- and near-term objectives of the study mentioned above were emphasized. He indicated that the initial driver of the APEX study is to develop a concept that has the capability for a high neutron wall load and associated surface heat flux. This stems from the fact that, as currently stands, the average core power density in present fusion reactors design is much lower than that in fission rectors

(~0.4 MW/m3 in ITER for example vs. ~ 240 MW/m3 in LMFBR). The proposed concepts must satisfy the functional requirements of FPT, namely, (1) provision of vacuum environment, (2) exhaust of plasma burn products, (3) power extraction from plasma particles and radiation, (4) power extraction from energy deposition of neutrons and secondary gamma rays, (5) tritium breeding at he rate required to satisfy tritium self-sufficiency, (6) tritium extraction and processing, and (7) radiation protection. However, he indicated that, in developing the concept(s), one should not overconstrain the problem from the beginning. Success in finding high power density concepts will be followed by working later on making these concepts better for other issues. The other most challenging issues, he indicated, are reducing components' failure rate (increasing MTBF), increasing plant availability (reducing MTTR), and satisfying tritium self-sufficiency requirement. Abdou gave also the list of proposed goals for neutron wall load and surface heat flux at the first wall. They are: average wall load of 5 MW/m^2, peaking factor of 1.4, peak neutron wall load of 7 MW/m^2, and leak surface heat flux of ~ 1.5 MW/m^2. He discussed the sequence of tasks to be followed during the APEX study and the formation of eight (8) project groups to undertake these tasks (the tasks and schedule are defined in Table I and the function of the project groups is given in Appendix III).

There has been group discussion during Abdou's presentation on several issues of importance. Among these issues is that the attractive economy future of any developed concept should be the primary goal of the study. This was debated by the argument that by having a concept capable of high power density removal and coupled with high availability could achieve this goal. There was also a concern that concepts based solid breeders, as they stand now, can not take 7 MW/m^2 wall load. However, it was argued that by putting effort to increase thermal conductivity could improve the situation. Another issue raised during the discussion is that some of the revolutionary concepts may not be compatible with the plasma. Also the need to define normal transient scenario in developing a concept and taking the disruption as a factor in choosing a concept was raised. It was clear during the discussion that there is a need to form a Physics Group in APEX study to address these physics issues.

After this group discussion, Mahmoud Youssef, the APEX scientific secretary presented some administrative and technical coordination procedures to follow during the APEX study. It was decided to create a web site for the study which can be accessed by participants to review the presentations and summary of each APEX meeting.

II.2 Summary of Session II: Key Limitations of Present Concepts (Chairperson: John Haines)

Session II addressed power density limits for mainline design approaches, i.e. expected limits for low activation materials using schemes that conduct the heat deposited on the first wall through its plasma facing surface to a coolant.

Mahmoud Youssef presented information on the poloidal distribution of the neutron wall loading and surface heat flux. Using results obtained in previous assessments, Youssef showed that the peak-to-average ratio of the neutron wall loading ranged from 1.34 to 1.43, thereby justifying the 1.4 value specified for the APEX study. The poloidal distribution of the surface heat flux in the ARIES-RS device presented by Youssef showed that the peak-to-average value for the surface heat flux was less than 1.1.

Anter El-Azab presented results of his assessment of the wall loading limits for the three low-activation material candidates - vanadium alloy V-15 Cr - 5 Ti, ferritic steel alloys, and SiC composites. Key assumptions included (1) a 5 mm thick plasma facing wall thickness for vanadium and ferritic steels and a 3 mm wall thickness for SiC composites, (2) a very low thermal conductivity for SiC composites (6 W/m-K), representing the expected value after a short period for irradiation, and (3) a surface heat flux that is 20% of the neutron wall loading, which is consistent with the APEX study assumption of having most of the alpha power radiated from the edge with only a small fraction conducted and convected to the divertor. Limits based on either peak temperature or thermal stresses were considered. The wall loading limits were shown to be about 2.5 MW/m^2 for ferritic steel alloys, 3.5 MW/m^2 for the vanadium alloy, and 1.6 MW/m^2 for SiC composites. El-Azab pointed out several approaches to increasing these limits including (1) the use of porous SiC structures to make the wall more compliant and infiltrate it with liquid metal to increase the thermal conductivity, (2) using flowing films to transport the heat thereby reducing the heat that must be conducted through the solid wall, or (3) using enhanced heat transfer schemes to more effectively remove the heat from the backside of the first wall.

