IFE R&D Planning Based on FESAC Reports

- 1999 FESAC Priorities and Balance Report
- 2003 FESAC Plan for the Development of Fusion Energy

Robert J. Goldston
Princeton University
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The 2003 FESAC Plan for the Development of Fusion Energy presented an integrated development plan for MFE and IFE. The 1999 FESAC Priorities and Balance Report provides some specific goals and metrics that were not discussed in detail in the 2003 Plan. Both reports are worthy of review by the NAS Panel.

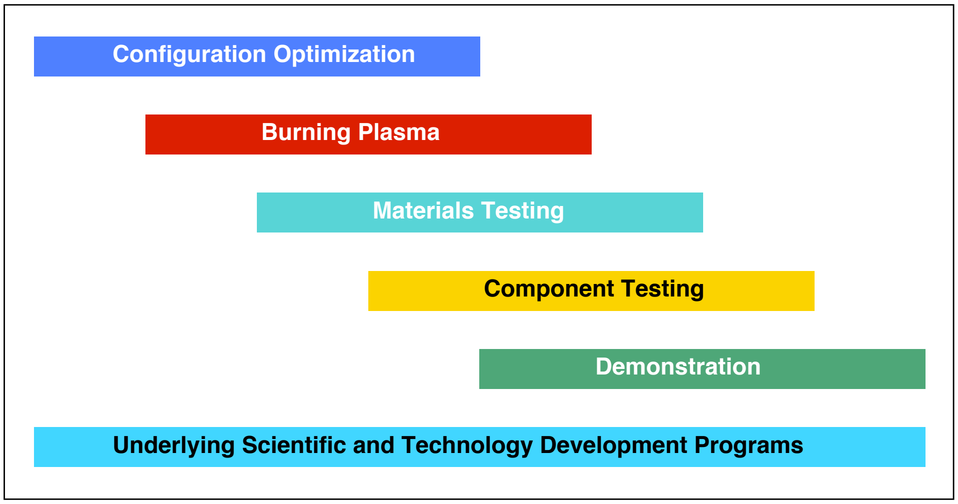
FESAC MFE/IFE Study in 2002-3

- Mohamed Abdou, University of California, Los Angeles
- Charles Baker, University of California, San Diego
- Michael Campbell, General Atomics
- Vincent Chan, General Atomics
- Stephen Dean, Fusion Power Associates
- Robert Goldston (Chair), Princeton Plasma Physics Laboratory
- Amanda Hubbard, MIT Plasma Science and Fusion Center
- Robert Iotti, CH2M Hill
- Thomas Jarboe, University of Washington
- John Lindl, Lawrence Livermore National Laboratory
- Grant Logan, Lawrence Berkeley National Laboratory
- Kathryn McCarthy, Idaho National Engineering Laboratory
- Farrokh Najmabadi, University of California, San Diego
- Craig Olson, Sandia National Laboratory, New Mexico
- Stewart Prager, University of Wisconsin
- Ned Sauthoff, Princeton Plasma Physics Laboratory
- John Sethian, Naval Research Laboratory
- John Sheffield, ORNL, and UT Joint Institute for Energy and Environment
- Steve Zinkle, Oak Ridge National Laboratory

Technology
IFE
MFE
Wise Persons

This panel included a balance of fusion technology, IFE, and MFE experts, as well as individuals considered to have a wide perspective on fusion energy development. The Panel was not asked to evaluate the prospects for inertial or magnetic fusion energy, but to articulate an integrated fusion energy development plan.

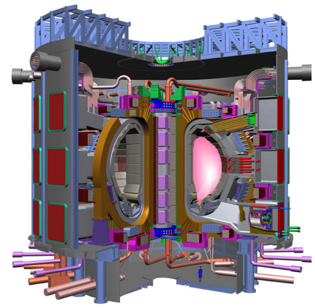
The 2003 Plan Conceptualized MFE and IFE Development Paths Similarly



A set of overlapping stages needs to be traversed for both approaches.

