Fusion Energy

An Industry-Led Initiative

September 10, 1993

A Team Effort

TRW

Rockwell

Bechtel

General Dynamics

SAIC

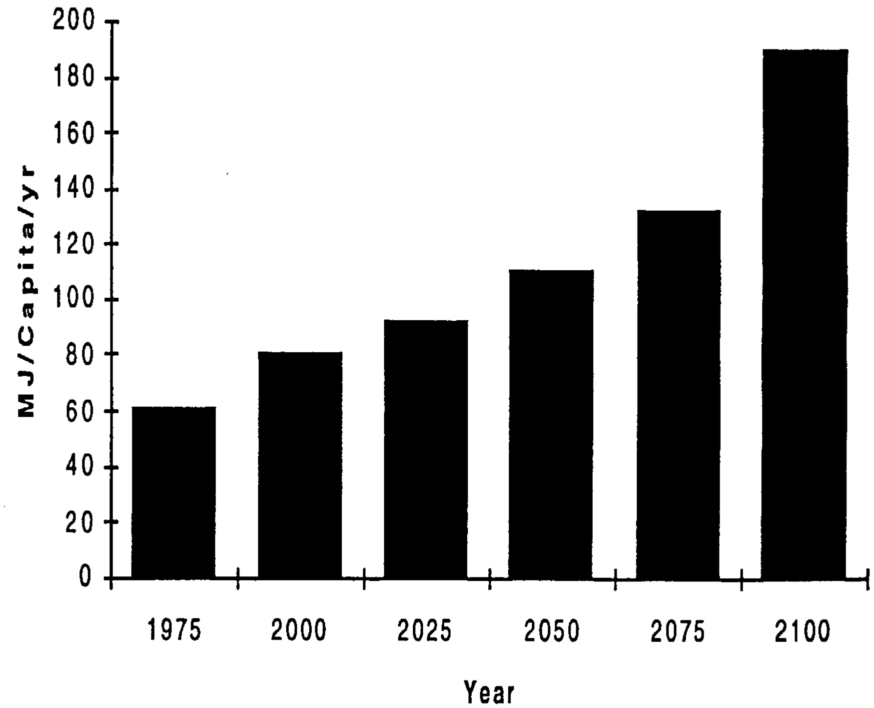
Lawrence Livermore National Laboratory

University of California at Los Angeles

Energy Supply and Needs

- Global Per Capita energy usage will increase even under the best assumptions of conservation
- We cannot meet these needs with our current approaches and satisfy environmental needs
  - Atmospheric carbon release
  - Non-renewable

