CHAPTER 3: STUDY APPROACH

3. STUDY APPROACH

As stated earlier, the objective of the APEX study has been "to identify and explore novel, possibly revolutionary, concepts for the Chamber Technology that can substantially improve the attractiveness of fusion energy systems". This is a challenging objective that necessitates careful attention to how the study is carried out, i.e. the "study approach" on both the organizational and technical levels.

On the organizational level, the key aspects of the APEX approach have been to:

1) Foster an environment conducive to innovation.

   Innovation cannot be planned. However, the research environment has been set up to encourage innovation. Scientists are encouraged to think "out of the box". New ideas are given careful attention and time for exploration and evolution. Talented scientists and engineers are given the opportunity to lead and to propose ideas and are supported by analysts who can perform the necessary calculations. Furthermore, DOE provided funds for open competitive solicitation in order to "attract ideas" from within and from outside the community.

2) Understand and advance the underlying engineering sciences.

   Chamber Technology is complex and involves many technical disciplines, particularly engineering sciences. Understanding and advancing the underlying engineering sciences are prerequisites for innovation. Engineering scientists in APEX are given the time and the opportunity to understand the unique features and problems of the fusion environment and to develop the scientific basis necessary to explore new ideas. Modelling and experiments are carried out to obtain predictive capabilities and tools for analysis.

3) Utilize a cross-institutional, multidisciplinary team to foster collaboration, pool talents, and expand specialty and expert input.

   The APEX team is drawn from twelve institutions that include universities, national laboratories, and industry. The human resource base in the fusion community is relatively small compared to the numerous technical disciplines and the multitude of specialties required to address technical issues. So, the team approach provides for efficient and effective utilization of the available limited human resources. It also enhances synergism among ideas.

4) Enhance partnership between plasma physics and fusion technology.

   The Chamber Technology is in the immediate exterior of the plasma. There are strong interactions between the plasma and chamber technology performance and operation.

Therefore, the APEX team has plasma physicists and engineering scientists who can jointly address these interactions.

5) Direct participation of scientists from other programs.

   Scientists from Materials, Safety, System Studies, and other programs directly participate in APEX as members of the team. This assures that all relevant technical aspects of new ideas for Chamber Technology are addressed.

6) Direct coupling to the IFE Chamber Technology community.

   Although APEX focus is on Chamber Technology for magnetic fusion, many of the issues and ideas (e.g. liquid walls) are common to both magnetic and inertial (IFE) fusion. Scientists working on IFE Chamber Technology directly participate in APEX. This allows issues generic to IFE and MFE to be effectively addressed and enhances the synergism between IFE and MFE.

7) Encourage international collaboration.

   Scientists from Europe, Japan, and Russia were invited to participate in APEX. Current participation from Germany, Japanese universities, and Russia strengthens APEX by extending the pool of innovative ideas, resources, and skills available. It is worth mentioning that the idea for one of the top three concepts that evolved from APEX was proposed by one of the German scientists.

Figure 3.1 shows the functional units of the APEX Team Organization during the past 18 months of the study. This organizational structure served APEX well during the past phase of the study. A new organizational structure will be utilized beginning in FY 2000 in order to maximize effectiveness in carrying out the new tasks in the study's next phase.

The technical approach for APEX started by: 1) identifying parameters and features of the Chamber Technology that have the largest impact on the attractiveness of fusion systems, and 2) assessing and understanding the limitations and constraints of traditional concepts for the Chamber Technology.

