SUMMARY OF THE FORUM FOR MAJOR NEXT-STEP FUSION EXPERIMENTS
Madison, 27 April - 1 May 1998

Gerald A. Navratil
Columbia University

Fusion Energy Sciences Advisory Committee
Gaithersburg, 26-27 May 1998
Goals of Forum

• Identify set of candidate “credible” strategy options for advancing fusion energy which have broad community support.

• Take a step towards a more effective method of building a community consensus and set stage for continuing this process.

• Provide a sense of the US fusion community views on potential major next steps in fusion energy research as input into the ITER SWG discussions.
Forum for Major Next-Step Fusion Experiments

- Program arranged by Organizing Committee of ~40 drawn broadly from most institutions involved in fusion research.

- Organizing Committee met on February 26-27 at PPPL to plan Forum format and assign session organizational responsibility.

- Forum was held for 4.5 days in Madison and was well attended with about 165 people registered.
ORGANIZING COMMITTEE:
FORUM FOR MAJOR NEXT-STEP FUSION EXPERIMENTS

Co-chairs: Drake – Navratil – Nevins

Columbia                      Boozer, Navratil                        [Mauel]
Cornell                      Hammer
Georgia Tech                 Stacey
NYU                          Weitzner
Swarthmore                   Brown
UC-Irvine                    McWilliams
UCLA                         Abdou, Cowley
UCSD                         Najmabadi
U. Colorado                  Cary
U. Maryland                  Dorland, Drake
U. Texas                     Hazeltine*, Van Dam
U. Washington                Jarboe
U. Wisconsin                 Callen*, Fonck, Prager
ANL                          Dale Smith
GA                           Luce, Taylor*                        [Baldwin]
ITER                         Tom James, Rutherford               [Baker]
LANL                         Schoenberg
LLNL                         Nevins, John Perkins                [Thomassen]
MIT                          Hutchinson, Montgomery*              [Porkolab]
ORNL                         Lazarus, Peng                         [Saltmarsh]
PPPL                         F. Cheng, Hawryluk, Meade,
                            Neilson, S. Zweben*                  [Goldston]
Sandia                       Ken Wilson
Boeing                       Davis
Raytheon                     Ellis
Fusion Power Assoc.          Dean
Jefferson Lab                Grunder

* FESAC Member

[ex officio] head of sponsoring organization
Forum Agenda Structure

Monday

- Background Briefings: Outside Views and Input
- Breakout Group Assignment

Tuesday

- Strategy Option Introduction and Charge to Breakout Groups
- Key Physics & Technology Issues

Tues. PM - Wednesday

- Review and Discussion of Major Next Step Experiment Options

Wed. Evening - Thursday

- Discussion & Breakout Groups: Formulation of a set of 'credible' strategy options for advancing fusion energy

Friday

- Summarize Progress and Discuss Plans for Follow-on Activity (Martha Krebs Participates in Discussion)
Consensus Building in Science:
High Energy Physics, Nuclear Physics, & Astrophysics

• Scientific consensus on program direction and major experiments has been achieved and has led to larger/successful programs.

  HEP and NP: Snowmass meetings sponsored by APS provide “internal education” of the community

  Astrophysics: Decade Survey examines science issues and technical readiness as a “bottom-up” process

• All 3 sub-fields “invented” their own process over the past 20-30 years:

  → Common Feature: Very high fraction of the community was heavily involved and the process took up to 5 years. Process was very open and broad based.
Forum Process: Rules of Procedure

- BREAKOUT GROUPS
  
  + Every participant randomly assigned to one of 6 groups
  
  + Each group selects its own spokesman to report its finding and views in plenary session
  
  + Each group assigned a “Facilitator” who will assist spokesman and group in making progress on charge to the group.
Charge to Breakout Groups

① Formulate a set of credible strategies within your group, which your group supports, for the fusion energy science and technology leg of our program.

② Identify the strengths and weaknesses of each strategy.

Your group should take into consideration primarily scientific and technical issues such as:
- Status of fusion energy science and technology today
- Relationship to and integration with the other elements of the fusion program in the U.S.

and, secondarily, other issues such as:
- Ability to muster support of the scientific, environmental, and energy policy communities
- ITER process & our partnership in the international effort
- FESAC/Grunder panel recommendations & options
General Findings

• Need to reduce the cost of the individual development steps in our program to develop scientific and technical basis for a practical source of fusion energy:
  “Cost of major steps characterizes the cost of the final product”.

• Attractiveness of a Next Step experiment is a primary concern: must emphasize innovation in our plan

• Exploration of a Burning Plasma was the primary priority for a strategy for a major next step experiment.
Approach toward DEMO and Fusion Power Reactor

Fusion power development should be made so that people agree the cost as "rational expenditure" for the energy development.
Three Strategy Options

- Single Machine: take an integrated step forward now with the tokamak.

- Multiple machine: split mission elements and take a number of smaller parallel, phased, or sequential steps.