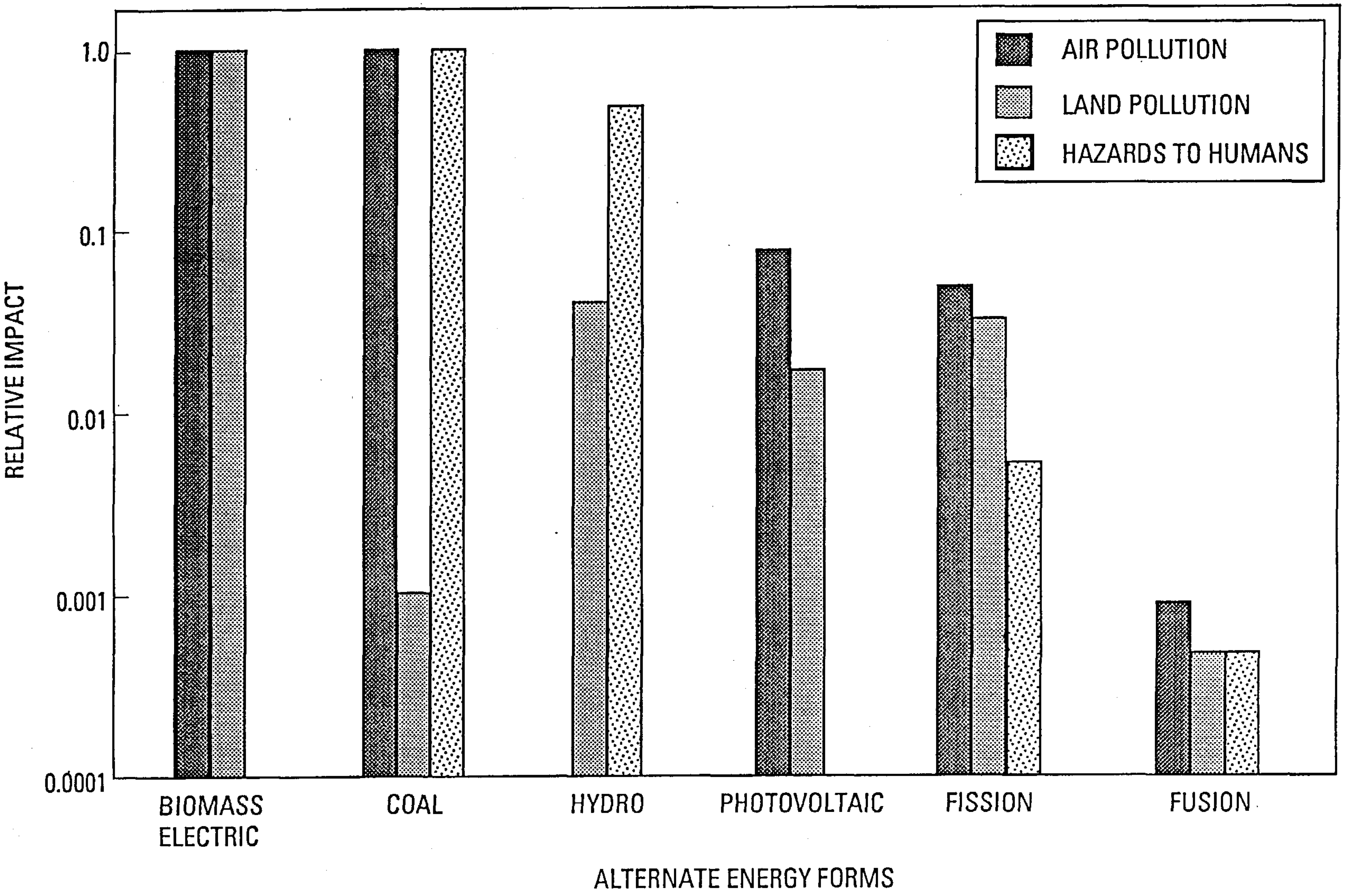
Global per capita energy usage



The Cost and Benefit of Energy Technology in the Global Context
Dr. John F. Clarke October 1991

Fusion: The Most Desirable Form of Energy

TRW



SOURCE: "SAFETY AND ENVIRONMENTAL ISSUES FOR FUSION ENERGY: ACHIEVING THE POTENTIAL,"
JOHN P. HOLDREN, CLASS OF 1935 PROFESSOR OF ENERGY, UNIVERSITY OF CALIFORNIA, BERKELY

R1M 93.0118.01

Fusion is a Solution

- Big business not big science
  - International Competitiveness issue - $26T/yr energy market with $300B/yr future market for fusion power stations (10% of market assumption)
  - Industrial base is needed to capitalize on this market opportunity
- Comprehensive program is needed for success
  - Identify and focus on key issues requiring resolution for DEMO and Power Plant
  - Add content to assure a complete program
  - Involve industry with expertise in implementation of complex multi-disciplined programs

U.S. Energy Supply and Needs

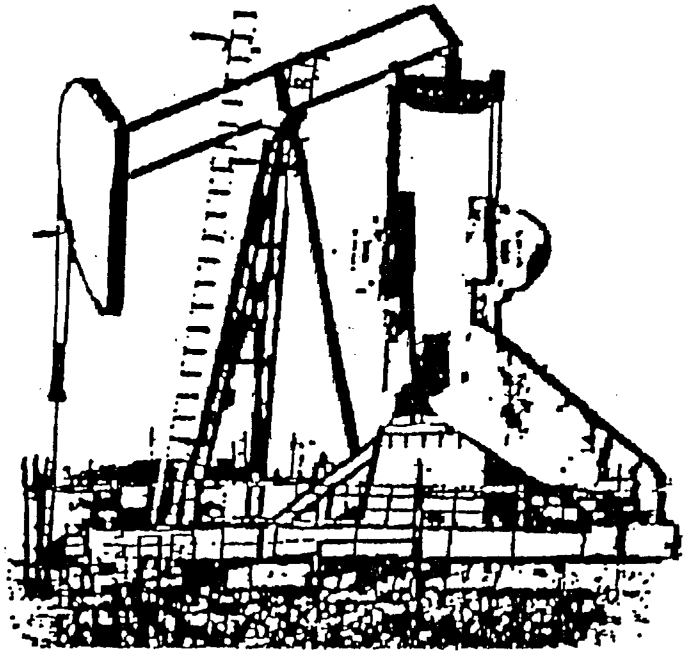
- **Coal, oil and natural gas will continue to be the dominant sources of energy in the U.S. during the next thirty years**
  - Coal for electrical power production
  - Oil for transportation
  - Natural gas for heating/electrical power
  - Nuclear fission's role is diminishing
- **Global warming from greenhouse gases and pollution may require shift from fossil fuels**
- **Domestic supply of oil is decreasing by 10% per decade but growing usage of natural gas is occurring**
- **Nuclear fission is not being pursued in the U.S. because of poor public acceptance and regulatory response**
  - Radioactive waste and safety concerns
- **The long term sources of energy are**
  - Geothermal energy
  - Sunlight and its derivatives
  - Fission energy based on breeders
  - Clean coal (several hundreds of years)
  - Fusion energy

U.S. Energy Supply and Needs *(continued)*

- **Fusion offers the following advantages when compared to the other long term sources**
  - Reduced impact on ecological and geophysical processes and lower cost when compared to geothermal, biomass and sunlight
  - Reduced radiological and nuclear materials proliferation hazards when compared to fission breeders
  - Reduced emissions to the atmosphere when compared to coal

- **Global warming, pollution and national economic competitiveness make it important to have a viable fusion energy option by the 2020's**

High Energy Import Cost Will Decrease U.S. Competitiveness in Energy Intensive Industries and Increase Trade Imbalance Problems


TIME March 16, 1992

Rising U.S. Imports	*Economic Impact*
1982 1.4 billion barrels 30% of usage	**1982** $47B of imports 1.1% of GNP
1990 2.9 billion barrels 43% of usage	**1990** $54B of imports 1% of GNP (1.7% at 1982 prices)
2010 5.5 billion barrels* 70% of usage	**2010** 75% of oil company investments are currently outside of US

