

VNS

**A Volumetric Neutron Source for
Fusion Nuclear Technology Testing and
Development**

Mohamed A. Abdou

Authors

M. Abdou, M. Peng, A. Ying, M. Tillack, S. Sharafat

Invited Paper, ISFNT-3, June 1994

VNS

A Volumetric Neutron Source for Fusion Nuclear Technology Testing & Development

Outline

- Goals of Fusion R & D
- R & D Tasks for DEMO
- Role of ITER
- Role of Nonfusion Facilities
- FNT Needs for Fusion Facilities
- Facilities SCENARIOS to DEMO
- Role of VNS
- Design Concepts for VNS
- Arguments against VNS?
- Summary

Why Support Fusion R&D?

The Promise of Fusion:

- Renewable Energy Source
- Safe and Environmentally Attractive
- Economics is comparable to other long-term energy options

BUT

- Why Continue Support Fusion R&D at the Present World Level of \$1B/yr.?
- And, Why Increase Fusion R&D Budget to higher level?

Some of the Prerequisites to Accelerating (or just sustaining) the Fusion Program

1. Well Defined GOAL as ENERGY Program

Construct and Operate DEMO by the Year 2025

- Necessary for Fusion to Contribute to Power Production by second half of the 21st century

2. Technically and Programically Sound PROGRAM PLAN

- Program Plan must show how the major R&D Issues For Demo will be resolved on timely basis
- Plan should withstand scrutiny of external reviews

3. Systematic PROGRESS

- Technical

- Public

How Do We Score?

1. Good

2. Poor

3. Average

DEMO Goals

- Demonstrate the Potential of Fusion
 1. Safety
 2. Environmental Impact
 3. Economics
- The Size, Operations, Performance, and Reliability of DEMO must be sufficient to Demonstrate that there are no open questions about the safety, environmental impact, and economics of First Commercial Reactor.

The Private Sector

- R&D Prior to DEMO Must be sufficient to ensure High Potential for success of DEMO in order for Private Sector to Participate in DEMO
- The results of DEMO Operation Must be sufficiently successful for the Private Sector to Begin Commercialization of Fusion Power

DEMO Parameters & Characteristics

Plasma Mode of Operation	Steady State
Neutron Wall Loading	2-3 MW/m ²
Fuel Cycle	Self Sufficient
- Tritium Release/Extraction - Tritium Breeding	
Thermal Conversion Efficiency (High Temperature Operation)	>30%
Lifetime of Blanket	10-20 MW.a/m ²
DEMO Reactor Availability	>60%
Safety (low decay heat, low failure rate, etc.)	High
Environmental Impact (low long term radioactivity, etc.)	Minimal

Major 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 Combinations**

[Blanket, First Wall, High Performance Divertors]

ITER will address most of 1,2 and 3
ITER will not adequately address 4

**What to do about Fusion Nuclear
Technology and Material Development?**

Can ITER Satisfy Fusion Nuclear Technology Testing Requirements?

NO

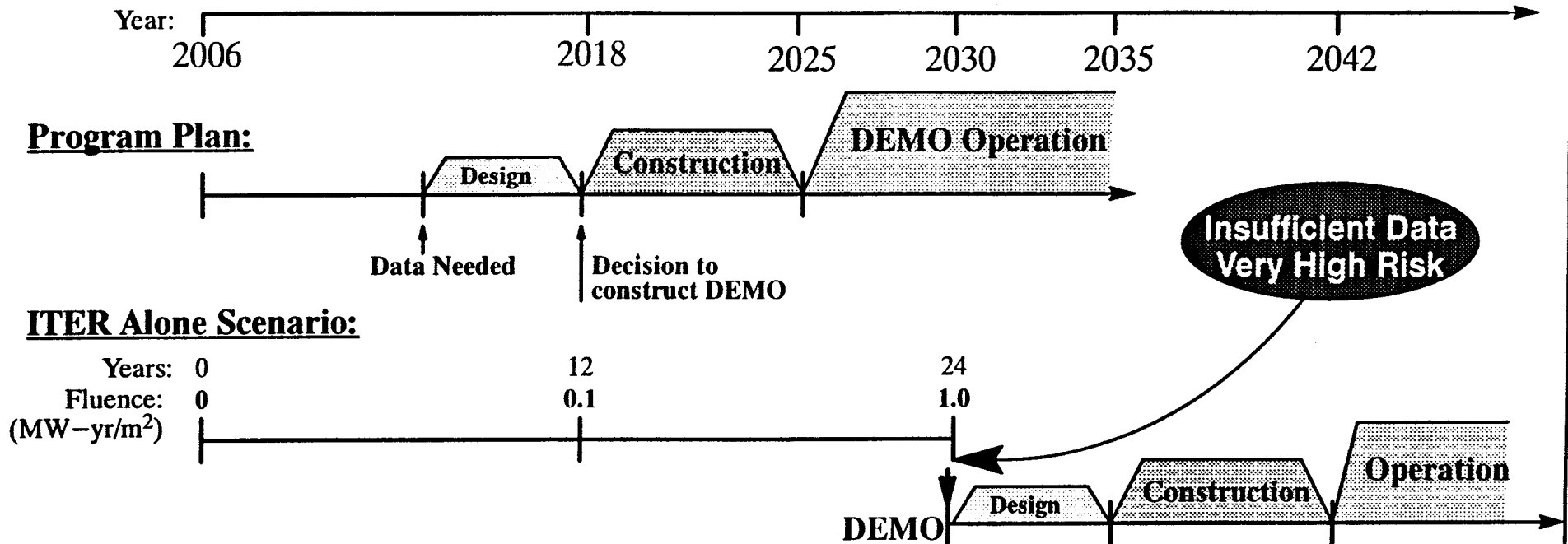
- Pulsing Characteristics Not Suited to FNT Testing
- Fluence is too low (availability is too low)
- Conflict Between Physics Mission and FNT Testing Needs

Should ITER Play a Role in FNT Testing?

