U.S. Fusion Plans

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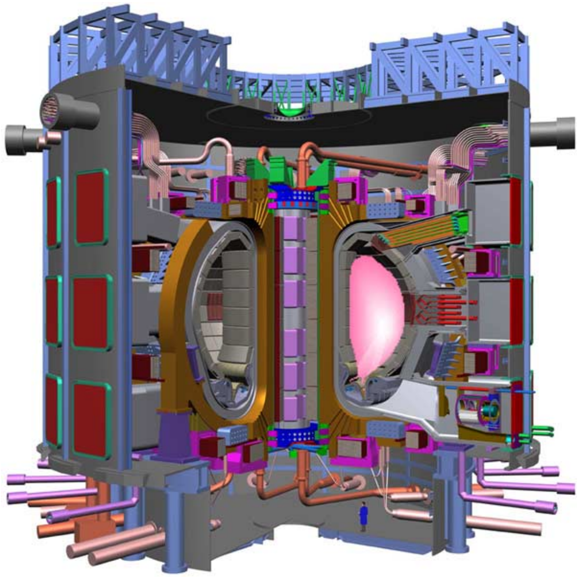
Principles

The goal of the plan is operation of a US demonstration power plant (Demo), which will enable the commercialization of fusion energy. The target date is about 35 years. Early in its operation the Demo will show net electric power production, and ultimately it will demonstrate the commercial practicality of fusion power.

The plan recognizes that difficult scientific and technological questions remain for fusion development. A diversified research portfolio is required for both the science and technology of fusion, because this gives a robust path to the successful development of an economically competitive and environmentally attractive energy source. In particular both Magnetic Fusion Energy (MFE) and Inertial Fusion Energy (IFE) portfolios are pursued because they present major opportunities for moving forward with fusion energy and they face largely independent scientific and technological challenges.

NIF and ITER Drive the Urgency of the Plan

NIF **ITER**



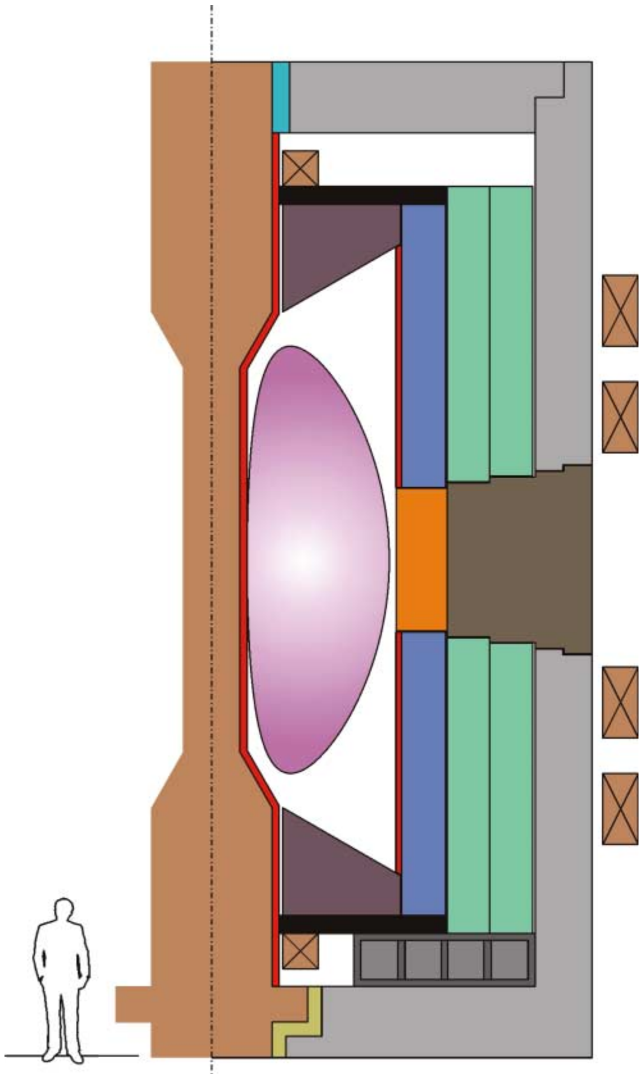
A strong parallel effort in the science and technology of fusion energy is required to guide research on these experimental facilities and to take advantage of their outcome.

What is CTF?