* Congressional assessment

The Status of Magnetic Fusion Energy Development

- **Fusion research has been supported worldwide since the 1950s as a promising energy option**

- **The promise of fusion:**
  - **Unlimited fuel supply from seawater — universal availability**
  - **Safe and environmentally attractive**
    - no greenhouse gases, acid rain or pollution
    - minimal radiological and nuclear proliferation hazards
    - no possibility of a runaway or meltdown
    - minimal land use and mining
  - **Monetary costs are comparable to other long-term energy options**

- **JET and TFTR are establishing the scientific feasibility of the Tokamak approach to fusion**
  - **JET has achieved energy equivalent breakeven with deuterium**
  - **TFTR is expected to demonstrate energy breakeven with deuterium and tritium next year**

- **Long pulse, ignited burn and the physics of reactor relevant Tokamaks remain to be demonstrated in ITER**

- **Safe, environmentally attractive and economic designs of commercial fusion remain to be developed and demonstrated**

Suggested Objectives for the Fusion Program

➤ **Objectives**

1) **Establish fusion as a viable energy source for the U.S. by 2025**
   - Develop a realistic approach to acquire engineering, material, and operational data for a demo plant by 2025
   - Satisfy environmental, safety and economic concerns early

2) **Position U.S. industry to become a competitive world supplier of fusion power**
   - Establish U.S. commercial preeminence
   - Establish a sustained industrial program with design, fabrication and operational experience

3) **Participate in the International program to reduce the national cost of fusion development**
   - Commit to build ITER

A Suggested U.S. Strategy for Fusion

- **Objective 1**
  - Establish fusion as a viable energy source for the U.S. by 2025

- **U.S. Strategy Towards Objective 1**
  - Provide the comprehensive set of required data for fusion development by utilizing a complete set of machines
  - Assure that ITER maintains its current schedule
  - Add program content to provide data in time for a 2025 demo design
    - Long lead engineering and environmental issues
    - Operational and safety issues
  - Gain public, environmentalist and utility support for the demo

What is Needed for Demo

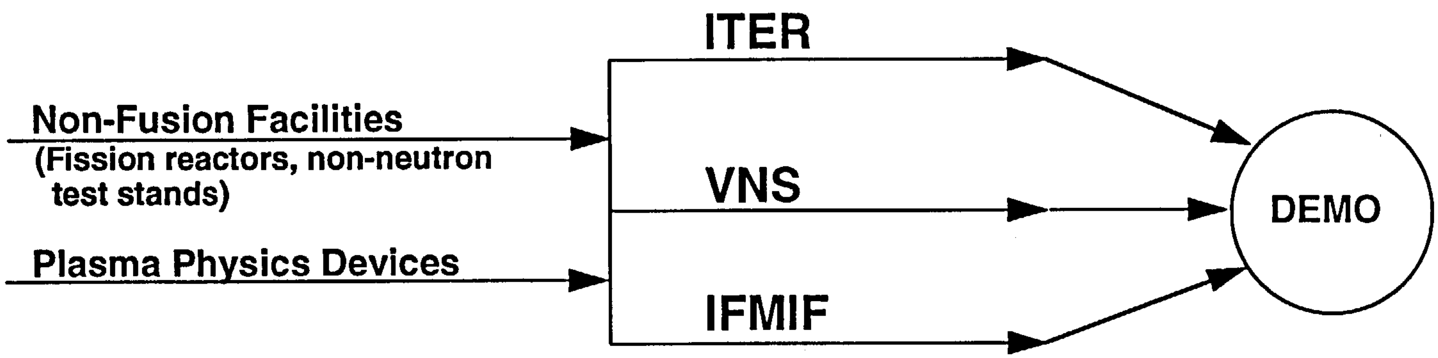
- **Complete set of requirements**
  - Physics and Engineering basis
  - Nuclear technology
  - Operability and maintainability
  - Environmental desirability
  - Economic impact
  - Safety
- **Balanced tradeoff of these requirements to achieve optimal design**
- **Verification program to remove uncertainties and complete design in parallel**
- **Significant involvement of Aerospace industries that have performed this task for significant national programs**
  - Ballistic Missile Development
  - Apollo program

R&D Tasks to Be Accomplished Prior to DEMO

1) **Plasma**
   - Confinement
   - Divertor
   - Disruption control
   - Current Drive
2) **System Integration**
3) **Plasma Support Systems**
   - Magnets
   - Heating
4) **Fusion nuclear technology components and materials (blanket, first wall, high performance divertors)**
   - Materials combination selection
   - Performance verification and concept validation
   - Show that the fuel cycle can be closed
   - Failure modes and effects
   - Remote maintenance demonstration
   - Reliability growth
   - Component lifetime

- **ITER will address most of 1, 2 and 3**
- **Fusion Nuclear Technology (FNT) components and materials require dedicated fusion-relevant facilities parallel to ITER**

