

# **ALTERNATIVE CONCEPTS REVIEW**

**A Report to the Fusion Energy Sciences Advisory Committee**

**Presented to FESAC by**

**Farrokh Najmabadi**

**on behalf of  
The FESAC/SCICOM Alternative Concept Panel:**

**July 16, 1996**

## CHARGE

- This review should fundamentally be directed at recommending an investment strategy for funding alternative concepts.
1. Review the present status of alternative concept development in light of international fusion program.
  2. The review should produce an overall strategy for a U.S. alternative concepts development program including experiments, theory, modeling/computation and system studies:
    - Recommendation on how best to collaborate internationally;
    - Recommendations for encouraging new innovations;
    - A methodology for assessing on a comparative basis the scientific progress of alternative concepts;
    - A set of criteria for us in determining when an alternative concept is ready to undertake a “proof-of-principle” scale experiment.
  3. An interim report on spherical tokamak ( which was delivered to FESAC in May)

# The FESAC/SCICOM Alternative Concepts Panel Members

Dr. Farrokh Najmabadi (Chair)	University of California, San Diego
Dr. James Drake	University of Maryland
Dr. Jeffrey Freidberg	Massachusetts Institute of Technology
Dr. David Hill	Lawrence Livermore National Laboratory
Dr. Michael. Mauel	Columbia University
Dr. Gerald Navratil	Columbia University
Dr. William Nevins	Lawrence Livermore National Laboratory
Dr. Masayuki Ono	Princeton Plasma Physics Laboratory
Dr. Stewart Prager	University of Wisconsin, Madison
Dr. Marshall Rosenbluth	University of California, San Diego
Dr. Emilia Solano*	University of Texas, Austin
Dr. Ronald Stambaugh	General Atomics
Dr. Yuichi Takase	Massachusetts Institute of Technology
Dr. Kenneth Wilson	Sandia National Laboratories

## CONSULTANTS:

Dr. Osamu Motojima	National Inst. for Fusion Studies, Japan
Dr. Tom Todd	UKAEA Government Division, Fusion
Dr. Friedrich Wagner	IPP Garching

\*Dr. Solano resigned from the Panel before this report was completed.

## Panel Activities

- The Panel met three times. One half of each meeting was devoted to presentations by community and review of alternative concepts.
- In order to focus the discussion, Panel distributed a set of standard questions for each concept and proponents provided a written “assessment” paper for each concept.
- The Panel maintained a World Wide Web site for the panel activities. The Panel actively solicited input and received many written comments and assessment papers. Full text of this community input can be found on the Web site:  
<http://aries.ucsd.edu/SCICOM/AC-PANEL/index.html>
- The Panel deliberations were also guided by the FESAC January 1996 report, “A restructured Fusion Energy Sciences Program,” and by the FEAC Panel 3 report on “Concept Improvement” (1992).

## BACKGROUND

- The term “alternative concept” refers to magnetic configurations other than standard or advanced tokamak that is the focus of the worldwide tokamak program.
- Fusion research has historically pursued many configurations. In late 1960’s the tokamak proved to have a superior confinement and became the focus of the worldwide program.
- Programmatic distinction between “mainlines” and “alternatives” was put in a place in U.S. to “protect” the alternative concepts and maintain the program breadth. Up to late 1980’s, a healthy but modest level of research in alternatives was carried out in U.S.
- In fall of 1990, the alternative concepts program was essentially terminated.
- In 1992, the OFES was re-evaluating this decision. FEAC Panel 3 report notes a miscommunication between community and OFES as the community believed that alternative concept research has a low priority and will not be supported.

## BACKGROUND

- There exists a programmatic as well as cultural distinction between mainline and alternative research.
- Alternatives and tokamaks are viewed by OFES and part of the community as “competitors” rather than complimentary.
- This ignores the strong connection between most magnetic confinement approaches and the research techniques they share. Examples of past discoveries of significance to tokamaks and fusion plasma physics includes the discovery of bootstrap current, development of neutral beam heating, to name a few.
- In fact, a fusion power plant will likely draw on the broad-based physics foundation that comes from experimental and theoretical studies in a variety of plasma confinement approaches including alternative concepts.

## **GENERAL PRINCIPLE**

- A sound investment strategy for the fusion program includes a broad Concept Development Program (inclusive of all concepts, including tokamaks) with emphasis on science and innovations.
- OFES and the community should strive to remove any programmatic and cultural distinction between confinement concepts and alternatives. The decision to expand and/or reduce the research effort in any concept should be solely based on its contribution to the goals of the fusion program and evaluation specific proposals.