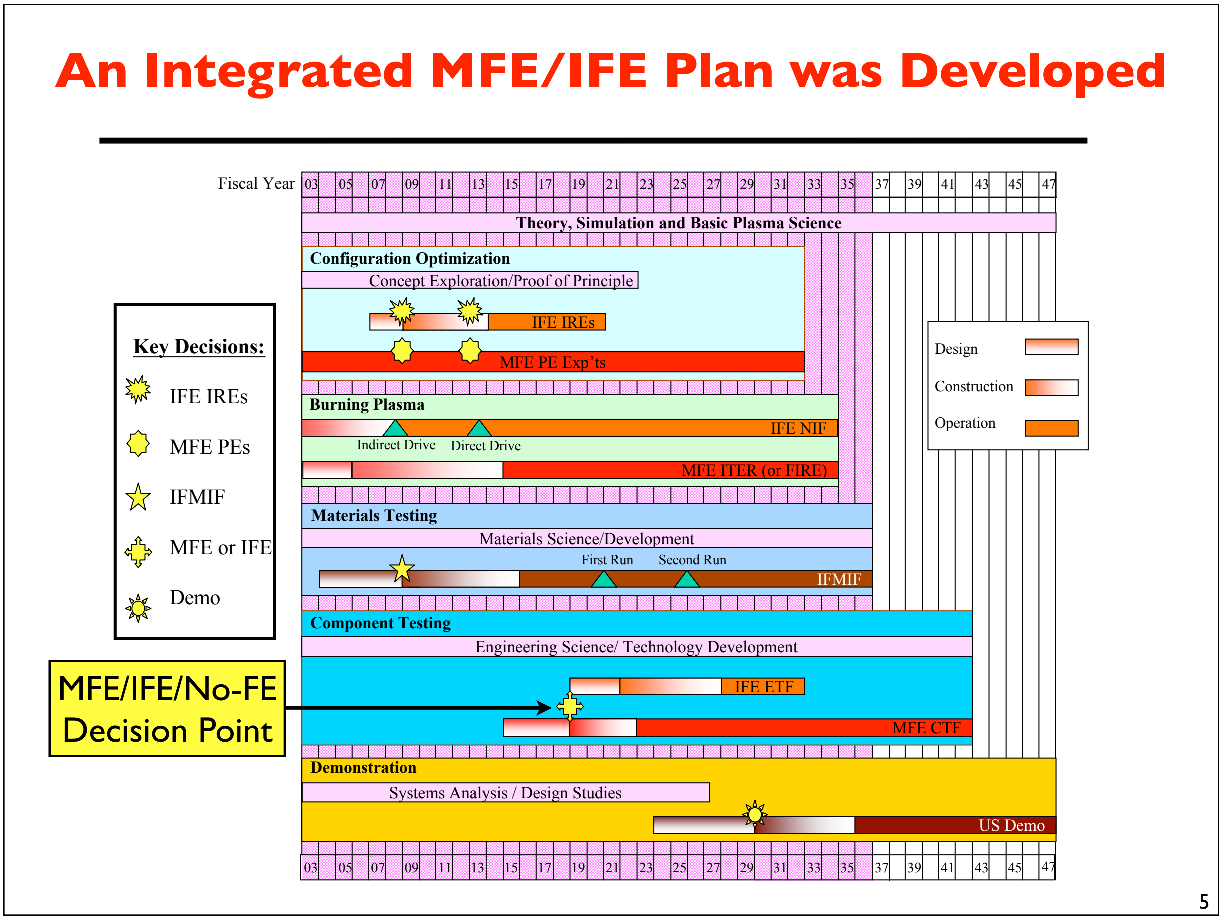
The same overall framework functioned well for MFE and IFE.