Prudent and Optimum Path to DEMO Requires Three Parallel Facilities

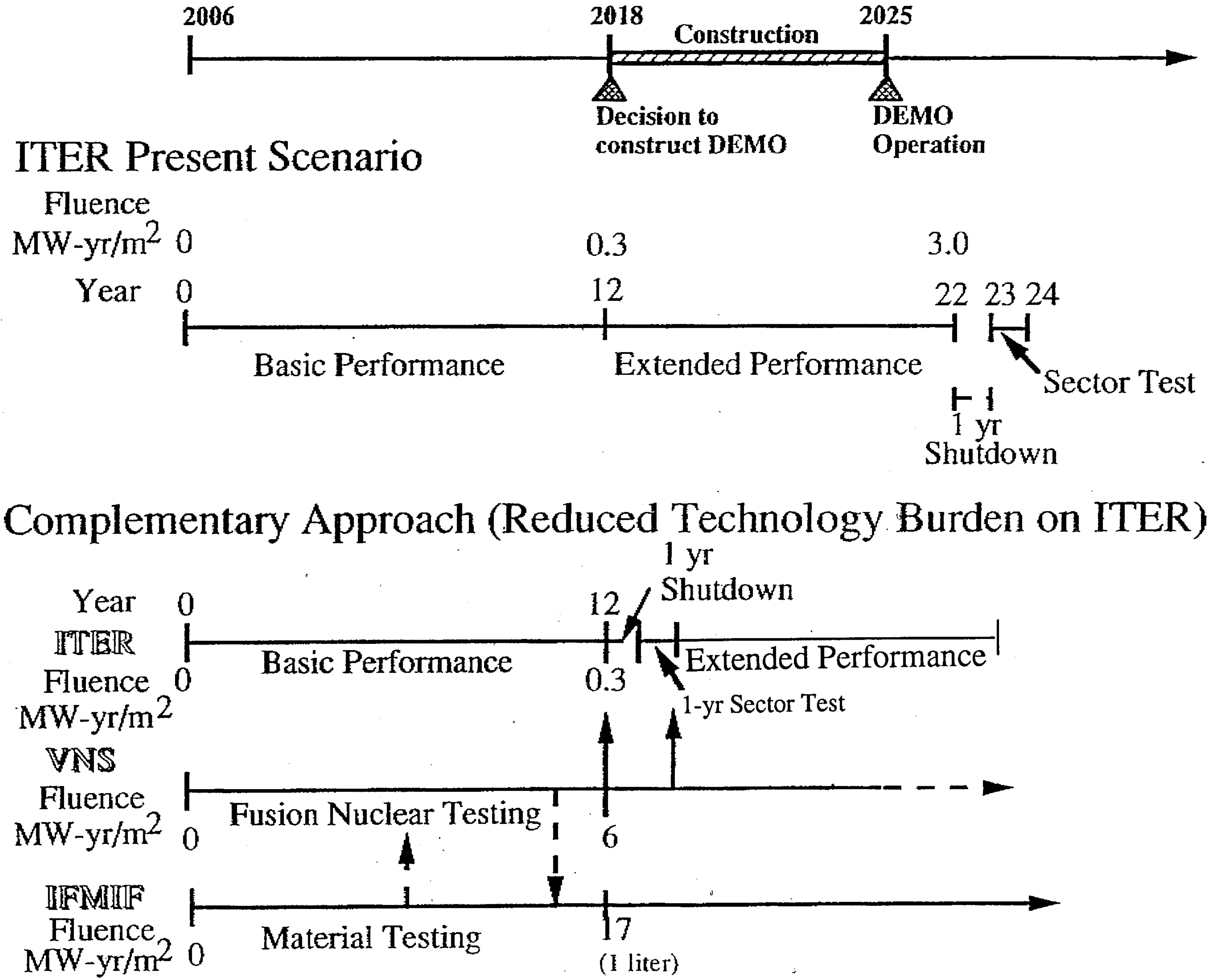


ITER Fusion core (plasma), system integration, plasma support technology

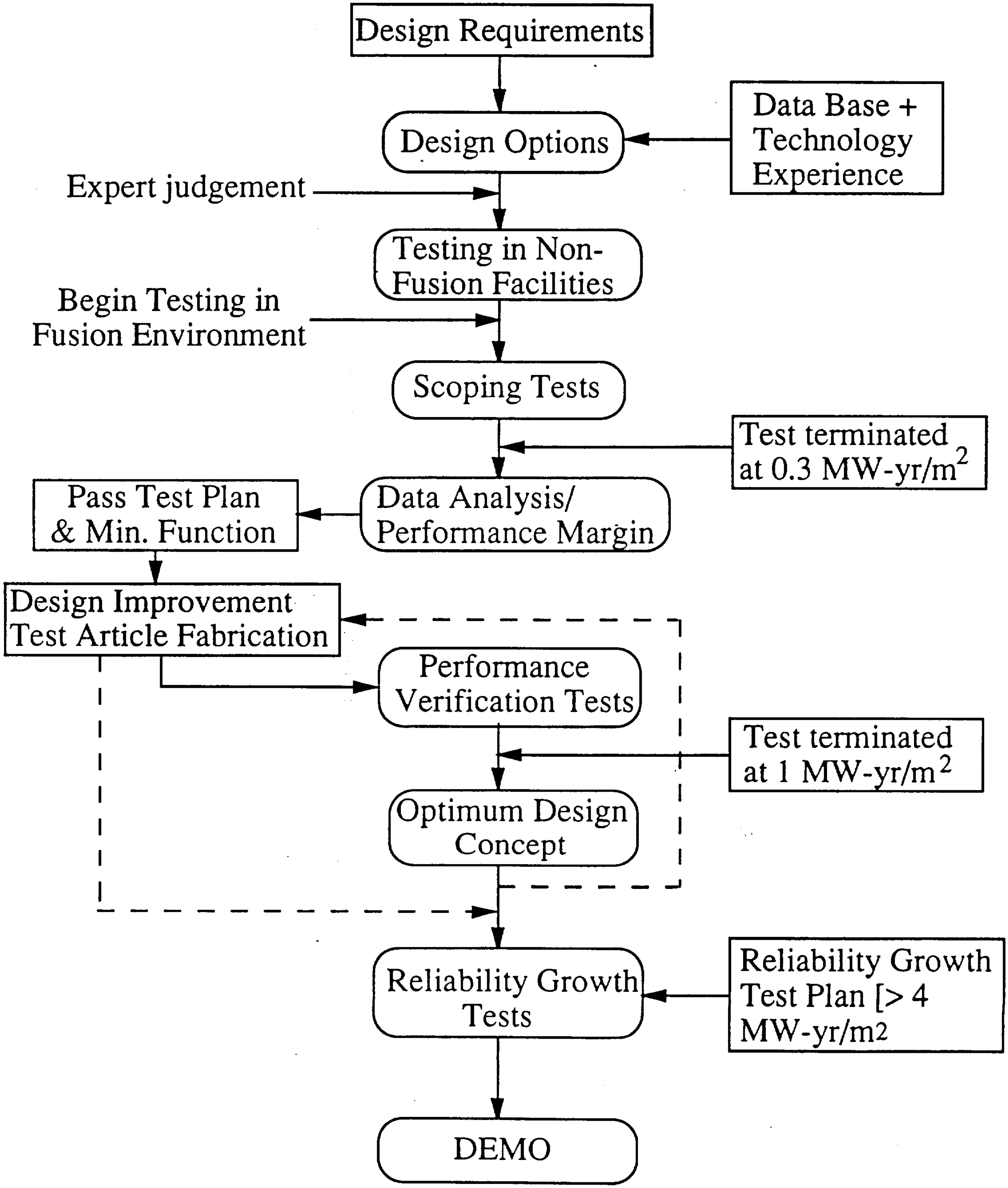
VNS (<u>V</u>olumetric <u>N</u>eutron <u>S</u>ource) Dedicated fusion facility to test, develop and qualify