A discussion of the key factors limiting the power density capability of current concepts was held following El-Azab's presentation. These discussions focused initially on the assumptions he used to determine these limits. Temperature limits were considered to be reasonable, although some felt that these were rather soft limits, e.g. vanadium limit could be as high as 700°C instead of 650°C. Steve Zinkle pointed out that there is a reasonable hope of producing a more radiation tolerant form of SiC composite that would have a significantly higher thermal conductivity after irradiation than that assumed in El-Azab's studies. Considerable discussion on the minimum thickness of the plasma facing surface of the first wall ensued. Although thinner walls may be possible, it was concluded that considerable effort would be required to define the details of such a design and its mechanical constraints. It was agreed that the stress criteria applied by El-Azab were reasonable and consistent with standard practice, however some argued that more aggressive criteria such as those used in the aerospace industry may be worth considering.

Rich Mattas gave a briefing on the status of the ALPS Activity. The ALPS Activity is focused on developing a liquid free-surface concept for divertor applications. The schedule outline for the ALPS activity is essentially the same as that for the APEX Activity, i.e. a three month planning phase, followed by a three year evaluation phase, and finally an R&D phase. Rich pointed out that the potential advantages of free-surface liquid systems include unlimited erosion lifetime, no neutron damage, high power density capability, active pumping of the plasma exhaust by the liquid surface, high temperature operation, and low pressure operation. The key issues and initial design concepts under consideration were also outlined. As Rich pointed out, there are several individuals involved in both the ALPS and APEX Activities, which is especially important since liquid free-surface concepts will also be considered in the APEX Activity.

Clement Wong concluded this session with a presentation on the needs for connection to the plasma physics community and a broadening of attitudes toward innovative solutions to this complex problem. He stressed that the first wall/divertor design is strongly coupled to the edge plasma, which in turn can dramatically affect the overall performance of the core plasma. He cautioned that artificially separating studies of these three elements into three different activities has led in the past to unattractive first wall and divertor design solutions or left the engineers with a set of constraints that are impossible to satisfy. Clement emphasized the importance of integrating or coupling the engineering and plasma physics efforts for the ALPS Activity.

<u>Comments by Session II Chair (John Haines)</u>

The APEX design requirements appear to be well thought out and clearly formulated and the factors limiting present concepts have been identified. However, the specific values for limits on current design schemes and materials appear to be overly pessimistic. The specified limits could potentially be doubled by developing a design with a thinner wall (2.5 mm thickness instead of 5 mm) and reducing the surface heat flux peaking factor to a more realistic value (20% effect). This would lead to a neutron wall loading limit of about 7 MW/m^2 for a vanadium first wall, which satisfies the minimum goal of the APEX project. It was confirmed that the intent of the APEX Activity is to develop "revolutionary" concepts rather than working to evolve the current concepts to meet this goal. I agree with this approach, but encourage the APEX activity to acknowledge the realistic extrapolation of current first wall concepts/materials to neutron wall loading values approaching 5-7 MW/m^2.

II.3 Summary of Session III: Preliminary Examples of High Power Density Concepts (Chairperson: Neil Morley)

During this session, several people presented concepts for blankets and FWs which, in principle, have the potential for high power density removal and power conversion. They are not given here in the order presented at the meeting, but are instead grouped into categories.

Liquid Wall Concepts

<u>Thin liquid film FW, Neil Morley, UCLA</u>

This concept utilizes a flowing liquid film on the plasma facing side of the FW to actively convect away FW surface heat and initial high intensity neutron energy deposition. The liquid is then recirculated as coolant through the blanket to heat it to efficient power conversion temperatures. The liquid jet would adhere to the surface by the centrifugal force, and its “once through” design would reduce time for large surface instabilities to develop.

All liquid surface concepts must ultimately address the issue of evaporation contaminating the core plasma. The ALPS effort headed by Dr. Rich Mattas will address this issue to a large extent, and their results will likely give APEX an indication about whether such concepts are acceptable from a plasma physics point of view. Some debate occurred during this presentation about what upper temperature limit one could assume for doing the preliminary heat transfer calculations. An absolute vapor pressure limit was rejected by the group, and instead, an evaporation rate limit must be determined. Some effort to determine such a limit has been addressed by Ralph Moir in his presentation and papers. The required flow speed for this concept will depend heavily on this limit, as well as the radiation penetration depth, thermal conductivity and mixing of the liquid flow. It seems likely that the speed required for effective heat transfer will exceed that required for inertial adhesion to the wall, but this must also be shown for each candidate liquid.