Concepts for the Chamber Technology must satisfy the basic functional requirements shown in Table 3.1, which include providing a vacuum environment, plasma exhaust, heat removal, and tritium breeding. The key parameters and features of the Chamber Technology that have the largest impact on the attractiveness of fusion energy systems were identified to be:

1) High power density capability
2) High power conversion efficiency
3) High availability:
   - Low failure rates
   - Fast maintenance

4) Simpler technological and material constraints

An assessment to understand the limitations and constraints of traditional concepts was carried out in the early part of APEX. The results were published (see reference 1) and are not repeated in this report. Some of the key findings are:

a) The power density capability of a solid first wall is limited by the high thermal stress resulting from the surface heat load. This limitation can potentially be eliminated or reduced either by eliminating the solid first wall facing the plasma or by using structural materials with higher thermal conductivity, a lower thermal coefficient of expansion, and a higher stress limit.

b) The limits on achievable conversion efficiency derive primarily from temperature and cost limitations. The limitations on maximum operating temperature of the solid structural first wall are mostly to avoid excessive radiation damage. Secondly, the cost of the primary heat transport system including heat exchangers is expensive if high-temperature materials are used in the entire primary heat transport system and also in the chamber.

c) The Chamber Technology must have an availability of about 97.8% or higher in order to achieve competitive overall fusion energy system availability. Achieving such a high availability for the chamber requires that the mean-time between failures (MTBF) be sufficiently long and that the mean-time to recover from failure (MTTR) be sufficiently short. The condition MTBF > 43.8 MTTR must be satisfied in order for the Chamber Technology availability to exceed 97.8%.

Based on the results from the early work of APEX, the primary goals for the fusion Chamber Technology were defined as shown in Table 3.2. It must be noted that these goals cannot all be reached through innovations in Chamber Technology alone. For example, achieving faster maintenance depends on the simplicity of the plasma confinement configuration as well as on the characteristics of the Chamber Technology. Therefore, the goals in Table 3.2 are used as "guidelines" for calibrating the attractiveness of new ideas and for measuring progress.

A "process" for proposing and evaluating new ideas was also developed in the beginning of the APEX study. As illustrated in Figure 3.2, the APEX objectives and performance goals, together with a better understanding of the path to overcome technological limits, stimulated scientists to propose new ideas. These ideas went through a "screening process" which relied on "expert judgement" by the APEX team. The team tolerated "high-risk" ideas whenever there was a clear high-payoff. The ideas that passed the screening test proceeded to the stage of "Design Idea Formulation and Analysis" using existing tools. The technical work on those ideas is what is reported in this "Interim Report". It should be noted, however, that in the course of this work it became evident that existing models and data were not sufficient. Therefore, as the APEX study moves forward, substantial effort will be devoted to developing new models and conducting small scale experiments and more detailed exploration for the concepts with the greatest potential. It should be noted that this is a "dynamic process" rather than a static one. The aim has been to meet the challenging objectives of the APEX study.

Reference:

1. Mohamed A. Abdou, The APEX Team, "Exploring Novel High Power Density Concepts for Attractive Fusion Systems", Fusion Engineering and Design, vol 45. (1999), pp 145-167

Table 3.1
Functional Requirements of Chamber Technology

- Provision of Vacuum environment
- Exhaust of plasma burn products
- Heat removal and power extraction of surface heat loads (from plasma particles and radiation)
- Heat removal and power extraction of bulk heating (from energy deposition of neutrons and secondary gamma rays)
- Tritium breeding at the rate required to satisfy self sufficiency
- Radiation protection

Table 3.2: Primary Goals for Chamber Technology
(Goals used in APEX to calibrate new ideas and measure progress)

1. High Power Density Capability (main driver)

    Neutron Wall Load > 10 MW/m^2
    Surface Heat Flux > 2 MW/m^2

2. High Power Conversion Efficiency (> 40%)

3. High Availability

    -Lower Failure Rate (MTBF > 43 MTTR)
    -Faster Maintenance (MTTR < 0.023 MTBF)