- Most Definitely

For large scale, sector-type, tests that do not require much fluence

CAN ITER ALONE PROVIDE SUFFICIENT DATA BASE FOR DEMO ?



Clearly: No!

A Strategy Based on ITER Alone Leads to:

- Very High Risk to DEMO
- Likely Need for Another Device Between ITER and DEMO
- Long Delays in Start of DEMO

Why Fusion Nuclear Technology is Crucial to Fusion

- **Has Most of the Remaining Feasibility Issues**
 - Not sure there is a good blanket that will work
- **Key to Realizing Fusion PROMISE**
 - Renewable Energy Source
 - Must Demonstrate Tritium self sufficiency
(Blanket Issue)
 - Safety/Environment
 - Decay heat, Tritium, Accidents, Radwaste, etc
are blanket issues
 - Economics
 - FNT Major Cost Element
 - Failure Rate, Recovery Rate, Reliability, etc. of
Blanket is key to Reactor Availability
- **Difficult Engineering Development**
 - Lack of Adequate facilities Now
 - Need "Expensive" Fusion Facilities
 - Need Long Test Time

Blanket Options for DEMO

Breeder	Coolant	Structural Material
<u>A. Solid Breeders</u> Li_2O , Li_4SiO_4 , Li_2ZrO_3 , etc.	He <u>or</u> H_2O	FS, V alloy, SiC
<u>B. Self Cooled</u> <u>Liquid Metals</u> Li, LiPb	Li, LiPb	FS, V alloy with Electric Insulator (SiC with LiPb only)
<u>C. Separately Cooled</u> <u>Liquid Metals</u> Li LiPb	He He <u>or</u> H_2O	FS, V alloy FS, V alloy, SiC

- All options have feasibility and performance issues.
- Resolving many of these issues requires testing of material combinations in subcomponents in the fusion environment (n, γ , B, T, V, etc.).
- R&D needs: basic properties, material interactions, synergistic effects; technology for alloy production, fabrication, etc.

Critical Issues for FNT

1. D-T fuel cycle **self sufficiency**
2. **Thermomechanical** loadings and response of blanket components under normal and off-normal operation
3. **Materials compatibility**
4. Identification and characterizations of **failure modes, effects and rates**
5. Effect of imperfections in electric (MHD) **insulators** in self cooled liquid metal blanket under thermal/mechanical/electrical/nuclear loading
6. **Tritium inventory** and recovery in the solid breeder under actual operating conditions
7. **Tritium permeation** and inventory in the structure
8. Radiation shielding: accuracy of prediction and quantification of radiation production requirements
9. In-vessel component thermomechanical response and lifetime
10. **Lifetime** of first wall and blanket components

Capabilities of Non-fusion Facilities for Simulation of Key Conditions for Fusion Nuclear Components Experiments are Limited

	Neutron Effects(1)	Bulk Heating(2)	Non-Nuclear(3)	Thermal/ Mechanical/ Electrical(4)	Integrated Synergistic
Non-Neutron Test Stands	no	no	partial	no	no
Fission Reactor	partial	partial	no	no	no
Accelerator-Based Neutron Source	partial	no	no	no	no

(1) radiation damage, tritium and helium production

(2) nuclear heating in a significant volume

(3) magnetic field, surface heat flux, mechanical forces

(4) thermal- mechanical-electrical interactions (normal and off normal)

Contribution of Nonfusion Facilities to Resolving Critical Issues
for Fusion Nuclear Technology
Important BUT Extremely LIMITED

Critical Issues	Non-neutron Test Stands	Fission Reactors	Accelerator Based Neutron Sources	
			DT	d-Li
1. D-T fuel cycle self sufficiency.	none	none	partial	none
2. Thermomechanical Loadings	small	small	none	none
3. Materials compatibility	some	some	none	none
4. Failure modes, effects and rates	none	none	none	none
5. Imperfections in electric (MHD) insulators	small	small	none	none
6. Tritium inventory, recovery in solid breeder	none	partial	none	none
7. Tritium permeation	some	partial	none	none
8. Radiation shielding and radiation protection equipment	none	small	partial	small
9. In-vessel component thermomechanical response and lifetime	some	some	none	some
10. Lifetime of first wall and blanket	none	partial	none	partial

H

Achieving A High Reactor Availability Requires A Very High Blanket System Availability

- Main Component Reference Mean Down Times, Target Failure Rates and Outage Risk for NET

Component	Mean down time (h)	Target failure rate (1/h)	Outage risk
NBI System	50	2.0e-3	1.0e-1
PF Coil System	4200	2.4e-5	1.008e-1
TF Coil System	1400	0.7e-4	9.8e-2
RF System	50	1.1e-3	5.5e-2
Vacuum Vessel	2160	2.5e-5	5.4e-2
Plasma Vacuum Pumping	100	3.2e-4	3.2e-2
Cooling Cycles	30	1.0e-3	3e-2
First wall System	600	4.4e-5	2.64e-2
Limiter System	600	4.4e-5	2.64e-2
Blanket System	600	4.0e-5	2.4e-2
Shield	2160	1.1e-5	2.376e-2
Divertor Plate System	100	1.4e-4	1.4e-2

- The outage risk is defined as, failure rate x mean down time, which gives the availability being equal to $\frac{1}{1 + \text{outage risk}}$
Reference reactor outage risk = 0.68478; Reactor availability = 59%
Reference Blanket outage risk = 0.024 ; Blanket availability = 97.6%
- Failure rates for various components were from industrial engineering, processing engineering and nuclear power plant, etc.
- Components above line require improvement in failure rate data to achieve target values, components below line require verification of failure rate data.