fusion nuclear technology components and material combinations (>10 m^3 test volume)

IFMIF ("Point" Neutron Source, Materials Test Facility,MTF) Small volume (<0.001 m^3), high availability facility to address radiation effect lifetime issues

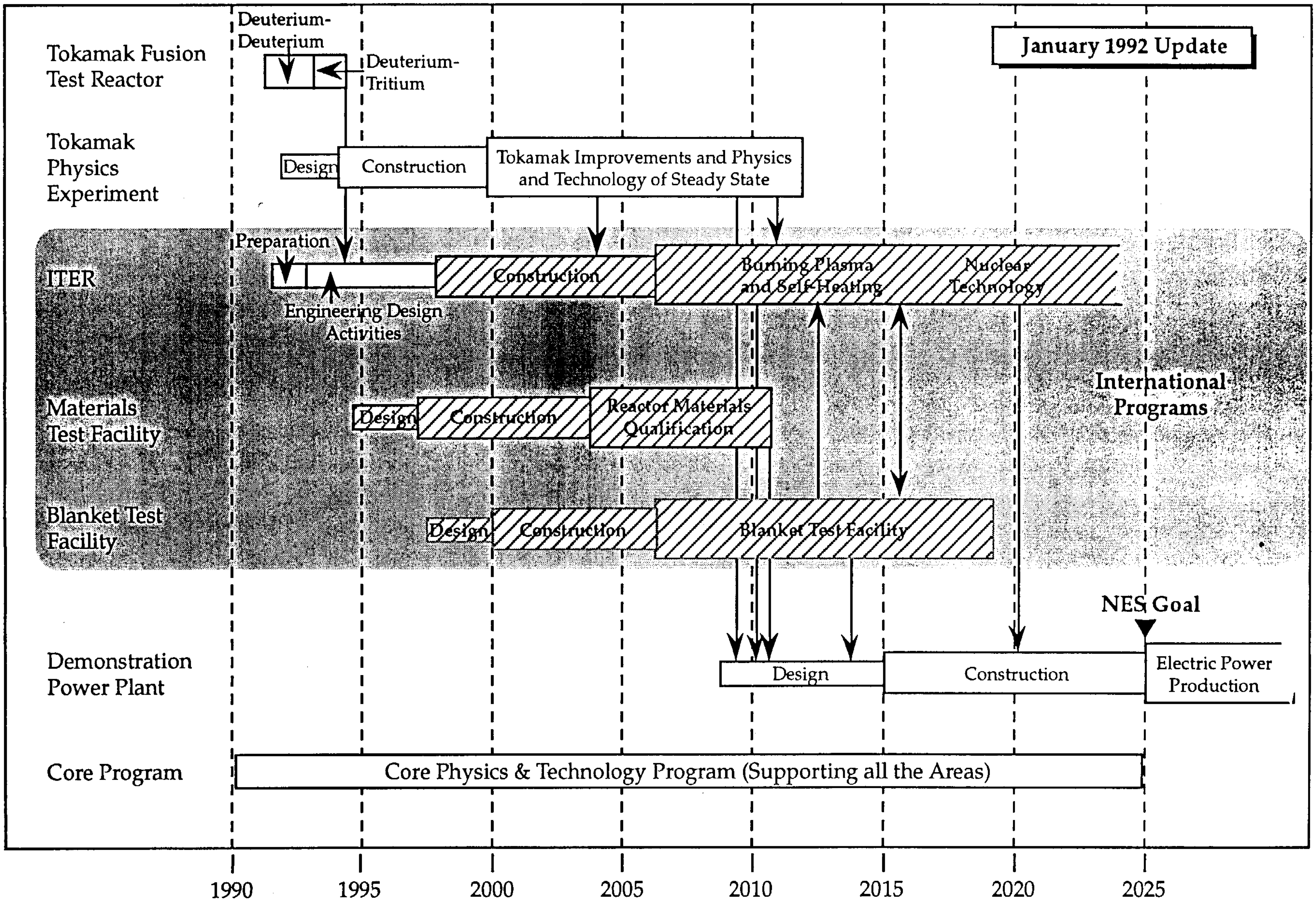
VNS Is Necessary to Meet DEMO Time Schedule