- The idea of CTF is to build a small size, low fusion power driven DT plasma-based device in which Fusion Nuclear Technology experiments can be performed in the relevant fusion environment at the smallest possible scale, cost, and risk.
  - In MFE: small-size, low fusion power can be obtained in a low-Q plasma device such as a tokamak, ST or possibly gas dynamic trap.
  - Equivalent in IFE: reduced target yield and smaller chamber radius

- This is a faster, much less expensive, less risky approach than testing in a large device which will be strongly limited by tritium consumption as full breeding and tritium purging is achieved, and which will have a very large blanket to be replaced in multiple tests.

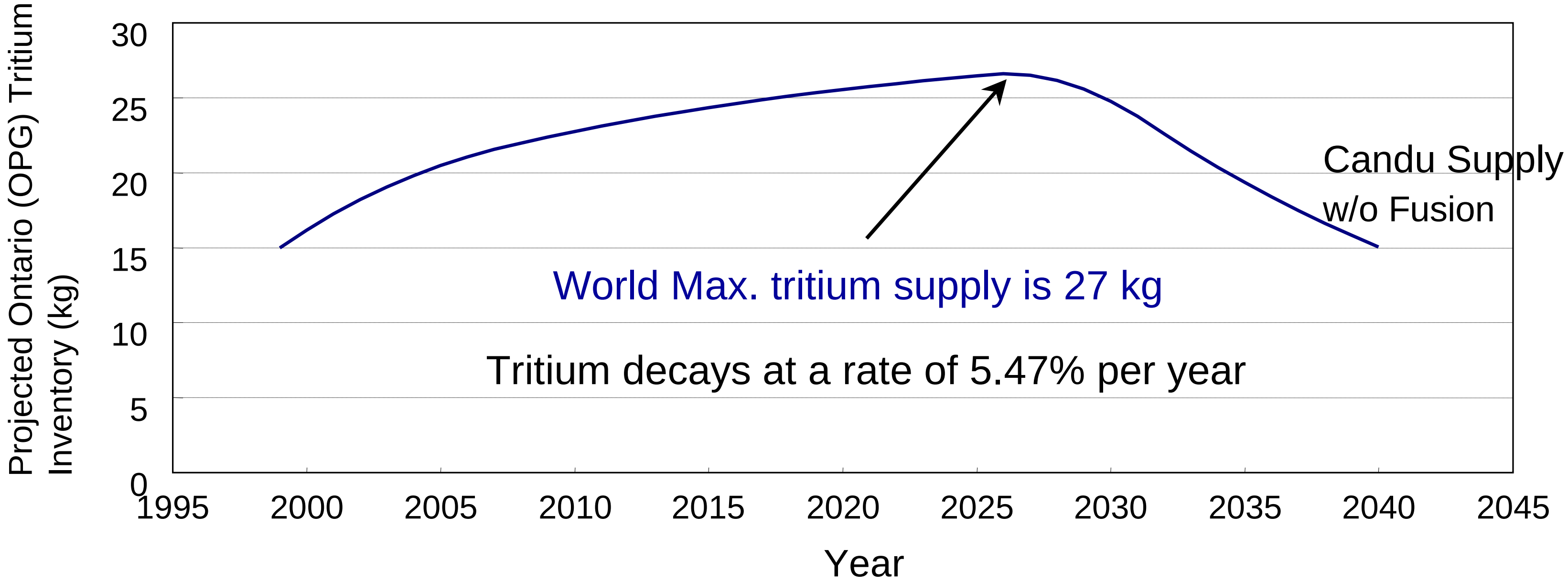
Single Turn TF Leads to an Attractive ST CTF



R = 1.2m, a = 0.8m

Wall Loading at Test Modules (MW/m²)	1.0	3.0
HH (ITER98pby2)	1.4	1.8
Applied toroidal field (T)	2.4	2.2
Plasma current (MA)	12.6	11.4
Normalized beta (β_N)	4.1	7.0
Toroidal beta (β_T, %)	26.8	45.1
n/n_{GW} (%)	17	52
Q (using NBI H&CD)	2.4	5.8
Fusion power (MW)	72	214
Number of radial access ports	7	7
Radial access test area (m²)	12.8	12.8
P_{Heat}/R (MW/m)	37	67
Tritium burn rate (kg/full-power-year)	4	12
Total facility electrical power (MW)	286	272
Fraction of neutron capture (%)	81.6	81.6
Local T.B.R. for self-sufficiency	1.23	1.23
Toroidal field coil current (MA)	14.6	13.2
Center post weight (ton)	89	89
Capital cost ($B) with 40% contingency	1.47	