Reference: R. Buende, "Reliability and Availability Issues in NET," Fusion Engineering and Design 11 (1989) 139-150

Requirements on Blanket System Availability as a Function of Reactor Availability

Reactor Availability	Blanket System Availability
75 %	> 99 %
59 % (Reference case)	97.6 %
56 %	90 %
52 %	80 %
37 %	50 %

Blanket Module Availability vs Blanket System Availability

- The overall availability of a blanket system (BS), A_{BS} , is written as:

$$A_{BS} = \frac{MTBF_{BS}}{MTBF_{BS} + MTTR_{BS}} = \frac{1}{1 + \lambda_{BS} MTTR_{BS}}$$

where

$MTBF_{BS}$ = Mean time between failures of the blanket system
 $MTTR_{BS}$ = Mean time to replace the blanket system
 λ_{BS} = Failure rate of blanket system

and
$$\lambda_{BS} = \frac{1}{MTBF_{BS}}$$

- In general, a blanket system consists of a series of modules. This implies that the failure rate of the blanket system is equal to:

$$\lambda_{BS} = n \lambda_n$$

- Note on the average the time to replace the blanket system is approximated as the time to replace a failed module

i.e. $MTTR_{BS} = MTTR_n$

and

$$A_{BS} = \frac{1}{1 + \lambda_{BS} MTTR_{BS}} = \frac{1}{1 + n\lambda_n MTTR_n}$$

where

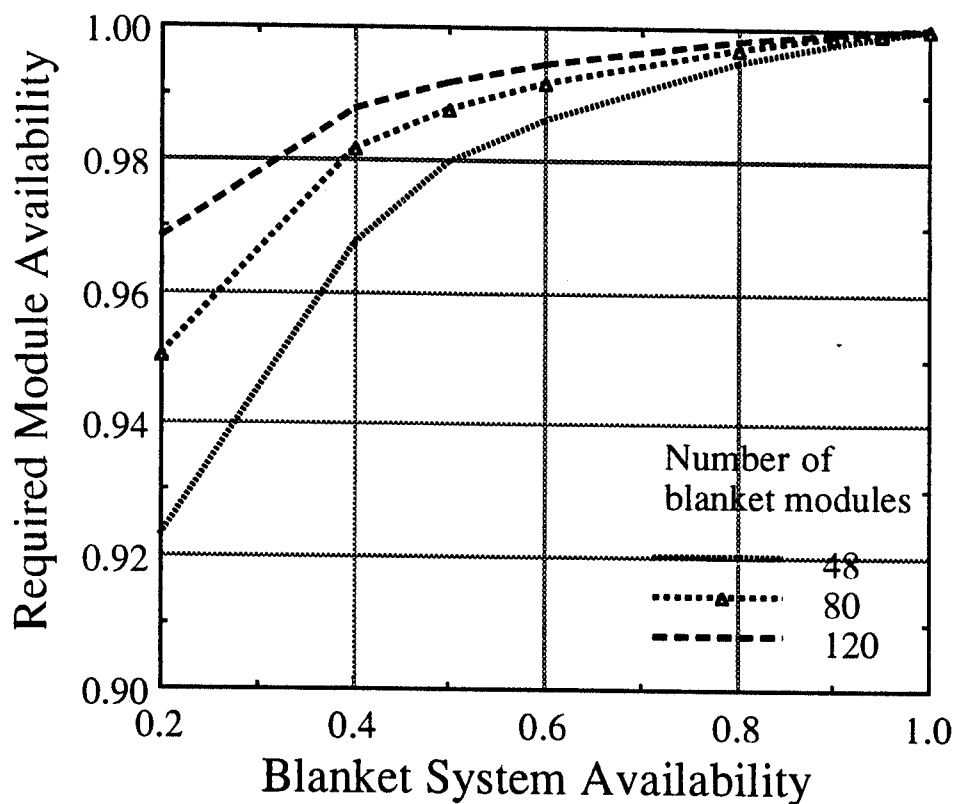
n = # of modules (A module is the smallest physical element that can be replaced when a failure occurs.)
 λ_n = Failure rate per module
 $MTTR_n$ = Mean time to replace a module

- A Blanket Module Availability (A_n)

$$A_n = \frac{1}{1 + \lambda_n MTTR_n}$$

Achieving a High Blanket Availability Requires A Very High Module Availability

- A Blanket System Availability $ABS = \frac{A_n}{A_n(1-n)+n}$



- Achieving a blanket system availability of 80% requires a blanket module availability of > 99%

The Blanket Determines the Critical Path for Fusion Testing Because a Long Mean Time Between Failure is Required for the Blanket Module.

- Requirements on Blanket Module MTBF for Different MTTRs (Number of blanket modules = 80, Reactor Availability = 52%, and Blanket System Availability = 80%⁽¹⁾)

MTTR _n	No of failures in any module per year	Required MTBF _n (Years)
1 week	13	6.1
2 weeks	6	12.3
1 month	3	26.6
2 months	1.5	53

(1) Calculations estimated based on data presented in "Reliability and Availability Issues in NET" by R. Buende in Fusion Eng. and Design 11 (1989).