Fusion Nuclear Technology Development Approach



U.S. Magnetic Fusion Energy Development Strategy



Not committed to in current program

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TR#3-9/10/93-L1-15

A Suggested U.S. Strategy for Fusion (continued)

- **Objective 2**
  - Position U.S. industry to become a competitive world supplier of fusion power
- **U.S. Strategy Towards Objective 2**
  - Continue industrial effort in design and siting of ITER
  - Establish significant meaningful industrial role in TPX
  - Assure a substantial, sustained U.S. industry-led fusion engineering project
  - Commit to industry design and siting studies of needed facilities (MTF and VNS) now

Volumetric Neutron Source (VNS)

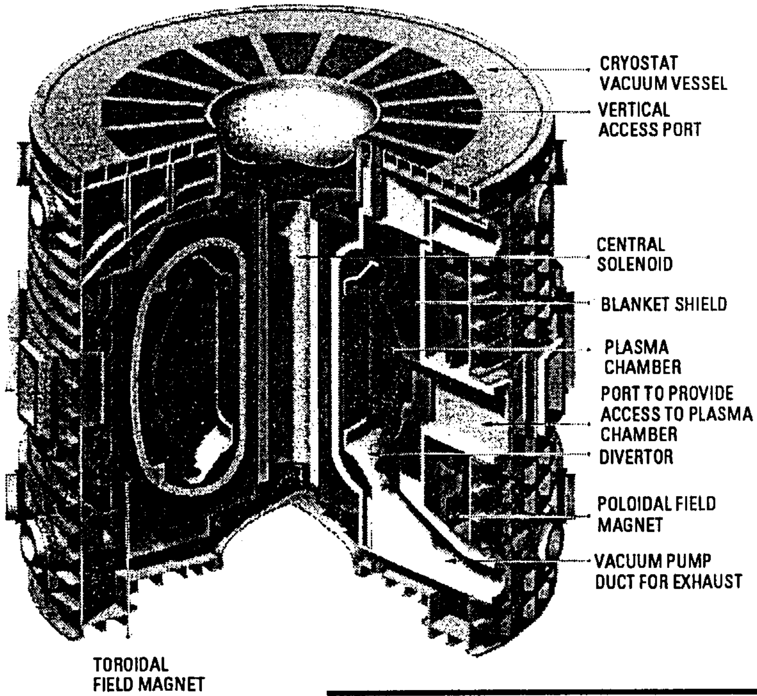
- **Objectives**
  - Provide the engineering basis for economical and environmentally sound designs for fusion power plants
  - Establish safety and design standards for the fusion power industry
  - Gain utility acceptance prior to demo
  - Provide the basis for competitiveness in fusion development and commercialization by a U.S. industry-led design activity

- **Approach**
  - Establish an industry led team and design an engineering test reactor to accomplish
    - Testing of fusion blankets, high heat flux components and other nuclear technologies
    - Qualification of components and subsystems that have high impact on economics, environment and safety
    - Maintainability and reliability qualification
    - Operational experience

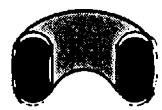
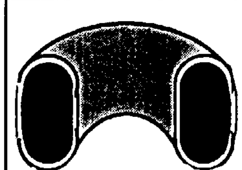
Volumetric Neutron Source (VNS) *(continued)*

- **Key features and operating parameters**
  - Industry-led and operated
  - Size is small relative to ITER
    - — One-tenth of the plasma volume
  - Based on established Tokamak physics
  - 100-200 MW of fusion power
  - 30% availability with continuous operation for several weeks
  - Greater than 10 m^2 of surface area with neutron fluxes of 1 MW/m^2

The VNS Design Will Use Existing Tokamak Physics Base



- TFTR (U.S.) — operational
- JET (E.C.) — operational
- ITER (U.S., E.C., Japan, Russia) — design
- VNS (U.S.) — proposed

		TFTR	JET	ITER ($8-10B)	VNS ($4-5B)
					
Minor radius	a	0.85	1.25m		0.75-~~8.8~~ 0.88m
Major radius	R	2.48m	2.96m	6.0-7.75m	3.25-3.5m
Toroidal field	B	5.0T	3.45T	4.8-6T	4.2T
Input power	P	30MW	36MW	30-180MW	150-200MW
Fusion factor	Q_{DT}	0.25	0.9	40	1-1.2
Plasma current	I	3	7	22-30	3