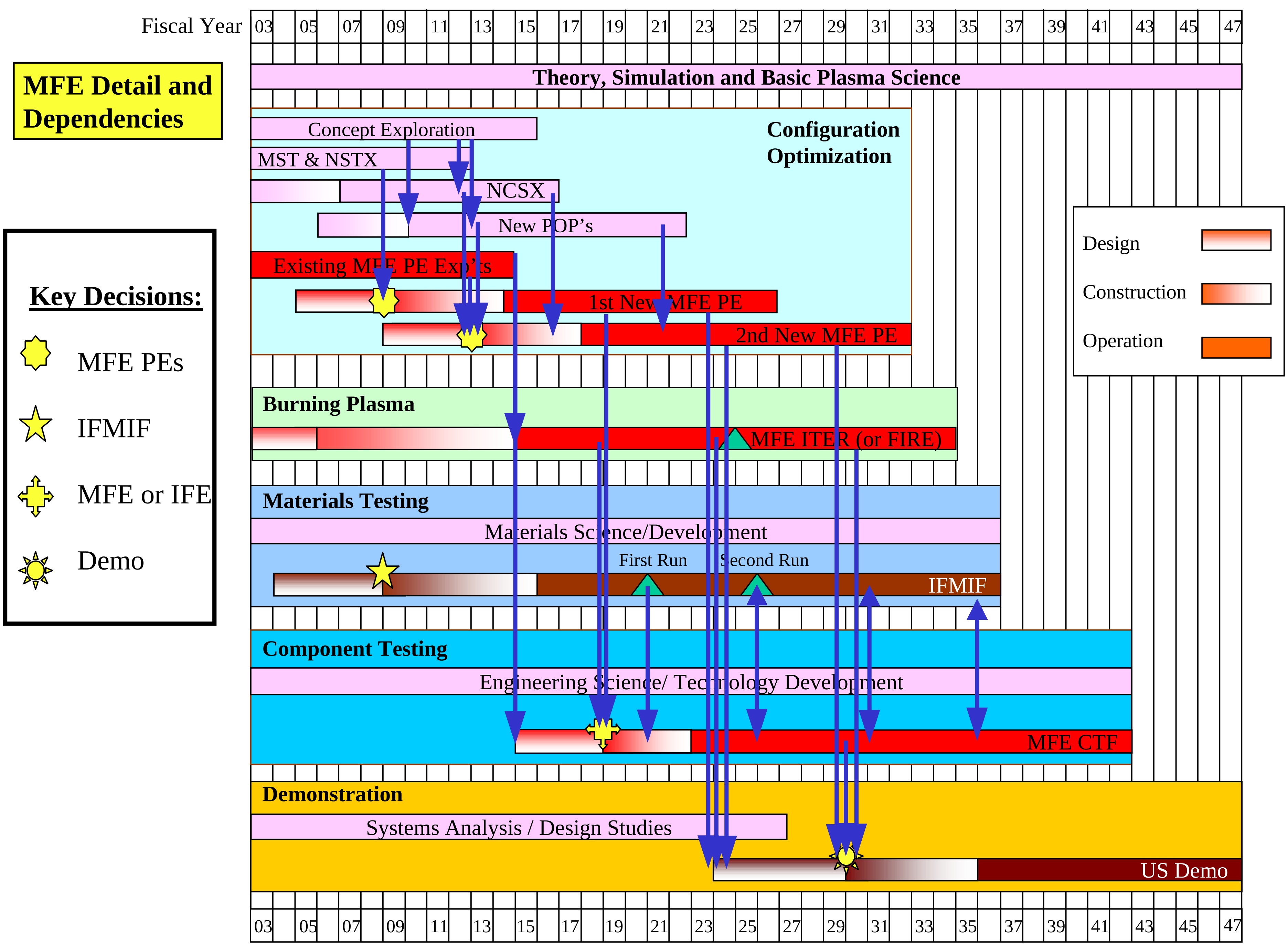
Projected Tritium Supply Impacts Blanket Testing



- ITER will burn ~7.5 kg T and provide ~2 weeks of Demo neutron fluence.
- A fission reactor can produce a few kg of tritium per year, at $200M/kg.
- A DT facility burns tritium at a rate of:

3 kg/week per 2800 MW of fusion power

You must stop any test and replace the full blanket if 500g of tritium is not regenerated or is held up in the blanket.
*At 3% loss this is **6 weeks** for Demo – an unacceptable period to change out **~1000 m²** of blanket.*
*For a 100 MW CTF the period is **3 years** and the area is **~50m²**.*



MFE Detail and Dependencies
Fiscal Year
03 05 07 09 11 13 15 17 19 21 23 25 27 29 31 33 35 37 39 41 43 45 47
Theory, Simulation and Basic Plasma Science
Configuration Optimization
Concept Exploration
MST & NSTX
NCSX
New POP's
Existing MFE PE Exp'ts
1st New MFE PE
2nd New MFE PE
Burning Plasma
MFE ITER (or FIRE)
Materials Testing
Materials Science/Development
First Run
Second Run
IFMIF
Component Testing
Engineering Science/ Technology Development
MFE CTF
Demonstration
Systems Analysis / Design Studies
US Demo
Key Decisions:
MFE PEs
IFMIF
MFE or IFE
Demo
Design
Construction
Operation

Goals, Specific Objectives and Key Decisions - I

Present – 2009: ***Acquire Science and Technology Data to Support MFE and IFE Burning Plasma Experiments and to Decide on Key New MFE and IFE Domestic Facilities; Design the International Fusion Materials Irradiation Facility***

Specific Objectives:

- Begin construction of ITER, and develop science and technology to support and utilize this facility. If ITER does not move forward to construction, then complete the design and begin construction of the domestic FIRE experiment.
- Complete NIF and ZR (Z Refurbishment) (funded by NNSA).
- Study attractive MFE configurations and advanced operation regimes in preparation for new MFE Performance Extension (PE) facilities required to advance configurations to Demo.
- Develop configuration options for MFE Component Test Facility (CTF).
- Participate in design of International Fusion Materials Irradiation Facility (IFMIF)
- Test fusion technologies in non-fusion facilities in preparation for early testing in ITER, including first blanket modules, and to support configuration optimization.
- Develop critical science and technologies that can meet IFE requirements for efficiency, rep-rate and durability, including drivers, final power feed to target, target fabrication, target injection and tracking, chambers and target design/target physics.
- Explore fast ignition for IFE (funded largely by NNSA).
- Conduct energy-scaled direct-drive cryogenic implosions and high intensity planar experiments (funded by NNSA).
- Conduct z-pinch indirect-drive target implosions (funded by NNSA).
- Provide up-to-date conceptual designs for MFE and IFE power plants.
- Validate key theoretical and computational models of plasma behavior.

2008 Decisions: Assuming successful accomplishment of goals, the cost-basis scenario assumes that by this time decisions are taken to construct:

- International Fusion Materials Irradiation Facility
- First New MFE Performance Extension Facility
- First IFE Integrated Research Experiment Facilit

Goals, Specific Objectives and Key Decisions – II

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)

Goals, Specific Objectives and Key Decisions – III

2020 – 2029 *Qualify Materials and Technologies in Fusion Environment*
Specific Objectives:

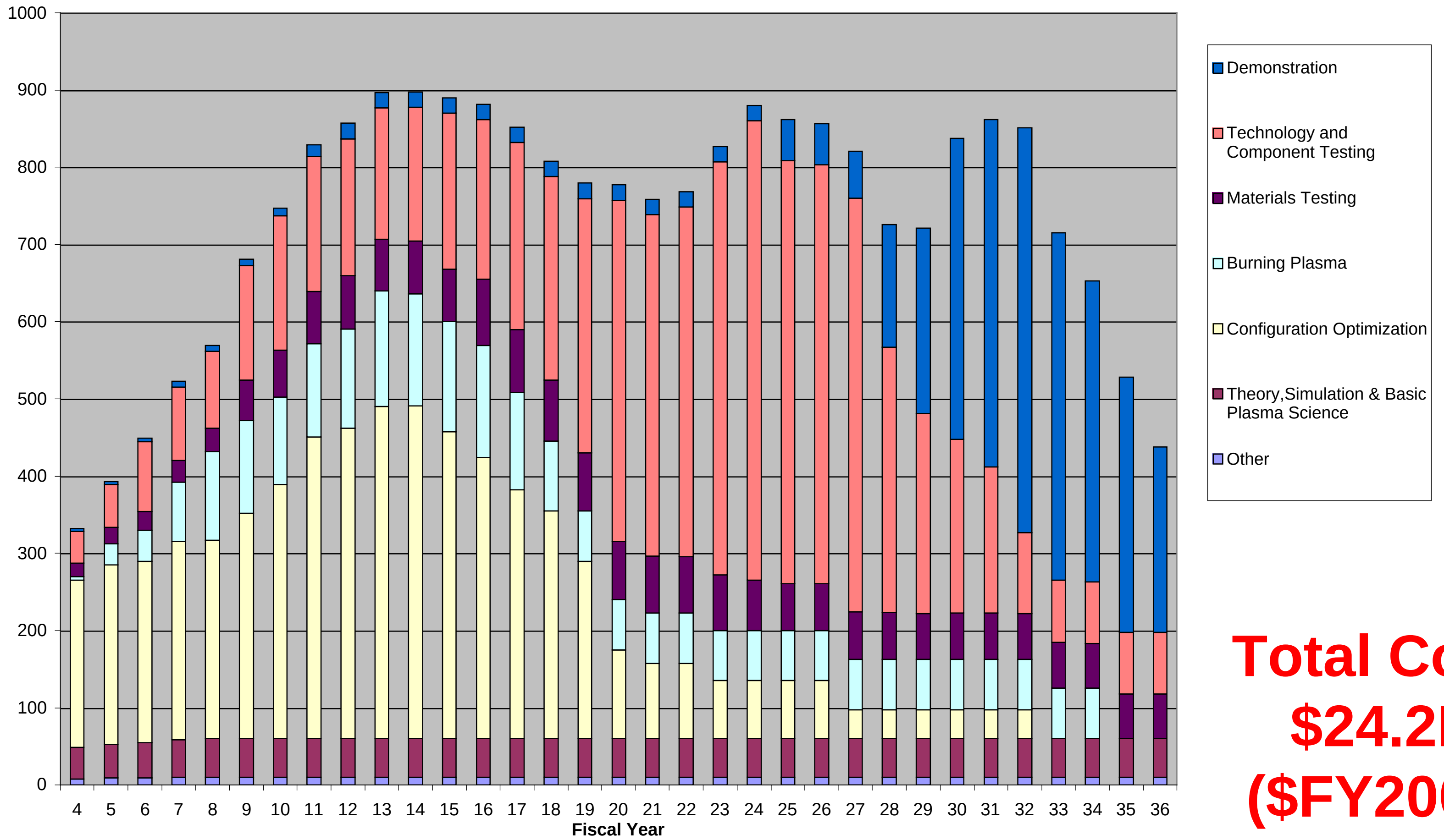
- Operate ITER with steady-state burning plasmas providing both physics and technology data.
- Qualify materials on IFMIF with interactive component testing in CTF or ETF, for implementation in Demo.
- Construct CTF or ETF; develop and qualify fusion technologies for Demo.
- On the basis of ITER and CTF/ETF develop licensing procedures for Demo.
- Use integrated computational models to optimize Demo design.