- Defer major next step: emphasize existing programs & innovative concept development
Single Machine

ITER-RC

Tokamak Innovations

Innovative Confinement Concepts

Materials & Technology

Pre-Demo

Integrated Test Facility

Demo

Reduced Cost ITER: More flexibility and AT capability

Pro: Earliest Physics/Technology integration
    Builds on established international structure

Con: Less flexibility
    Costly single step
MULTIPLE-MACHINE

INTERNATIONAL PROGRAM

Normal Conductor / Burning Plasma

Superconducting / Steady State- DD
Tokamak Innovations

Innovative Confinement Concepts

Materials & Technology

Integrated Test Facility

Demo

Pros: Greater Flexibility
Less Costly Elements

Cons: Delays Integration
Not in Present International Game Plan
Example of Modular Strategy Element Costs

Range of normal conductor D-T burning plasma experiments:
  • Italian Ignitor design ~<$1B
  • US BPX design ~$1.7B
  • US "PCAST" machine ~$4B

Range of steady-state D-D advanced tokamaks:
  • Korean KSTAR ~$0.4B
  • US TPX ~$0.7B
  • Japanese JT-60SU design ~$2.0B

The capital cost of the BPX plus TPX combination is about $2.4B, or about 1/3 of the cost of the ITER EDA design.

VNS cost ~$1B, therefore it seems reasonable to extrapolate that the full cost of these machines need not be significantly more than half the cost of the present ITER EDA design.
DEFER MAJOR NEXT STEP

AT
Stellarator
ST
RFP
FRC

\{ Burning Plasma \}

PRO: MAY LEAD TO GREATLY IMPROVED APPROACH

CON: NOT MOVING TOWARDS FUSION ENERGY

*IFE: not the appropriate forum
Views on the Strategies

- Both the Single-Machine and Multiple-Machine Strategies had substantial support.

- The Defer Strategy had no broad support and was opposed by several groups.

- Multiple-Machine strategy was preferred over the Single-Machine Strategy, and a minority was opposed to the Single-Machine Strategy.

- Consensus that we should not withdraw from the ITER process at this time: support for ITER contingent on improved flexibility to explore Advanced Tokamak physics in a reduced cost ITER.
Combined Parallel Strategy (Near-Term)

ITER-RC

2000-2001

Evaluate Multiple Machine Options

Multiple Machine Elements
Follow-on Activities


- Some additional work is needed/expected on elements of the Multi-machine or Modular Strategy over next 2 years.

- Fusion “Snowmass” meeting endorsed by American Physical Society Division of Plasma Physics is now being planned for 2 weeks in Summer of 1999.
### Forum for Major Next-Step Fusion Experiments
27 April - 1 May 1998, Madison, WI

**Monday, April 27 (9:00 am - 6:05 pm)**

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<thead>
<tr>
<th>Time</th>
<th>Event</th>
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<tr>
<td>8:00</td>
<td>Continental Buffet Breakfast in Convention Center</td>
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<td>9:00</td>
<td><strong>Introduction &amp; Fusion Program Status (Prager)</strong></td>
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<td>Navratil (Columbia)</td>
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<td>Baker (UCSD)</td>
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<td>Davies (DOE)</td>
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<td>Perspective on Fusion Energy Sciences Program</td>
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<td>Grunder (Jeff. Lab)</td>
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<td>Consensus Building &amp; Planning in Astrophysics</td>
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<td>Rosner (U. Chicago)</td>
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<td>Consensus Building &amp; Planning in High Energy Physics</td>
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<td>Reeder (U. Wisc.)</td>
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<td>12:00</td>
<td><strong>LUNCH</strong></td>
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<td><strong>Science, Economic &amp; Environmental Issues (Drake)</strong></td>
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3:10  Break  15 min

3:25  International Fusion Program (Weitzner)
Views on a Next-Step in the International Fusion Program  Baldwin (GA)  40 min
DISCUSSION  40 min

4:45  ICF (Perkins)
NIF & IFE  Campbell (LLNL)  40 min
DISCUSSION  Campbell, Bangerter  40 min

6:05  Adjourn

Tuesday (8:30 am - 6:40 pm)

7:45  Continental Buffet Breakfast

8:30  Preliminary Discussion of Strategies for Fusion & Charge to Breakout Groups  Mauel (Columbia)  25 min
DISCUSSION  25 min

9:20  Physics Issues to be Addressed by Major Next-Step Expts
[Each talk 10 min + 2 min for questions]
Session Intro  Van Dam (U. Texas)  12 min
Confinement  Dorland (U. Md.)  12 min
MHD & Profile Control  Taylor (GA)  12 min
Edge Physics Issues  Pitcher (MIT)  12 min
DISCUSSION  22 min