Porous FW infiltrated with high k liquid, Neil Morley, UCLA

A porous wall block infiltrated with high thermal conductivity, k, liquid would result in a reduction of the elastic modulus of the FW without degrading its thermal conductivity. The liquid provides a high k path to coolant tubes, or monoblock self-cooled liquid channels. A thin quasi-stagnant film on the surface would allow use of a relatively thin structure since the plasma contact surface would be self-healing.

Comments from the author and APEX group reflected the concern that the strength of the material would be affected, and that calculations must be performed to verify that a porous/liquid system could indeed yield a benefit in heat removal at lower stresses. There were some remarks that this type of system is proposed by Red Star in Russia, and that they have some results related to it already. Some high heat flux testing has been successfully performed in Russia on porous FW systems, but this testing utilized the vaporization of the LM as the heat transport mechanism. This is not what is proposed here.

SiC would benefit the most since currently the thermal conductivity after neutron irradiation is low, and so can be significantly improved by the presence of the liquid. In addition, the porous SiC may retain a good portion of its strength since the fiber weave will still be in place, and matrix cracking will no longer be considered a failure.

Thick liquid FWs and blankets, Ralph Moir, LLNL

Several concepts were presented that use thick flowing liquids as both FW and blanket. For a tokamak, a rotating vortex-like liquid FW/blanket is proposed. New liquid is injected concurrent with the vortex flow, and this momentum sustains the vortex. Penetrations for pumping, fueling and beams will need to have a hydrodynamic design so as not to introduce excessive drag. Other concepts using thick liquid flows for stellarators and field reverse plasma confinement are favored by Dr. Moir, due to the fact that vaporized FW material can be evacuated out on open field lines, instead of remaining in the plasma chamber were plasma core contamination can result. An alternative tokamak design with a slug flow, straight through inboard and two counter rotating outboard sections is also proposed. Flibe is the favored liquid by Dr. Moir due to the best combination of shielding, breeding, pumping and evaporation characteristics.

Like the above liquid surface concepts, a key issue is whether or not the evaporated liquid can be removed without critically contaminating the plasma. In addition, grave concerns exist about the stability of the multiply rotating flow limiting the allowable speed.

<u>Use of liquid lithium as self-protecting FW, Bob Wooley, PPPL</u>

This concept is a once-through, top to bottom, free surface liquid lithium FW, where adhesion is aided by the introduction of an electric current which interacts with the toroidal field to push the liquid against the backing wall. The liquid is assumed to flow along flux surfaces so that no surface normal components of the field exist which introduce MHD drag into the flow. Additionally, the flow is not broken into segments toroidally, which will also result in current loop closure and MHD drag. Like Dr. Moir's concept, the flow is thick enough to serve as both blanket and FW. Preliminary calculations of the required current indicate that for lithium, it is rather modest. The idea of having a twice-through system is also presented, were a hot liquid sublayer is covered by a cooler surface layer so that evaporation in the chamber can be reduced, while keeping the average temperature hot enough for energy conversion. This is similar to the first concept of this section.

In addition, a FW/blanket system of this type is proposed to couple with an MHD power conversion system inside the toroidal field coils. In this manner, the toroidal field is used for plasma confinement, liquid adhesion, and power conversion. Dr. Wooley suggests the size of the reactor will need to be increased dramatically in order for this to be feasible, and that the power output should be greater than 30 GWe. Reactors of this type could possibly be used for large scale hydrogen production, since their marketability to power producers is likely to be poor.

The group reaction seemed to be that the simple MHD calculations may not accurately reflect the realistic conditions inside a fusion reactor, and that many destabilizing forces may be present. Also, penetrations will disrupt the axisymmetry and allow for current closure through boundary layers. The complete MHD problem is a difficult one, and further calculations are needed to show that the performance will be better than a simpler centrifugally-adhered liquid flow.

Two Phase Flow Concepts

<u>Possible heat pipe applications to fusion FWs, Alice Ying, UCLA</u>

The use of heat pipe FW modules that can remove a high power density at relatively low pressures is explored. Much work has been done on heat pipes and conceptual designs exist for FWs which utilize heat pipe modules to distribute the surface heat flux over a larger portion of the bulk blanket. Heat pipes with working liquids such as sodium, lithium and potassium have the capability of operating in the >500°C temperature range, which is good from a thermal efficiency point of view.