- Required Mean Time Between Failure For DEMO Blanket Module is > 26 years
- MTBF Testing i.e. Testing for Failure Modes and Failure Rates is More Demanding than Lifetime Tests

Failure is Different from Design Lifetime

Definition

Failure is defined as the ending of the ability of a design element to meet its function before its allotted lifetime is achieved, i.e. before the operating time for which the element is designed is reached.

5

Causes of Failures

- Errors in design, manufacturing, assembly and operation
- Lack of knowledge and experience
- Insufficient prior testing
- Random occurrence despite available knowledge and experience

Estimated Failure Rate Per Blanket Module Based on Nonfusion Technologies (Steam Generators, Fission)

Blanket Element	No. or Length of Elements per Blanket Module	Failure Rate(1)		Failure Rate per Blanket Module (1/h)	
		Mean	High	Mean	High
Longitudinal Welds	66 m	5.0e-8 /h-m	5.0 e-7/h-m	3.3125e-6	3.3125e-5
Butt Welds of Pipe	462	5e-9 /h-weld	1e-7/h-weld	2.31e-6	4.62e-5
Pipes (straight)	2.75 km	5e-10/h-m	1e-8/h-m	1.375e-6	2.75e-5
Pipe Bend	28	1e-8/h-bend	3.5e-7/h-bend	2.8e-7	9.8e-6
Overall Failure Rate per Module (1/h)	Range: 7×10^{-6} - 1×10^{-4}				
Calculated Time Between Failure per Module (years)	Range: 1 - 16				

- Expected Blanket System Failures ~ 5 - 80 per year of operation (for Blanket system of 80 Modules)

(1) R.Bunde, et. al., ISFNT-2 (Fus. Eng. & Design 1991)

- For Comparison:
(T. D. Marshall and L.C. Cadwallader, EGG-FSP-10928, March 1994)

In-vessel ITER Tubing Failure Rates:

Coolant Leakage	316 SS-water	Ferritic Steel-water,He	316SS-He
	1.2e-08/h-m	5.4e-9/h-m	1.4e-8/h-m

Failure Rate in Fusion FW/Blanket Could Be Much Higher than Estimates from Current Technologies

1. New Technology

- No prior experience in actual system
- Initial failure rate is higher by factors of 10 to 100 than bottom of bathtub
- Prior testing is severely limited in simulating fusion environment

2. Fusion FW/B is More Complex than Steam Generators and Fission Core

- Larger number of sub components and interactions (tubes, welds, breeder, multiplier, coolant, structure, tritium recovery, etc.)
- More damaging higher energy neutrons
- Other environmental conditions: magnetic field, tritium, vacuum, etc.
- Reactor components must penetrate each other
- Ability to have redundancy inside FW/B system is extremely limited

Reliability Growth :Background

- A discipline used to investigate the cause of each failure, and redesign to try to make sure it will not reoccur (a process known as test, analyze and fix).
- Past experience on reliability growth testing (non-fusion, a large variety of equipment such as pump) has shown that the rate of increase in the MTBF (M) of component can be expressed as(Duane Model):

$$M = A t^{\alpha}$$

where

α = development growth parameter (the larger the α the more effective is the development program).

M= cumulative MTBF (hrs)

t = testing time in hours

- Such a model would help to:
 - assess the effectiveness of the development process;

The value of α is interpreted as:

$\alpha > 0.4$	Reliability has top priority; very effective development program
$\alpha = 0.3 - 0.4$	Reliability has high priority
$\alpha = 0.2- 0.3$	Routine attention paid to reliability, important failure modes investigated and analyzed
$\alpha < 0.2$	Reliability has low priority

- estimate how much more development effort is needed to ensure a reliability target is reached, or
- estimate the final reliability of a product for a given amount of development effort.

An Aggressive Development Program Leads to Less Test Time Required and Faster MTBF Growth

- The instantaneous failure rate (λ_i) at time t is expressed as:

$$\lambda_i = \frac{dn}{dt}$$

where n = number of failures at time t , and

$$n = \frac{t}{M_c} = \frac{t^{1-\alpha}}{A}$$

Therefore
$$\lambda_i = \frac{d(t^{1-\alpha}/A)}{dt} = \frac{1-\alpha}{A} t^{-\alpha}$$

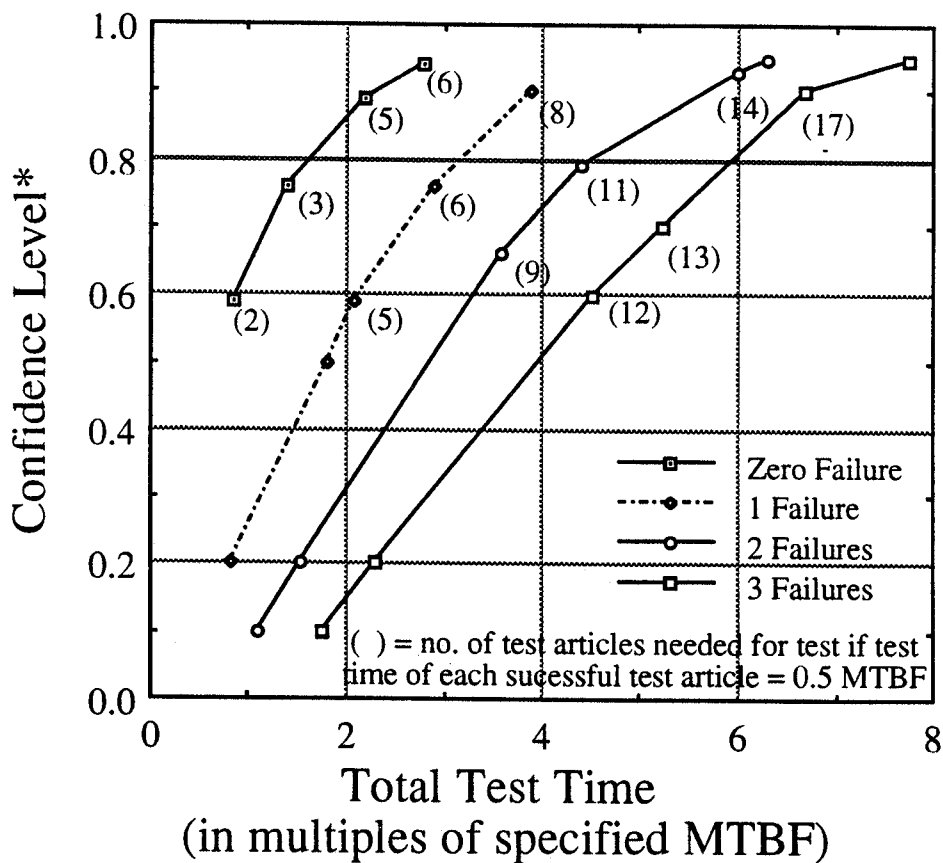
and
$$M_i = \frac{1}{\lambda_i} = \frac{1}{1-\alpha} A t^\alpha$$