Problem – Increased Funding
A California Industry-led Initiative

- **California needs major federal projects to offset the impact of the declining defense budgets***
  - 178,000 jobs lost, 19% share of DoD loss, 3 times any other state
  - A politically important State

- **Federal funds are being made available for the defense industry conversion to commercial applications**
  - Fusion development could be to the high-tech California defense industry what aerospace has been
  - The business potential for commercial fusion power could be greater than $100B/yr
  - Fusion energy addresses the need for a long range economic, environmentally sound source of energy

- **A California industry-led fusion initiative should be considered for these funds**
  - Industry has the capability to take the lead on VNS design and siting
  - An early fast start on VNS design provides jobs now
  - Positions U.S. industry for a prime role in fusion energy
  - Initiates a substantial industry program now

"Adjusting to the Drawdown" – report of Defense Conversion Commission, Dec. 1992

Gaining Support for the Initiative

➤ **Use <u>new</u> federal funds to create a fast track schedule which has early impact on jobs and makes a major commitment by 1996**

	FY '94	FY '95	FY '96	>FY'96
Funding	$25-50M	$100M	$150M	>$250M
Milestone	Program plan conceptual design, design start, site characterization	Design and site selection	Complete design, gain International commitment to build	Construction and operation
Employment (direct only)	400	1000	1500	>5000

- **Form industry-led team (defense, energy engineering, utilities, national laboratories and universities)**

Gaining Support for the Initiative *(continued)*

- **Gain support for VNS in the current fusion program**
- **Seek California legislative and administration support**
  - Increases chance for a major fusion facility
  - More jobs now
- **Seek Federal administrative support from the Clinton administration officials who are responsible for:**
  - Helping the California community
  - Defense alternatives, nuclear non-proliferation, jobs and economy, science and technology and energy
  - Show that this project is an excellent candidate for defense conversion funding
- **Seek congressional support for same reasons**

Status of California Activities

- **California Trade and Commerce Department assigned lead by Governor Wilson for California ITER task force**
- **California Red Team of leading citizens is being formulated by Trade and Commerce**
  - Series of meetings planned for September and October
  - Recommendation for membership submitted by TRW and UCSD
- **Opening speech at IAEA meeting hosted by UCLA will be given by Mr. Loren Kaye of California Department of Trade and Commerce**

A Suggested U.S. Strategy for Fusion (continued)

- **Objective 3**
  - **Participate in the International program to reduce the national cost of fusion development**
- **U.S. Strategy Towards Objective 3**
  - Formulate and gain commitment to a set of international facilities such that all parties find it worthwhile
    - ITER ($8-10B)
    - VNS ($2-3B)
    - MTF ($0.5-1B)
    - Other ($1.5-2B)
  - Promote the idea that the host pays a larger share of the construction costs
    - Participants should pay for what they get

A Suggested U.S. Strategy for Fusion

- **U.S. cost Strategy Towards Objective 3**
  - Estimated cost of U.S. participation for two scenarios (assumes host pays 60% of the costs)

Facility	Total Cost $B	ITER at U.S. Site $B	VNS at U.S. Site $B
ITER Site	8.0-10.0	4.8-6.0	1.6-2.0
VNS Hardware	2.0-4.0	0.6-0.8	1.8-2.4
MTF Hardware	0.5-1.0	0.1-0.2	0.1-0.2
Other	1.5-2.0	0.3-0.4	0.3-0.4
COST	12.0-17.0	5.8-7.4	3.8-5.0

  - If U.S. wins ITER site, VNS will add less than $800M over 15 years
  - If U.S. loses ITER site, VNS will provide an alternative

Rationale for Fusion Development Program with TPX, ITER, MTF and VNS

- **Divide the missions and conquer the fusion demonstration problem**
  - TPX — Optimize the physics for reactor relevant Tokamaks with steady state operation
  - ITER — Demonstrate and optimize ignition and burn physics of Tokamak reactors. Demonstrate fusion technologies and serve as an integrated test bed
  - MTF — Demonstrate advanced material solutions through accelerated testing to high fluence of material coupons
  - VNS — Demonstrate engineering and operational solutions which make Tokamak power plants safe, environmentally attractive and economical
  - DEMO — Combine all the resulting solutions into a fusion power demonstration plant

Solutions Which are Needed Prior to the Construction of a Demonstration Power Reactor

REQUIRED SOLUTION	PRIMARY FACILITY
Physics/Technology	
Current drive for steady state operation	TPX
Profile tailoring to improve beta and reduce transport	TPX
Plasma heating, fueling and disruption control	ITER
Plasma ignition and sustained burn	ITER
Divertor power handling and particle control	ITER
Materials	
Qualification of structures, components and subsystems with low activation materials	VNS
Qualification of low activation materials to full lifetime	MTF
Radiation-resistant welds, insulators and conductors	MTF