However, the fundamental problem remains, which is how to conduct the heat through the solid FW into the coolant (in this case the heat pipe)? The heat pipe only seems to be valuable if it can operate at a low pressure, which may allow slightly thinner FWs to be used. Thus, the stress and temperature limitations might be slightly eased, and the creep phenomena reduced. Designs of corrugated FW heat pipes may also reduce the stress since the thermal expansion is somewhat accommodated by the corrugation.

Design optimization and structural material minimization will need to be explored in all cases.

Mist flow cooling, Alice Ying, UCLA

In this concept, the heat capacity of a gas flow system is enhanced by the entrainment of a liquid metal mist. The mist increases the heat capacity by its own sensible heat, but also by the evaporation of the liquid from the pipe walls, reducing the film temperature drop into the coolant. Thus for the same bulk temperature at the outlet, a gas/mist flow can remove more heat, reduce structural temperature and operate at low pressures. As above, it is possible that thinner tubes can be utilized if the gas pressure is reduced.

Mist injection systems, flow of mists around bends, and the design of the secondary heat exchangers are technology issues which must be addressed in addition to proving the concept is effective by itself.

Flowing Solid Concepts

Li_2O Particle Concept, Dai-Kai Sze, ANL

Similar to the flowing liquid concepts, this proposal involves removing the static solid FW and replacing it with a flowing bed of solid Li_2O breeder pebbles. In this way, the conduction of heat through a stagnant solid FW, and the associated thermal stresses, are eliminated, but evaporation concerns of liquids are not introduced. This concepts should improve the power removal and tritium breeding as compared to standard solid breeder designs.

Some design innovation must be introduced which guarantees the packing fraction of the falling pebbles so that adequate neutron absorption in the breeder material is attained. Also, a multi-layered approach, where the first layer is not enriched in Li_6 may need to be adopted to guard against excessive volumetric heating in the first several centimeters. Li_2O of natural enrichment must be used to obtain adequate breeding if the use of beryllium is to be avoided. Of course, handling of the pebbles both inside and outside of the vacuum chamber is an issue that still must be resolved.

Liquid Breeder Concepts

He-cooled FW/Blanket with LiPb breeder, Clement Wong, GA

This design looks similar to European solid breeder modules with the solid breeder pebbles replaced by liquid LiPb alloy. The good thermal contact between the liquid breeder and coolant/stiffener plates allows for higher neutron wall load. The FW and breeder are cooled by pressurized He flowing in vanadium tubes. The FW thickness is reduced to 2 mm in order to meet stress and temperature limits of the V-alloy structure. The design is to take 8 MW/m^2 wall load and 2 MW/m^2 surface heat flux.

A self-cooled LiPb blanket, He-cooled FW design was also recently proposed by Tillack, UCSD, and Malang, FZK, where SiC flow channel inserts are used to reduce MHD pressure drop in the blanket and provide thermal insulation and thus high LM operating temperatures. This design has a similar FW technology to the Wong concept above.

Rocket Engine Technology

Actively cooled structures for high heat flux applications, Don Clemens, Rocketdyne

The space shuttle main engine wall design is presented, where hydrogen coolant in small channels is used to cool heat fluxes up to 160 MW/m^2 at the throat of the engine. This peak flux removal is reached through a combination of special high k Cu alloys, thin walls, and low inlet temperatures. Other cooling techniques using mesh structures and transpiration cooling were also presented.

Foams for high heat flux applications, Nasr Ghoniem, UCLA

The use of metal and SiC foams for use in rocket engines was presented. The use of foams may have applications to fusion FW, like the porous wall / high k liquid concept presented above.

Conclusions by Session Chairman (N. Morley)

There is no doubt that one approach to solving the “FW problem” is to try to reduce the wall thickness to a value where a given heat flux causes stresses and temperatures that are within the limits of the material. This is evident in the presentations concerning rocket engine technology. However, concerns about creep (over a long component lifetime), surface erosion, durability, and fabricability probably limit the allowable FW thickness to something on the order of 3 mm or more, especially when highly pressurized coolants are to be used. A HPD concept with a wider design margin is desirable for APEX, especially one that minimizes failures.

All of the more radical concepts presented have significant problems that must be overcome. Liquid surfaces are especially worrisome because the evaporation may prove to be too significant, and will have a very significant negative impact on plasma operating scenarios currently envisioned. The use of a liquid surface may only be possible if radically different plasma operation scenarios are considered by the physics community. This does not necessarily mean non-tokamak options, although as Ralph Moir points out these may be more amenable geometries for liquid surface concepts. But instead plasma operation with significant cold lithium vapor in the edge and heavy H and Li pumping by liquid Li FW and divertor surfaces, for example, may need to be addressed.