10:30  Break  15 min
Energetic Particle Physics  Cheng (PPPL)  12 min
Self-Heating & Thermal Control  Perkins (ITER)  12 min
Ignition Physics Requirements  Coppi (MIT)  12 min
Long Pulse & Short Pulse Physics  Rosenbluth (UCSD)  12 min
DISCUSSION  20 min
GENERAL DISCUSSION  37 min

12:30  LUNCH
2:00 Technology Issues to be Addressed by (Smith) Major Next-Step Experiments
- Magnet Systems Montgomery (MIT) 10 min
- Plasma Facing Components Ulrichson (Sandia) 10 min
- Heating and Fueling Systems Berry (ORNL) 10 min
- Materials Mattas (ANL) 10 min
- Tritium Systems Willms (LANL) 10 min
- Energy Extraction Systems Abdou (UCLA) 10 min
- DISCUSSION 30 min
- Reactor Integration: ARIES Najmabadi (UCSD) 15 min
- Innovative Reactor Design Moir (LLNL) 10 min
- DISCUSSION 30 min

4:25 Break 15 min

4:40 ITER & ITER with Technical Modifications (Stacey)
- ITER Introduction Baker (UCSD) 10 min
- ITER Physics Sauthoff (PPPL) 25 min
- Advanced Physics Database for Reduced Cost ITER Simonen (GA) 15 min
- Reduced Cost ITER Design Space Stacey (GA Tech.) 15 min
- DISCUSSION 55 min

7:30-9:00 Buffet Dinner

Wednesday (8:30 am - 6:15 pm & 8:00 pm - 10:00 pm)

7:45 Continental Buffet Breakfast

8:30 Superconducting Burning Plasma (Montgomery) Next-Step Elements
- JAERI Views on Reduced-Cost ITER Kikuchi (JAERI) 20 min
- SUPERCODE Studies of Reduced Cost ITER Options Uckan (ORNL) 15 min
- Advanced Physics & Engineering: Cost Reductions for Next-Step Porkolab/Schultz 20 min
- DISCUSSION 55 min

10:20 Break 15 min
10:35 Other Major Next-Step Elements (Dorland)
JT60-SU Kikuchi (JAERI) 15 min
TPX/KSTAR Neilson (PPPL) 15 min
DISCUSSION 15 min
Point neutron sources Saltmarsh (ORNL) 15 min
ST, Tokamak and GDT Options for VNS Peng (ORNL) 15 min
DISCUSSION 25 min

12:15 LUNCH

1:30 Normal Conductor Burning Plasma (Nevins)
Next-Step Elements
Why Compact Ignition? Meade (PPPL) 5 min
A Proposal for a Modest-sized Ignited Plasma Luce (GA) 20 min
Impact of Recent Discoveries on the Feasibility of a CIT Hutchinson (MIT) 15 min
DISCUSSION 30 min

2:40 Break
Ignitor Coppi (MIT) 20 min
PCAST-scale Ignition Lazarus (GA) 20 min
Optimizing Normal Conductor Tokamaks Wooley (PPPL) 5 min
BPX-scale Ignition and Survey Meade (PPPL) 15 min
DISCUSSION 60 min

4:55 Advance Physics Base
Using Smaller Facilities (Cowley)
Time to Pause before Next-Step Siemon (LANL) 15 min
Synergy Between Innovative Concepts and a Burning Plasma Next-Step Fonck (U. Wisc.) 15 min
DISCUSSION 35 min

6:00 pm Review of Charge to Breakout Groups (TBD) 15 min

6:15 pm Break for Dinner

8:00 pm 6 Parallel Breakout Groups Meet:Session #1 120 minutes

10:00 Adjourn
Thursday (8:30 am - 6:30 pm)

7:45   Continental Buffet Breakfast

8:30   Strategies for Fusion Development/Discussion (Prager)
Summary of Issues & Elements  Prager 30 min
Report from Each Breakout Group 60 min
DISCUSSION/Discussion Leader: Prager 30 min

10:30  Break 15 min
Individual Strategy Views (≤ 10 min each)
   Goldston
   Politzer
   Stambaugh
   Meade
   Kotchenreuther
   others TBD
DISCUSSION/Discussion Leader Mauel

12:00  LUNCH

1:30   6 Parallel Breakout Groups Meet:Session #2 120 minutes

3:30   Break

3:45   Strategies for Fusion Development/Discussion (Nevins)
Report from Each Breakout Group 60 min
Discussion/Discussion Leader: Nevins 105 min

6:30   Adjourn

Friday (8:00 am - 11:30 am)

7:15   Continental Buffet Breakfast

8:00   Strategies for Fusion Development/Discussion
Progress in Identification  Navratil 20 min
of Credible Strategy Options
Comments by Dr.Krebs &
Discussion: Primary Conclusions of Forum 130 min
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<th>Time</th>
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<tr>
<td>10:30</td>
<td>Break</td>
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<td>10:45</td>
<td>Follow-on Meeting Plans</td>
<td>Baker/Mauel 20 min Discussion 25 min</td>
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