- Requirements on Testing Time for Achieving a Blanket MTBF of 5 Years as a Function of Reliability Growth Factors

	Testing Time, Years	
Target MTBF (M_i) for DEMO Blanket	Aggressive ($\alpha=0.5$)	Medium Priority ($\alpha=0.3$)
5 yrs	5.5	2.2×10^4

Test Time and Number of Test Articles vs Confidence Level

- For MTBF tests, if a minimum test time per component = 0.5 MTBF (assuming that MTBF is equal to the component useful operating lifetime) is imposed.
- With 1 failure during the test, the number of test articles would be 8 for achieving a 90% confidence and 7 for 80% confidence.

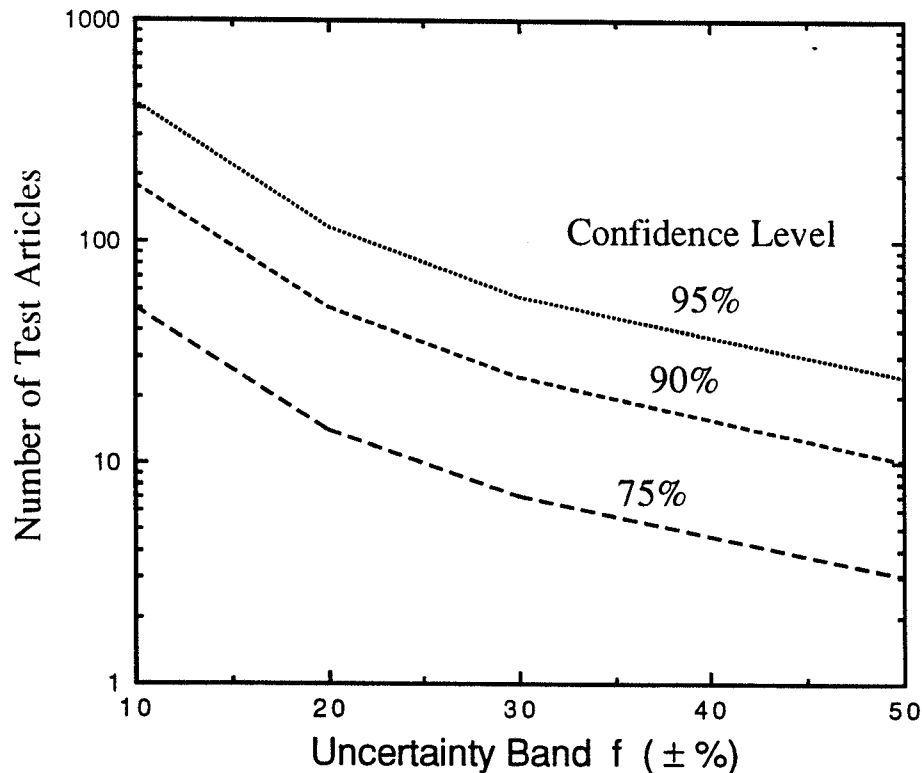


* Confidence level 0.8 means that the confidence of the lower limit on the MTBF being equal to the specified MTBF is 80%.

How Many Test Modules (per Concept)?

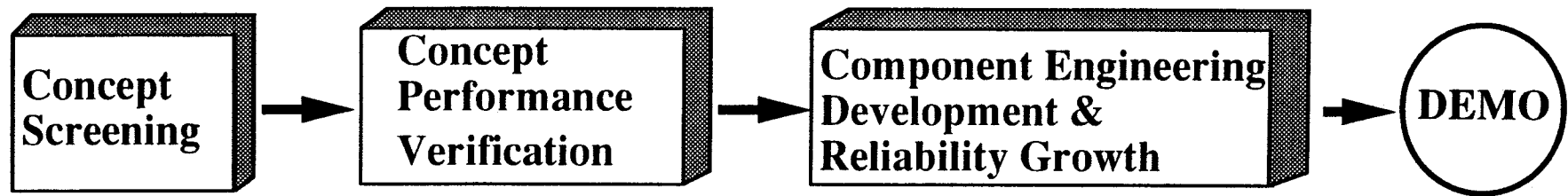
- When the number of test modules are small, it is difficult to resolve whether the observations are real or practically significant. Furthermore, a small sample size makes the statistics too dependent on the precise value of a few individual observations or a high uncertainty interval in estimating both mean and variance.