4. Simpler Technological and Material Constraints

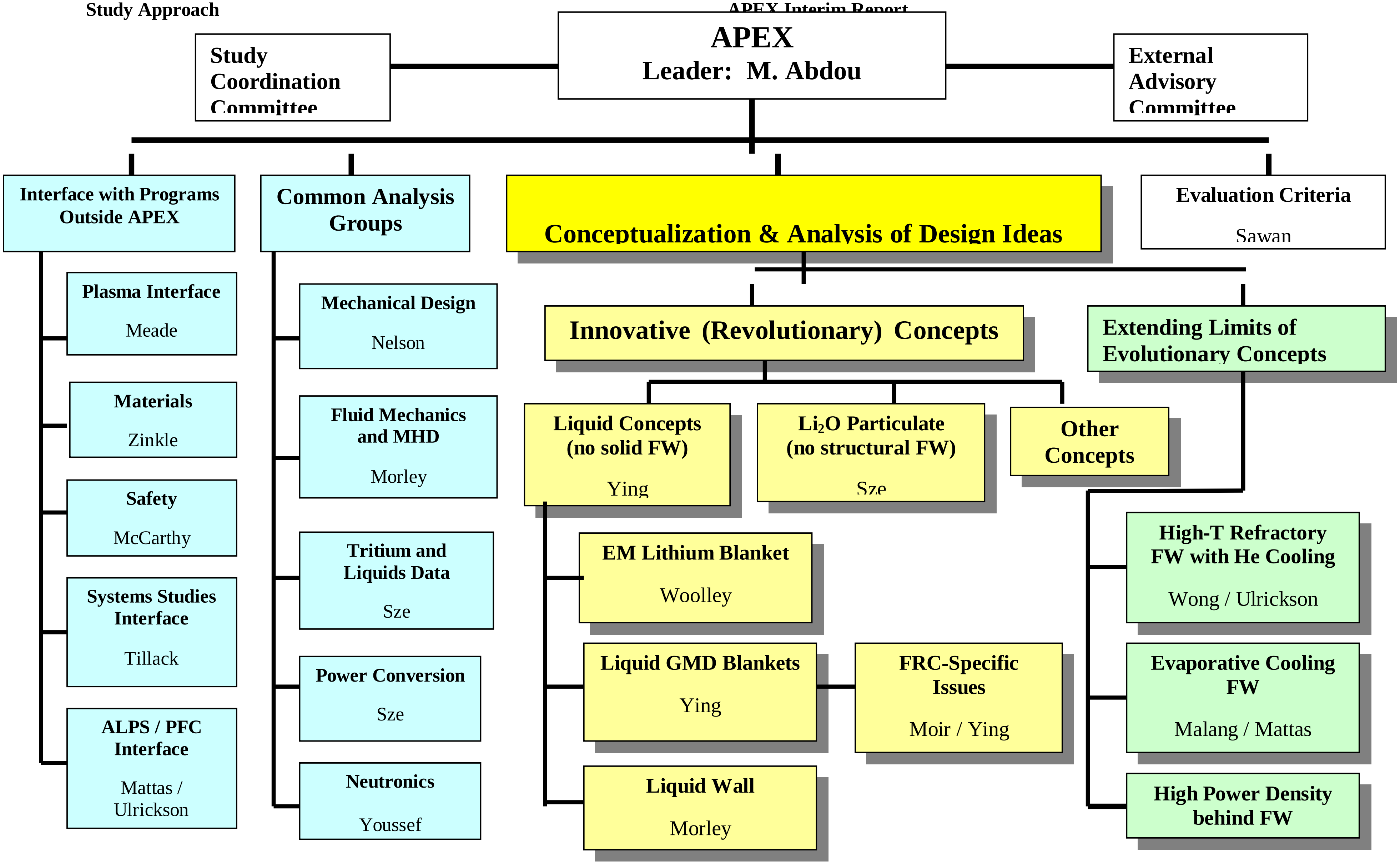

Fig. 3.1 Functional Units of