2029 Decision:

- Construction of U.S. Demonstration Fusion Power Plant

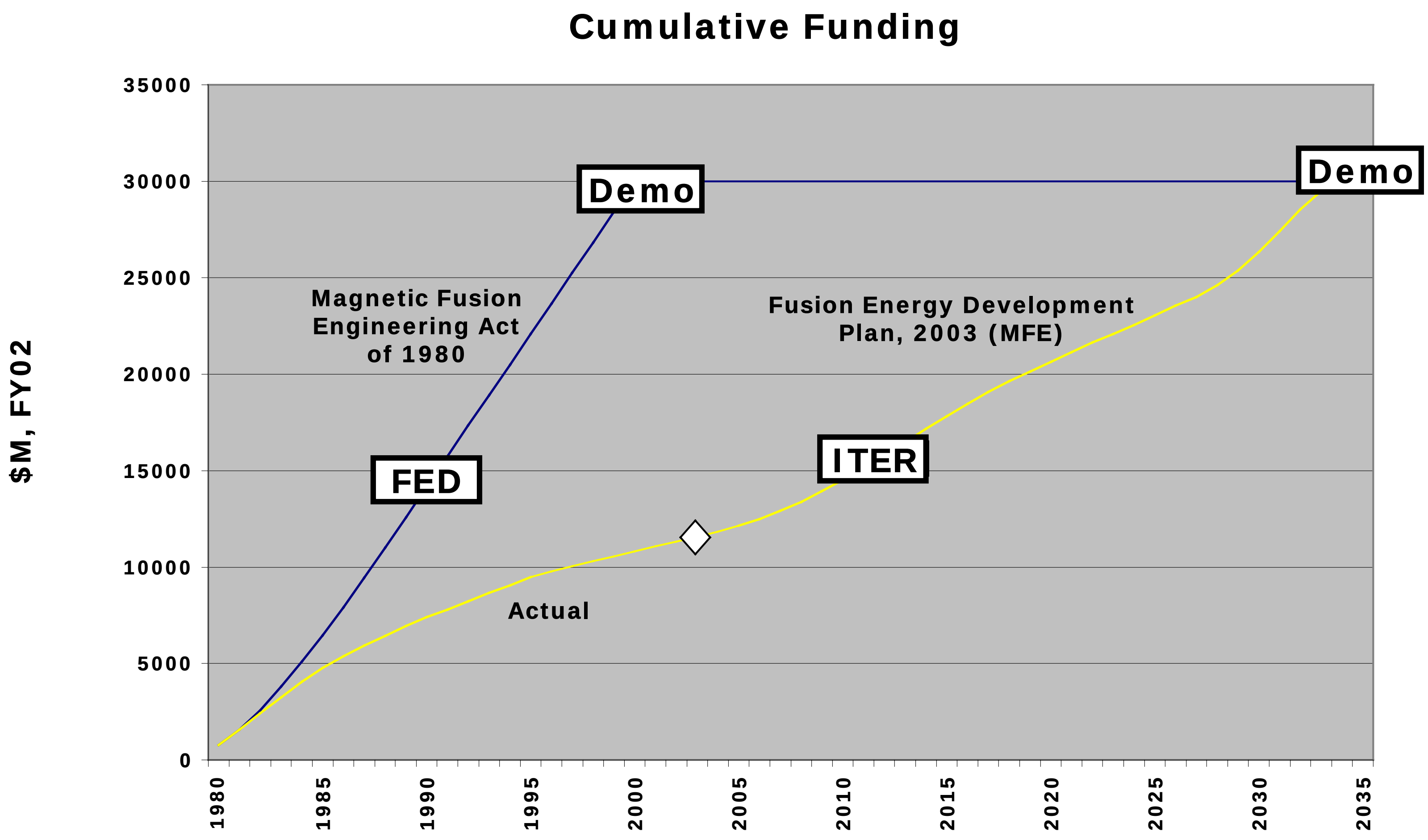
2030 – 2035: *Construct Demo*
Specific Objective: Operation of an attractive demonstration fusion power plant.

The Fusion Budget Needs to ~ Double over the Next Five Years, and if Positive Decisions are then made, will Need to Rise by a Further ~ 50%, to ~ 1980 Level



Total Cost: $24.2B ($FY2002)

The Estimated Development Cost for Fusion Energy is Essentially Unchanged since 1980



Fusion Development is on Budget.

Key Observations

The FIRE Scenario

In the FIRE path the integration of burning plasmas with steady state operation is deferred to a later time. One impact of the deferral is that the integration would then first occur in the Component Test Facility. Thus an initial period of CTF operation, likely of several year duration, would be required to acquire operating experience with steady-state deuterium-tritium plasmas and fusion chamber technology. Similarly the start-up time of the DEMO might be extended for integration at large scale.

The Plasma Configuration of the MFE Demo

The cost-basis scenario as articulated provides for the option that Demo can be configured differently from the advanced tokamak as it is presently understood. It should be anticipated, however, that the initial operation of Demo will require more learning in this case and the initial production of electricity would be somewhat delayed as a result.

Management Considerations

To achieve the goals of this plan, the program must be directed by strong management. Given constrained budgets, the wide variety of options and the linkages of one issue to another, increasingly sophisticated management of the program will be required.

Conclusions

The U.S. fusion energy sciences program is ***still suffering from the severe budget cuts of the mid-1990's and the loss of a clear national commitment to develop fusion energy.*** The result is that despite the exciting scientific advances of the last decade it is becoming difficult to retain technical expertise in key areas. ***The President's fusion initiative has the potential to reverse this trend, and indeed to motivate a new cadre of young people not only to enter fusion energy research, but also to participate in the physical sciences broadly.*** With the addition of the funding recommended here, an exciting, focused and realistic program can be implemented to make fusion energy available on a practical time scale. On the contrary, ***delay in starting this plan will cause the loss of key needed expertise and result in disproportionate delay in reaching the goal.***