Example: A mean value of TBR for a blanket design option is to be estimated within $\pm f\%$ at some confidence level



Number of test articles required as a function of required uncertainty band for different confidence levels

Testing in Fusion Devices For Fusion Nuclear Development Can Be Classified Into a Number of Stages



Stage	I	II	III
Required Fluence MW.Y/m ²	0.3	> 1.0	> 4 - 6
Size of Test Article	Submodules	Modules	Modules/Sectors

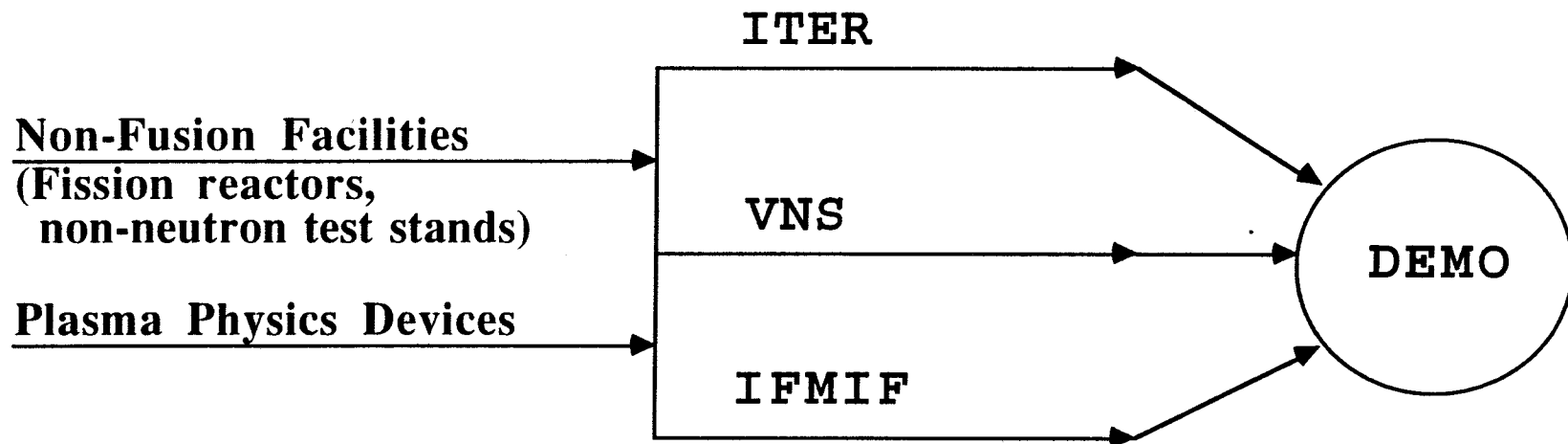
- Reliability Growth Testing is Most Demanding
 - Requires testing of components in real operating environment (n, γ , B, T, V)
 - Requires an aggressive design/test/fix iterative program
 - Requires many test modules and high fluence

Fusion Testing Needs

[How Much Fusion Testing is Needed to Construct DEMO Blanket]

Parameter	Value
Neutron Wall Load, MW/m ²	1-2
Plasma Mode of Operation	Steady State
Neutron Fluence at Test Module	
Stage I MW.a/m ²	0.3
Stage II MW.a/m ²	>1
Stage III MW.a/m ²	4-6
Total Neutron Fluence for Test Device, MW.a/m ²	6
Total Test Area, m ²	>10
Minimum Continuous Operating Time, Weeks	1-2

Prudent and Optimum Path to DEMO Requires Three Parallel Facilities



ITER

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

VNS [Volumetric Neutron Source]