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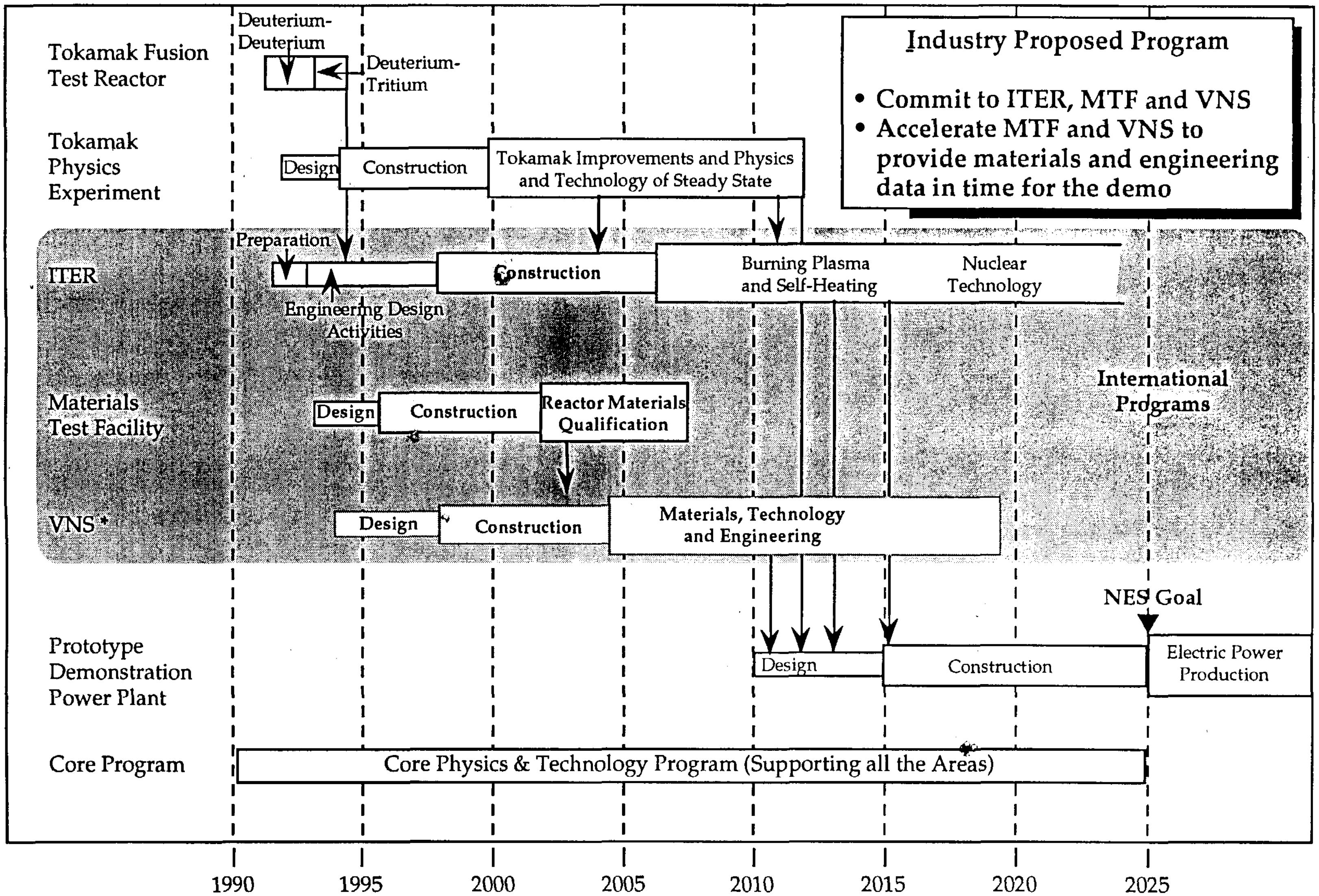
Solutions Which are Needed Prior to the Construction of a Demonstration Power Reactor *(con't)*

REQUIRED SOLUTION	PRIMARY FACILITY
Engineering/Technology	
Economical and environmentally acceptable fusion power and breeding blankets	VNS
Moderate availability operation (30%)	VNS
High maintainability and reliability	VNS
Safe and environmentally acceptable tritium fuel cycle	VNS, ITER
Shielding/neutronics in Tokamak geometry	VNS, ITER
Large scale magnets and structures	ITER
Demonstration of safe and environmental acceptable fusion power production	VNS

Proposed Magnetic Fusion Energy Development Strategy with VNS



*Referred to as Blanket Test Facility in U.S. MFE strategy.

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Requested Help from DOE

- **Incorporate the strategy discussed in the DOE Fusion Strategy**
  - Achieve a full set of programs to enable a 2025 demo and to attract full international participation
  - Focus on engineering and operational solutions to environmental, safety and economic issues
  - DOE support and/or leadership to identify defense conversion funds to allow early industry-led VNS design start
  - Early ITER and VNS industry-led siting studies to position the U.S. for a major project
  - Seek to have MTF and VNS an element of the International program

- **DOE enthusiasm to establish and manage the program**

- **Technical support from the DOE National Labs and Universities doing fusion research**

Summary

- **Objectives**
  - A logical, complete plan for acceptance of fusion energy and a 2025 Demonstration Power Reactor
  - Added support and funding to the magnetic fusion energy program
  - Increased probability of commitment to ITER construction and operation with full International participation
  - U.S. Industrial competitiveness in fusion power

- **Approach**
  - Add and accelerate MTF and VNS
  - Address need to bolster California economy and offset defense reductions
  - Use combination of ITER, VNS, MTF and other to provide an attractive International program set
  - An industry-led team to design VNS and site VNS/ITER
    - — Bechtel, General Dynamics, Rockwell, SAIC, TRW, University of California and Lawrence Livermore National Lab