the APEX Team Organization for

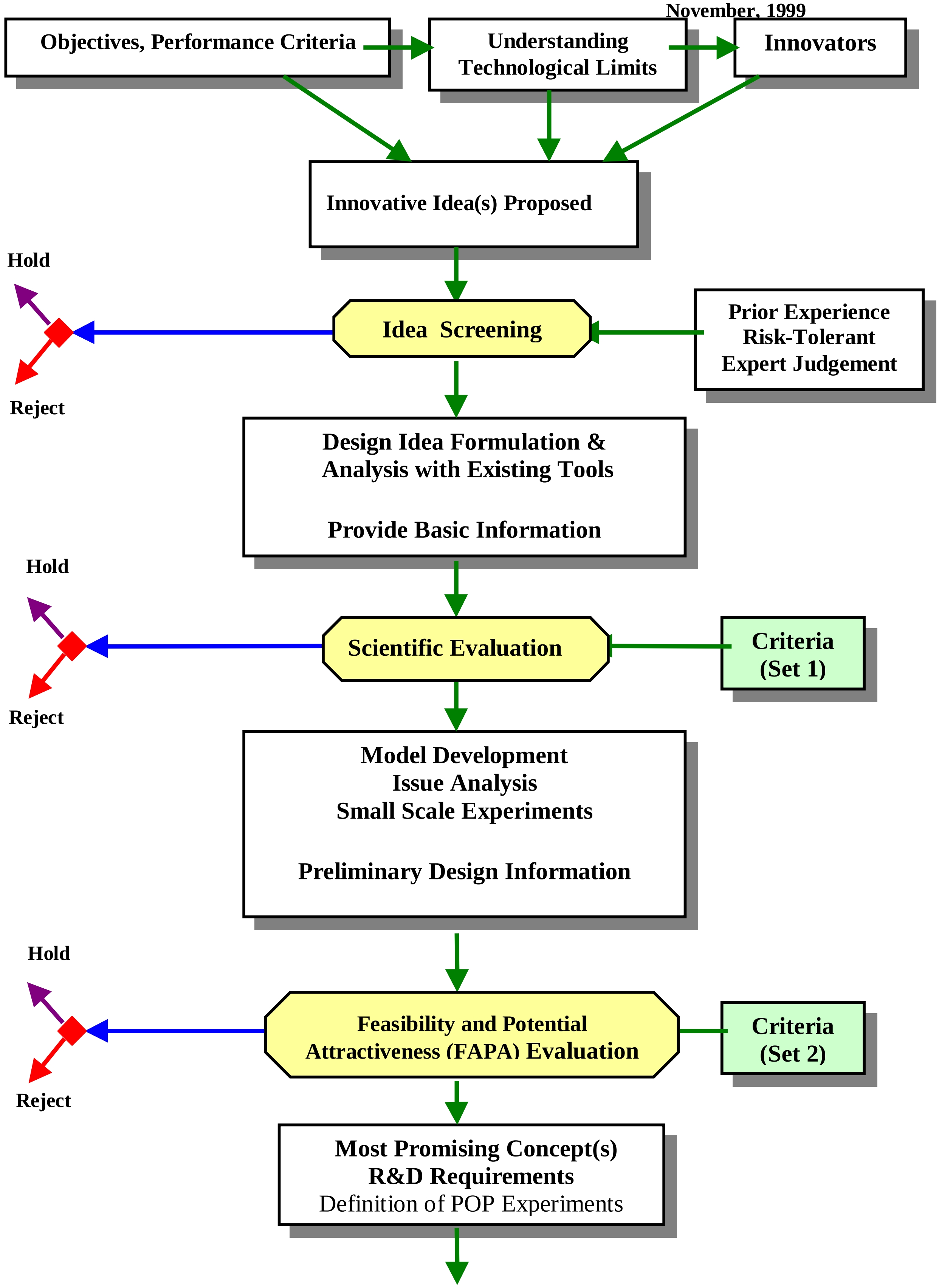

Fig. 3.2 Flow diagram illustrating the APEX process