# ALTERNATIVE CONCEPTS RESEARCH PLAN

In order to develop an overall strategy, one should devise:

- Criteria to measure benefit of the research;
- Classification of programs (size, maturity) as well required mix of experimental facilities, theory and modeling, and concept evaluation and power plant studies effort at each level.
- The implementation process should:
  - Include ways to encourage new initiatives;
  - Include a methodology to assess when a concept is ready for increased effort and/or it has not fulfilled its potential and should be scaled back or terminated.
  - Include a methodology to decide which program should be progressed to the next step;
  - Must be widely perceived as open and receptive to innovation;
  - Should not interfere with normal peer reviews of proposals.

## ANTICIPATED BENEFITS

- 1) Advancement of general plasma physics;
- 2) Advancement of fusion plasma physics;
- 3) Contribution to fusion energy development;
- 4) Development of candidates for fusion power plants.

- Potential as an attractive fusion power plant should not be used as a litmus test for fusion concepts that are at early stages of development because (1) the large extrapolation required for such an assessment makes these tests arbitrary and meaningless, and (2) some concepts may prove to be unattractive as power plants but may contribute significantly to understanding key issues.

- In early stages, the major benefits are in the first two criteria. At later stages, the emphasis shifts towards the latter two.

## STAGES OF DEVELOPMENT

**Concept Exploration.** Aimed at innovation and establishing (1) the basic feasibility of a concept and/or (2) exploring certain phenomena of interest and benefit to other concepts.

Many independent experiments and theory activities are preferred. High risk, large payoff research is desirable. Activities should be of short duration in order to allow for a high turnover rate.

**Proof-of-Principle.** This is the lowest-cost program aimed at developing an integrated and broad understanding of basic scientific aspects of a concept which can be scaled with great confidence. Requires at least one device with plasma of sufficient size and performance that can examine a range of physics issues. Key physics and technological issues for the concept should be identified at this stage.

Programs are about 8-10 years of duration. and should be national programs. Sufficient resources should be committed both to large experiment as well as supporting smaller experiments, theory and modeling, and power plant studies in order to ensure a healthy return on investment.

## STAGES OF DEVELOPMENT

**Proof-of-Performance and Optimization.** Aims at exploring the physics of concepts at or near the fusion relevant regime in absolute parameters but without a burning plasma.

At this stage, the physics of concept is refined, new physics in fusion-relevant regime is examined and the performance is optimized.

**Fusion Energy Development.** Aims at developing the technical basis for advancing to the power plant level at full fusion environment. It include devices such as ignition experiments and volume neutron source.

**Fusion Demonstration Power Plant.** Aims at convincing the electric power producers, industry, and the public that fusion is ready for commercialization.

# ALTERNATIVE CONCEPTS RESEARCH PLAN

- The implementation process should:
  - Include ways to encourage new initiatives;
  - Include a methodology to assess when a concept is ready for increased effort and/or it has not fulfilled its potential and should be scaled back or terminated.
  - Include a methodology to decide which program should be progressed to the next step;
  - Must be widely perceived as open and receptive to innovation;
  - Should not interfere with normal peer reviews of proposals.
  
- In addition, in a Concept Development Program which includes many concepts that each have its own unique challenging issues and span a wide range in their levels of development, there is a need to base the program priorities on a strong scientific foundation. This is the best way to ensure maximum return on the investment of talent and resources.

# CONCEPT DEVELOPMENT COMMITTEE

- We recommend that a continuing “Concept Development Panel” (CDP) including experts from the community should be constituted under the auspices of FESAC to provide consensus scientific input and recommendations on the directions and priorities of the Concept Development Program research in the U.S. to FESAC and DOE.
- This parallels process used in parts of NSF and NIH.
- It represents an experiment in community governance and can be extended to cover all concepts if successful. (initially charged to oversee alternative concepts.)
- We recommend that SciCom to be charged at act as CDP.
  - Consistent with SciCom mission;
  - SciCom has a broad view of the national program;
  - No need to set up yet another committee.

## **Review and Selection Process -- Concept Exploration**

- Proposal for exploratory experiments or paper studies should be submitted to OFES as is the case now.
- The OFES organizes a peer review of these proposals with at least one member of CDP participating in each review.
- The CDP meets once or twice a year to rank proposals which are peer-reviewed during the previous period.
- The CDP ranks the new and renewal proposals and provide a consensus recommendation to FESAC and DOE as to which should receive funding and at what level so as the maintain the desired emphasis among different approaches to Concept Development.
- The CDP maintains a set of assessment papers on various concepts including research plans, list of critical issues, and a historical record of progress for each concept.

## **Review and Selection Process -- Proof-of-Principle**

- In its annual report on the status of concept development research, the CDP provides a recommendation that a concept is ready for proof-of-principle program. If funding permits, it would be expected that OFES will issue a call for proposals.
- The OFES organizes peer reviews of these proposals as is the case now, with at least one member of CDP participating in each review. The outcome of these reviews should be passed to CDP.
- The CDP reviews these proposals and will provide a scientific assessment of each. The CDP will also provide recommendation for an implementation strategy or strategies depending on available funding. The goal will be to craft a Proof-of-Principle program that obtains the complete resolution of the issues. In some cases, it may be found that the proposals brought forward are collectively deficient in leaving some subsets of the issues unaddressed, the CDP will note these in its report and advise if further proposal solicitations are recommended.