However, the liquid wall concepts, of the ones discussed above, seem to have the greatest potential for both high wall load and high surface heat flux removal in fusion reactors. No other large design margin concepts are presented, except for maybe the flowing pebbles concept. So the conclusion of this section is that the APEX participants and the US fusion community at large should continue to pursue the development of new and innovative HPD FW/blanket concepts that meet (exceed) the APEX goals, while beginning to advance the more attractive liquid wall concepts already presented. One possibility that has emerged from the discussion of this session is, for instance, the creative use of foams or other "transparent" FWs that can smear out surface energy deposition (Ghoniem). Certainly there are other ideas still waiting to be discovered and developed.

II.4 Session IV Summary: How to Effectively Stimulate New Concepts (Including Materials) (Chairperson: Richard Nygren)

Steve Zinkle (ORNL) reviewed the database on materials ("Materials Selection Issues of High Wall Loading Concepts") and a general discussion on this area followed his presentation. Other materials related talks were given at the meeting by Nasr Ghoniem (UCLA), on metal foams, and by Don Clemens (Rocketdyne), on the applications of rocket engine technology.

The main topics covered by Steve Zinkle were: unirradiated thermophysical properties, radiation effects and selected issues regarding availability, fabrication and joining (e.g., large heats of V alloys have now been demonstrated). A "reference" list of possible structural materials include low activation materials (ferritic and martensitic alloys, V alloys and SiC/SiC composites); "conventional" materials (Nb-1Zr, various copper alloys, C/C composites, Cu-graphite composites, W, Ta, TiAl, etc); newly developed materials (e.g., Ti3SiC2 composites); and "innovative" materials (porous matrix metals and ceramics) that might be used where leak-tight walls are not required. Regarding low activation materials, the open question was posed, "Is limiting the materials choice to low activation materials too restrictive for APEX?"

The potential of SiC composites was questioned, and Steve indicated that recent improvements had led to "microstructural" strengths of 140 - 150 Mpa. In ranking materials based on a simple thermal stress figure-of-merit, sYKth(1-n)/aE, copper alloys ranked highest (values of 35-47) followed by Nb-1Zr (12 - helped by low modulus), F82H F/M steel (5), V-4Cr-4Ti (4) and SiC/SiC (2). Anter El-Azab noted that the SiC/SiC value would roughly double if a correction were included for "modulus softening" due to microcracking.

Ti3SiC2 was given as an example of a newly developed material that might have applications in fusion. Ti3SiC2 is a ceramic with some ductility at elevated temperatures and much higher thermal and electrical conductivity (~8% that of Cu) than conventional ceramics. Unpublished bend test data on a Ti3SiC2/SiC composite were shown. Steve cited two articles for those interested in more information: Barsoum and El-Raghy, J. Am.

Cer. Soc. 79,7 (1996) p1953, and Radhakrishnan et al., Scripta Mater. 34, 12 (1996) p1809. Nygren noted that Ti3SiC2 comes from a class of ceramics with unusual properties and that some advances and new materials with applications to fusion can be expected.

Steve Zinkle offered three general conclusions.

1. Low activation materials may be able to meet the APEX neutron wall loading goal of 7 MW/m^2 if a 3 mm wall thickness is considered viable. (This issue of wall thickness was discussed at length later in the meeting.)
2. Alternate materials (e.g. Ti3SiC2) and design philosophies (e.g., porous membranes), may allow additional increases in wall loading.
3. The material operating limits are determined by the temperature-dependent thermophysical properties of materials and radiation effects must be taken into account (e.g., radiation hardening sets temperature limit for BCC materials.)

In the subsequent discussion, the major points were as follows. Steve Zinkle and Nasr Ghoniem pointed out that, regarding SiC/SiC composites, there have been recent improvements, Microcracking of the SiC/SiC reduces the modulus and gives better accommodation of thermally induced deformation. Mohamed Abdou (UCLA) noted that even though there may be large improvements in unirradiated properties, for example by improving the matrix composition, irradiation will remove such increases. Also, there are H and He effects from irradiation. In response to the question of why SiC should be considered, Steve Zinkle suggested that SiC might be good as a blanket material even if it does not fare well as a potential first wall material.

Regarding V, It was suggested that the maximum temperature for V by 650°C when a strong temperature gradient was present (e.g. first wall) and that this be used as the maximum average bulk temperature with the maximum surface temperature being 700°C.