NIF and ITER have Different Programmatic Roles



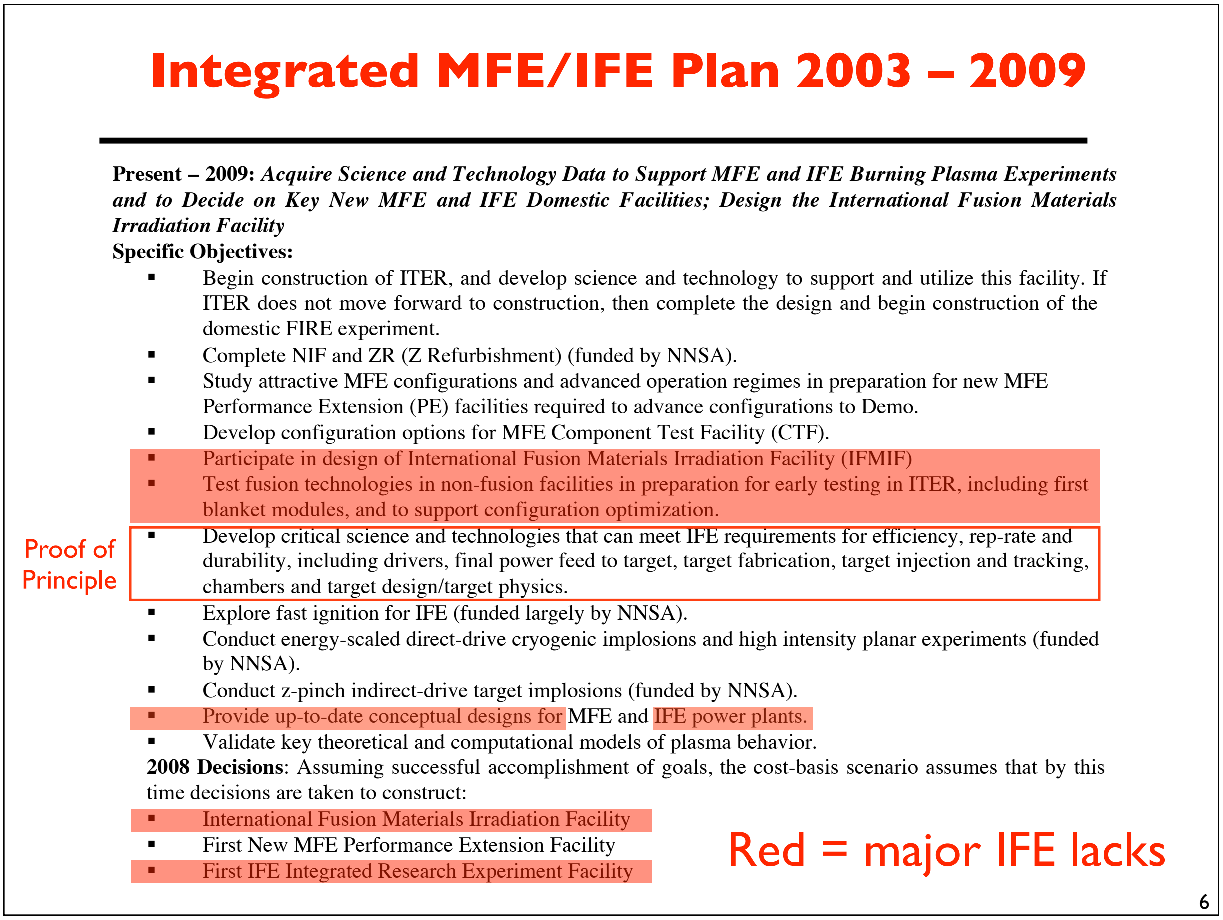
	NIF	ITER
Q	10	10
Q (power plant)	> 100	> 25
E/pulse	20 MJ	10^5 MJ
E/day	20 MJ	8 10^6 MJ
E/day (power plant)	~ 2 10^8 MJ	~ 2 10^8 MJ
Programmatic Role	Scientific Feasibility	Scientific and Technological Feasibility

Because of the different programmatic roles of NIF and ITER, IFE and MFE require different supporting programs.



IRE = Integrated Research Experiment; PE = Performance Extension; IFMIF = International Materials Irradiation Facility;
ETF = Engineering Test Facility; CTF = Component Test Facility

A key feature of the 2003 Plan for the Development of Fusion Energy was exploitation of synergy between MFE and IFE in the area of Materials Testing. In particular the International Fusion Materials Irradiation Facility could be used to develop neutron resistant materials for both. Another key feature of the plan was decision points with “off-ramps”. For example the down-selection between MFE and IFE (or the decision not to proceed with fusion energy development at all) was to be conditioned on results from NIF, ITER and IFMIF, as well as the supporting MFE and IFE programs.



Significant progress has been made on the Proof-of-Principle issues, but this effort is not yet completed. See for example J. D. Sethian et al., IEEE Transactions on Plasma Science, VOL. 38, No. 4, April 2010. The Integrated Research Experiment construction decision was to be driven by positive results from NIF and from the Proof-of-Principle program.

The 1999 FESAC Priorities and Balance Report Specified IFE Proof-of-Principle Goals & Metrics

- Ion beam development
  - Perform single-beam, high-current experiments to validate ion production, acceleration, and transport in a driver-relevant regime.
  - Perform focusing and chamber transport experiments at intermediate scale.
  - Complete detailed end-to-end numerical simulations of the IRE and full-scale drivers.
  - Develop technologies to minimize the cost of the IRE.
- Laser development
  - Energy of several hundred joules in a laser architecture scalable to 2 MJ at a cost of ≤ $500/J.
  - Wall plug efficiency of 6-10% at a repetition rate of 5 Hz.
  - Reliability of 10^5 to 10^8 shots between maintenance cycles.
  - Irradiation uniformity of ≤ 0.3%.
- Chamber development
  - Demonstrate that an IFE chamber can be cleared of droplets and/or vapor in less than ~200 ms to a level that lasers or ion beams can be focused on a target.
  - Driver/Chamber Interface issues:
    - Heavy ions: Produce a self-consistent design for final-focus magnets consistent with heavy ion target requirements and the standoff of protected wall chamber designs
    - Lasers: Tests to determine the plausibility of achieving laser final optics lifetimes of >1 full-power-year after being subjected to neutron, x-ray, and target debris.
- Identify methods for low cost manufacture and rapid injection of both direct and indirect drive targets.