## Status of Spherical Tokamaks

**Status.** The Panel believes that the spherical tokamak (ST) concept is scientifically ready to move to proof-of-principle stage based on

- Growing data base from concept-exploration experiments that confinement in ST is “tokamak-like” and no physics show stoppers to proceeding to next stage has been found.
- It appears that a large body of tokamak theoretical and experimental data base help provide a basis for next-step ST experiments.

**Benefits.** Research in ST can make important contribution to resolve key issues of conventional tokamaks because the ST concepts pushes the tokamak physics to the limit of extreme toroidicity. The ST research fits well with the U.S. emphasis on tokamak concept optimization. It is a financially realistic niche. Preliminary analysis indicates that ST with small size may be possible as fusion devices. However, technological issues such as design for center-post, divertor heat removal, and wall-loading limitations may limit the performance of a ST and set the optimum parameters.

**Program Mix.** A proof-of-principle experiment, with a broad, community-wide support program in theory/modeling, power plant studies as well small concept-exploration-class experiments.

## Status of Stellarators

**Status.** The stellarator program is in the transition from proof-of-principle to proof-of-performance stage.

**Benefits.** Stellarators are a strong driver of 3-D plasma physics and help define the possibilities and limitations of toroidal confinement systems.

**Program Mix.** In view of the planned operation of two large proof-of-performance-class devices world-wide (LHD and W7-X), there is little motivation for the U.S. to build similar scale devices. U.S. can play a valuable role at the concept exploration level focusing the effort on reducing the size of stellarator fusion power systems. Possibility exists for additional interesting experiments in the proof-of-principle class.

In order to maintain beneficial contact with the large stellarator efforts abroad and to gain knowledge from those important experiments, the U.S. should (1) seek to gain a support role on LHD and W7-X, (2) seek to provide substantial theory support to LHD and W7-X. This core of theory support could also stimulate concept exploration initiatives.

## **Status of Reversed-Field Pinch**

**Status.** The RFP program contains proof-of-principle activities because

- A large experimental data base from a variety of devices on gross MHD stability and a favorable confinement scaling with device size;
- The presence of several operating RFPs including a proof-of-principle-class device, RFX, in Italy, and modest programs such as MST in U.S.
- A developed theoretical and computational understanding of many key experimental observations such as equilibrium & stability, MHD dynamo, resistive MHD fluctuations in the core, relationship between confinement and fluctuations.

**Benefits.** RFP research has direct relevance to other concepts. Important scientific accomplishments include minimum energy states, observation of plasma dynamo, study of nonlinearly coupled tearing modes. It also promises a compact fusion system

**Program Mix.** Most of the RFP proof-of-principle issues can be addressed in existing facilities. The program should include: (1) A broader experimental investigation of advanced RFP issues, such as profile control within the US program; (2) Increased collaboration with the RFX device in Italy; (3) Increased support for RFP theory and computation.

## Less-Developed Concepts

**Field-Reversed-Configuration** is an interesting plasma configuration at the concept exploration level. Stability to large scale MHD-like modes remains a critical issue both in conventional FRCs and in ion-ring stabilized configurations. Because global stability is a potential show-stopper for these configurations, the U.S. program should focus on this issue prior to addressing the confinement and sustainment. This issue can be addressed in the LSX device.

**Spheromak** is at the concept exploration stage of development. Considerable experimental data already exists in short-duration experiments where equilibrium & stability is passively provided by a close-fitting conducting boundary. Demonstrating reasonable confinement in experiments where the equilibrium & stability is controlled by externally imposed magnetic fields remains as an important milestone for concept exploration. Addressing next-step spheromak issues will require at least one new experiment that can achieve high-temperature in quasi-steady state.

**Others.** The Panel also heard presentations on many less-developed concepts. These presentations clearly demonstrated to us that there exists a large number of interesting and intriguing ideas to be studied at concept exploration level.

## **INTERIM RECOMMENDATIONS**

Until the CDP is constituted and charged with providing scientific input on priorities for the Concept Development Program, we provide the following interim recommendation:

- A healthy alternative concept program require an increase in funding as proposed in the FY 97 Presidential budget and should include (not in priority order):
  - Expansion of Concept-Development Program;
  - Initiation of spherical tokamak proof-of-principle program and construction of new spherical tokamak facility(ies)
  - Strengthening and broadening the existing RFP program;
  - Contribution to international stellarator program through theoretical studies and collaboration on international experiments.
  - Establishment of a vigorous theory program in support of the alternative concept research.

**Panel's final report, these viewgraphs, FESAC transmittal letter and other goodies can be found at**

**<http://aries.ucsd.edu/SCICOM/AC-PANEL/index.html>**