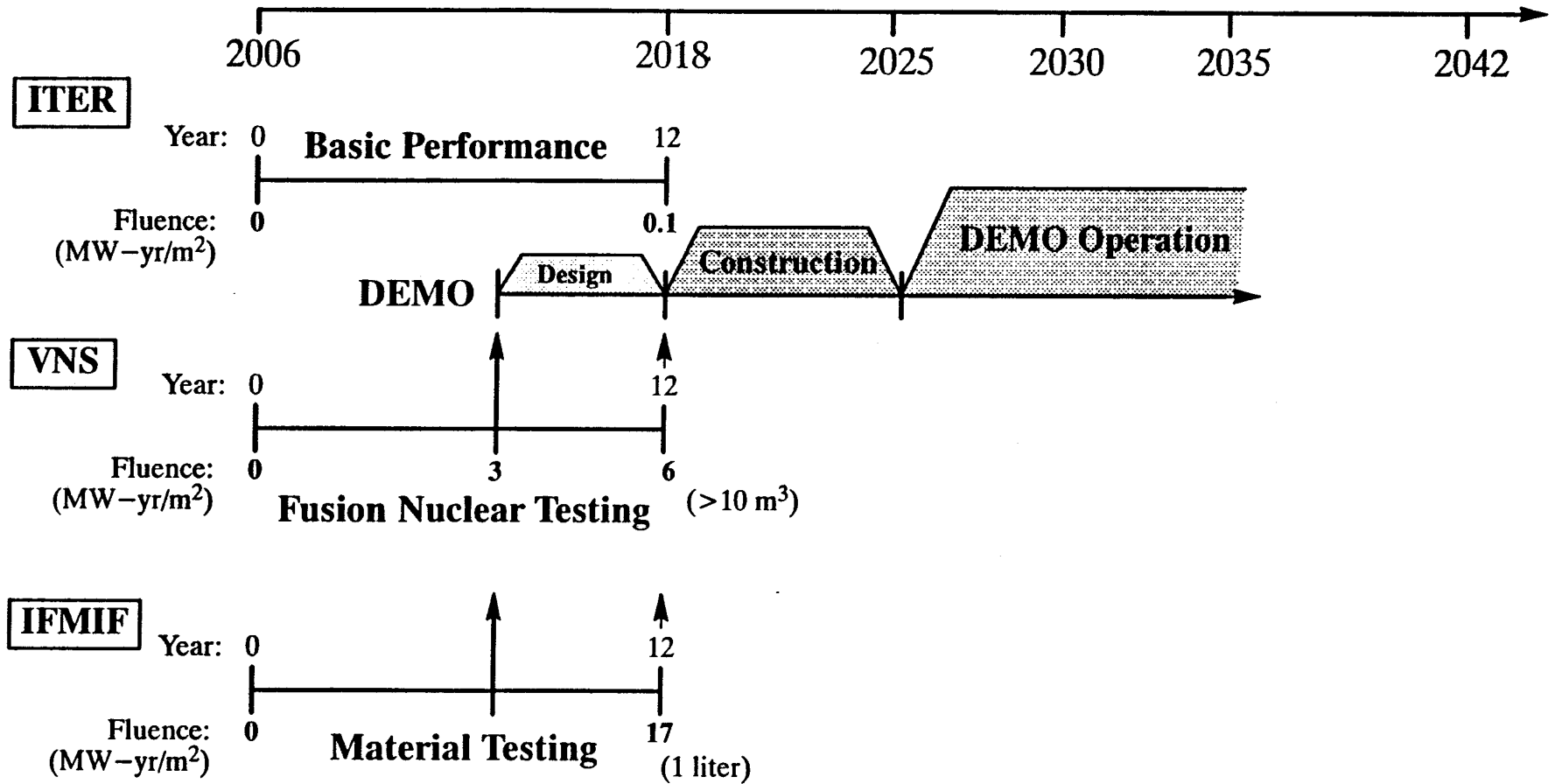
Dedicated fusion facility to test, develop, and qualify fusion nuclear technology components and material combinations [$> 10 \text{ m}^3$ test volume]

IFMIF ["Point" Neutron Source]

Small volume($<0.01 \text{ m}^3$), high availability facility to address radiation effect life time issues

VNS IS NECESSARY

ITER, VNS, IFMIF Parallel Facilities Scenario:

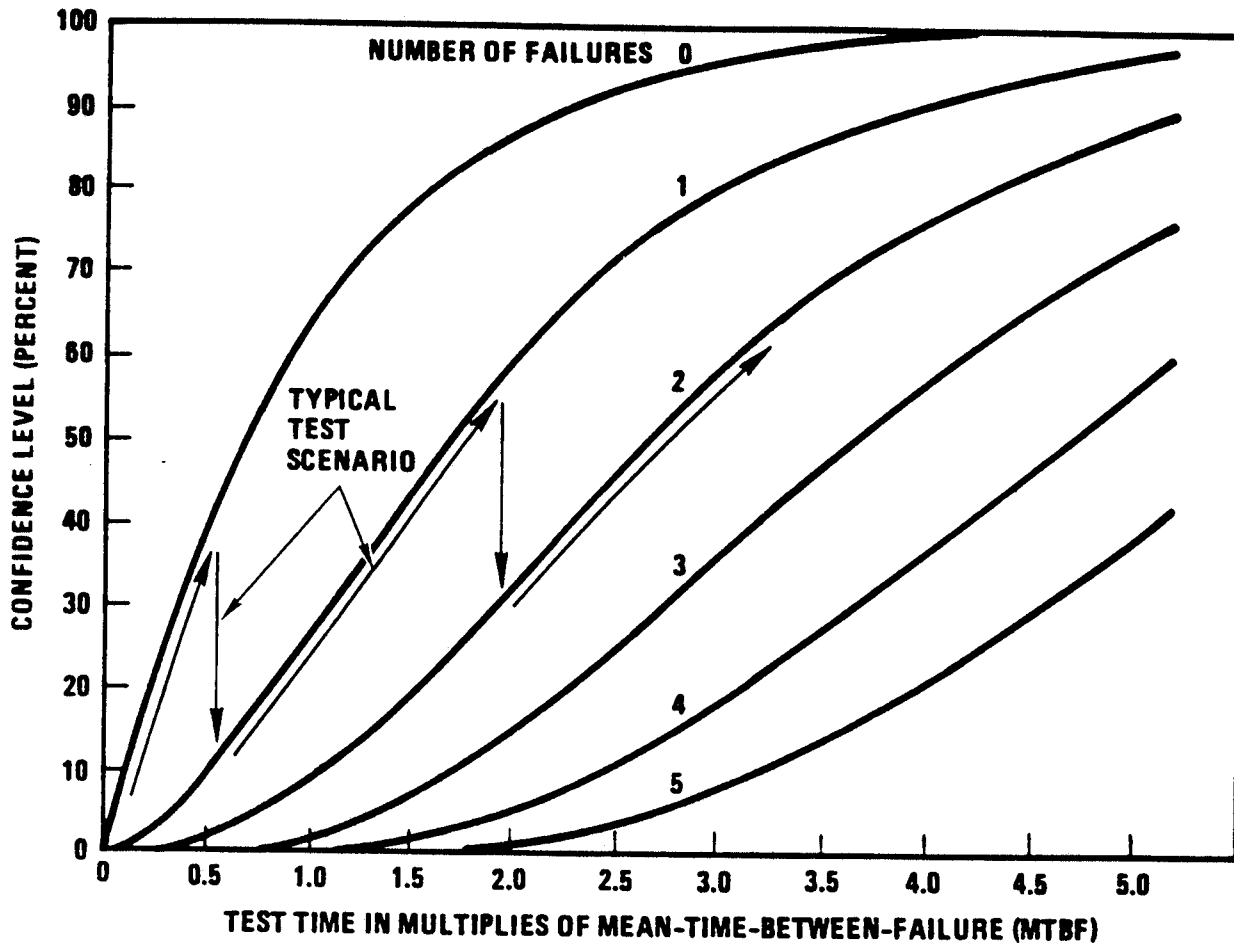


- (1) To meet DEMO time schedule
- (2) To reduce Risk to DEMO to acceptable levels
- (3) To reduce Technology Burden on ITER