The 1999 FESAC Priorities and Balance Report specified Proof-of-Principle goals and metrics for IFE.

MFE/IFE Integrated Plan 2009 – 2019

2009 – 2019: ***Study Burning Plasmas, Optimize MFE and IFE Fusion Configurations, Test Materials and Develop Key Technologies in order to Select between MFE and IFE for Demo***

Specific Objectives:

- Demonstrate burning plasma performance in NIF and ITER (or FIRE).
- Obtain plasma and fusion technology data for MFE CTF design, including initial data from ITER test blanket modules.
- Obtain sufficient yield and physics data for IFE Engineering Test Facility (ETF) decision.
- Optimize MFE and IFE configurations for CTF/ETF and Demo.
- Demonstrate efficient long-life operation of IFE and MFE systems, including liquid walls.
- Demonstrate power plant technologies, some for qualification in CTF/ETF.
- Begin operation of IFMIF and produce initial materials data for CTF/ETF and Demo.
- Validate integrated predictive computational models of MFE and IFE systems.

Intermediate Decisions: Assuming successful accomplishment of goals, the cost-basis scenario assumes a decision to construct two additional configuration optimization facilities, which may be either MFE or IFE.

- MFE Performance Extension Facility
- IFE Integrated Research Experiment

2019 Decision: Assuming successful accomplishment of goals, the cost-basis scenario assumes a selection between MFE and IFE for the first generation of attractive fusion systems.

- Construction of MFE Component Test Facility (CTF)

  or

- Construction of IFE Engineering Test Facility (ETF)

MFE/IFE/No-FE Decision Point

Red = major IFE lacks

The 2003 Development Plan called for exploitation of IFE IRE's and MFE PE's to demonstrate efficient long-life operation. A U.S. down-selection was to occur between MFE and IFE (or no fusion energy) before major new nuclear facilities were built, in order to control costs.

Missions of Integrated Research Experiments

- Integrated Research Experiments to be triggered by successful Proof-of-Principle programs and positive results from NIF.
- Each Integrated Research Experiment program must resolve the key issues that enable an Engineering Test Facility:
    - For the laser approaches – laser efficiency, durability, cost and beam quality, target fabrication and injection, first chamber wall materials and protection, and final optics durability.
    - For the heavy ion approach – focal spot size under fusion chamber relevant conditions, accelerator cost, target fabrication, thick liquid protected chambers with target material recovery and focus magnet lifetime.
    - For the z-pinch approach – economical RTLs, blast mitigation effects for the first wall, rep-rated pulsed power, target fabrication, and thick liquid protected chambers with target material recovery.

The 2003 Development Plan specified the mission elements for IFE Integrated Research Experiment programs.

My Observation: Key Steps have much Synergy Between MFE and IFE

- Long-life plasma-surface interaction physics and technology
  - Tungsten or liquid surface first walls are best options for both
  - Much physics and technology R&D can be done in common
  - Requires separate integrated testing environments
    - MFE Performance Extension exp't / IFE Integrated Research Experiment
- Fusion blanket technology
  - Test facilities can be shared between MFE and IFE
  - ITER Test Blanket Modules will benefit both
- Neutron-interactive materials
  - Shared irradiation facility highly synergistic
    - Development timescale is long ⇒ start soon (IFMIF or LANSCE?)
  - Effects of pulsed *vs.* steady neutrons anticipated to be small
- My thoughts on IFE research priorities:
  - Resolve outstanding IFE Proof-of-Principle issues.
  - Complete integrated IFE conceptual power plant design(s).
  - Trigger Integrated Research Experiment(s) by positive PoP and NIF results.
  - Give "extra credit" to elements that maximize MFE/IFE synergy to optimize benefits to fusion development (and avoid the no-FE outcome).

There is much synergy between IFE and MFE technology R&D needs, particularly in plasma-facing materials, fusion blanket technology and neutron-interactive materials. These synergies could be exploited in a plan for further development of IFE, in order to optimize the benefits for fusion development overall at minimum cost.