Mohamed Abdou noted that if the temperature window for a design was very narrow then the design would probably have to be considered less robust than designs that could accommodate a wider temperature window. Rich Mattas (ANL) noted that ASME rules are quite conservative, for a purpose, and those proposing designs could pose other criteria but would need to justify them.

In a discussion of materials, the consensus was to use Steve Zinkle’s list as a reference. Those proposing designs with other materials would have to justify the selection and feasibility of their selection(s).

III. Summary of M. Abdou’s Concluding Remarks and Action Items on Friday, October 17, 1997

(1) Date for Next Meeting

The next meeting is scheduled to be held at UCLA during the period January 12 - 14, 1998. It will start at 1:00 PM, Monday, January 12, and adjourn at Noon, January 14.

(2) Eight (8) groups have been formed. The relationship between APEX Tasks and these groups is outlined in Table I. Proposed organizations/individuals lead and support to undertake APEX Tasks is outlined in Appendix III.

(3) Several questions were raised at the meeting for which acting responses were issued. They are:

A. *Failure modes/rates and maintainability considerations should be incorporated early*

Response

1) Add availability (reliability and maintainability) as an additional important role for the mechanical design group

- come up with general guidelines/suggestions to designers to reduce failure rates and to enhance maintainability (and fault-tolerant designs).
- re-think the mechanical configuration from the edge of the plasma to the interior of the magnet (including vacuum boundary). "Invent" new configuration(s) for enhancing maintainability.

2) Encourage designers to account for failure rate & maintainability (but they must satisfy high power density requirements). Interact and listen to mechanical design/availability group.

B. *Stronger coupling with Physicists and Greater Accounting for plasma interface*

Response

1) Strengthen Group 5 Physics Interface

- Invite PPPL and key individuals (e.g. Dale Meade) to take the lead
- design concepts that are more tolerant of a wider range of plasma operating conditions (e.g. accommodating a number of disruptions) should get credit in evaluation

2) Utilize the ALPS physics boundary conditions. (Rich Mattas will ensure data base from ALPS is accessible to APEX).

3) Remember: It is still very useful to find out what the technology limits are. These provide boundary conditions for physics research (It is a two-way street)

C. *Alternate confinement concepts may have different requirements on FPT concept*

Response

1) Form a new group (Group 7: Alternate confinement concepts) to summarize the main configuration features and general range of parameters (wall load, surface heat flux, etc.) for alternate confinement concepts and to contrast them to Tokamaks

- Chair: Ralph Moir
- Invite Dale Meade (PPPL) to co-chair/help/advise

2) Plan a workshop concerning alternate confinement concepts to promote understanding of the main features and agree on general requirements for FPT designs (Group 7 will have the responsibility for organizing the workshop) Time Frame: about late February 1998

D. *Thickness of first wall: people have different viewpoints regarding minimum thickness*

Comment

Avoid the temptation to solve the problem by simply hypothesizing a very thin wall. This is not consistent with the APEX spirit of providing large design margin. If the feasibility of a concept depends on whether the thickness is 2 mm instead of 3 mm, this concept has to be questioned.

Response

1) The Mechanical Design/Availability Group is requested to examine the issue of minimum thickness consideration. Report findings ASAP and present them during the next meeting.

2) Designers (concepts advocates) have the burden of making and reporting sufficiently detailed analysis to justify their choice of first wall thickness

- concepts that use thinner walls, and where feasibility is crucially dependent on the thinness of the first wall, are required to have more detailed stress, failure rate, etc. analysis.

3) All concepts should assume 1 mm erosion over a nominal irradiation period of 15 $MW.y/m^2$. Concepts that have renewable liquid on the first wall are exempt from this requirement.

(4) The Design Conceptualization and Analysis Group has the core effort of APEX: For concepts proposed in the kick-off meeting the proposed/assigned organizations/individuals will pursue and present by next meeting (January 12) the following:

a) description of the basic features of the concepts (materials, novel features)

b) basic layout/configuration of the concept

c) self-consistent performance parameters based on Actual ANALYSIS (not all guesses)

- neutronics (simple 1-D OK)
- thermal-hydraulics analysis (temperature distribution)
- fluid mechanics analysis
- electromagnetic analysis where essential
- other key parameters

d) a set of issues related to difficulties in modeling, unknown phenomena, lack of database

Note: Design Groups can call on Mechanical Design Group for support

(5) Pursuing Additional Innovative Concepts:

The Group still encourage exploring new concepts. Those who have any truly new concepts are encouraged to present it during the next meeting and they do not have to present items required in 4 above.