Quantifying the Risk to DEMO As a Function of How Much FNT Testing

- The time has come to develop some quantitative parameters to measure the Risk to DEMO as a function of how much FNT testing we do in fusion facilities
 - Help in evaluating scenarios for facilities
- We Propose One Methodology Used in Other Technologies for Quantifying Confidence Level As a function of
 - How much Testing relative to MTBF
 - How Many Failures Occur During the Test

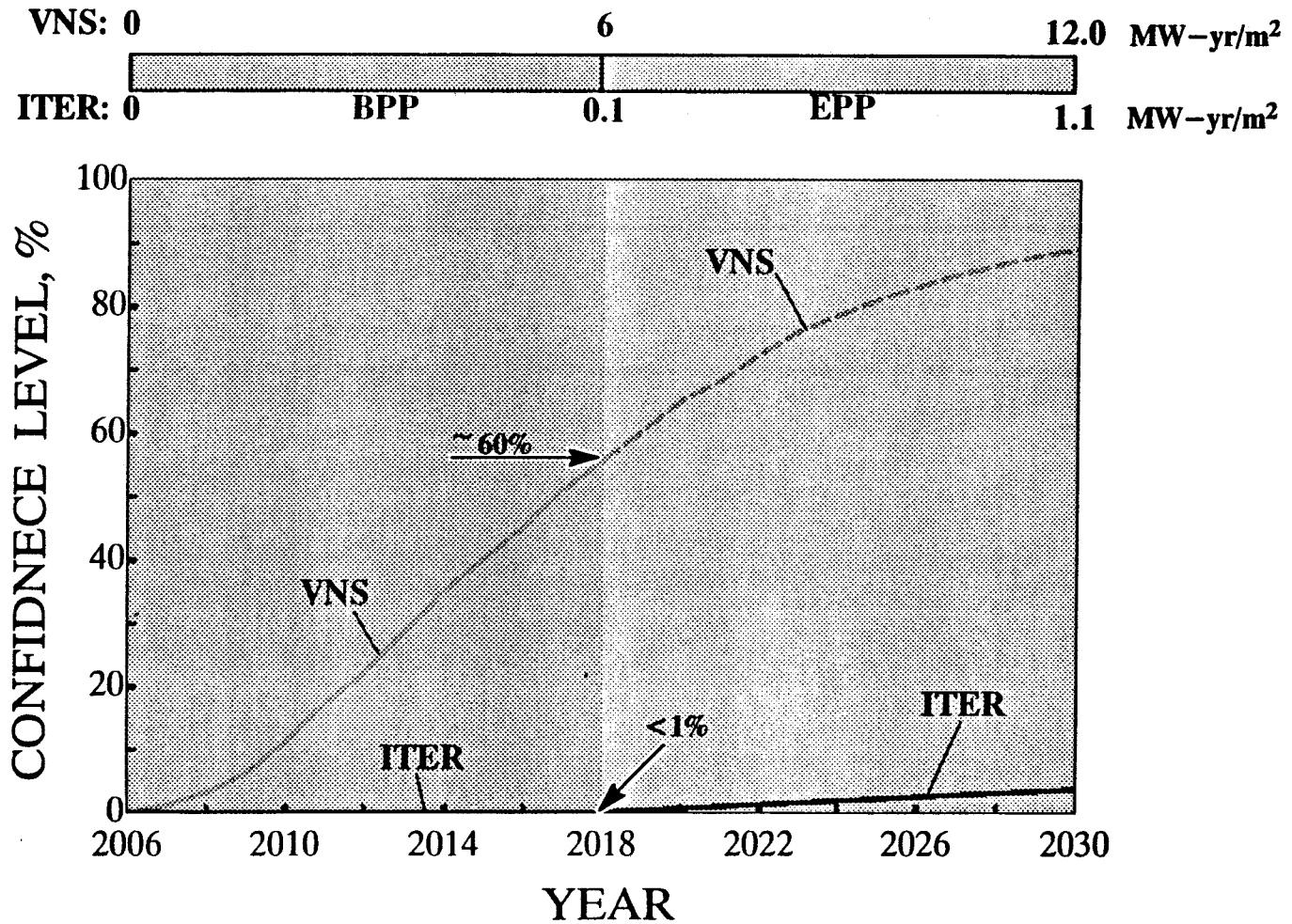
Confidence Level for a Poisson Distribution Time Terminated Test



Ref. M. Abdou et al., "FINESSE: A Study of the Issues, Experiments and Facilities for Fusion Nuclear Technology Research and Development", UCLA-ENG-84-30, PPG-821, Vol. IV, Ch. 15 (October, 1984)

CONFIDENCE LEVEL IN DEMO

Obtainable with FNT Testing in VNS and ITER
 (MTTR_n = 1 week, MTBF_n = 6.1 years)



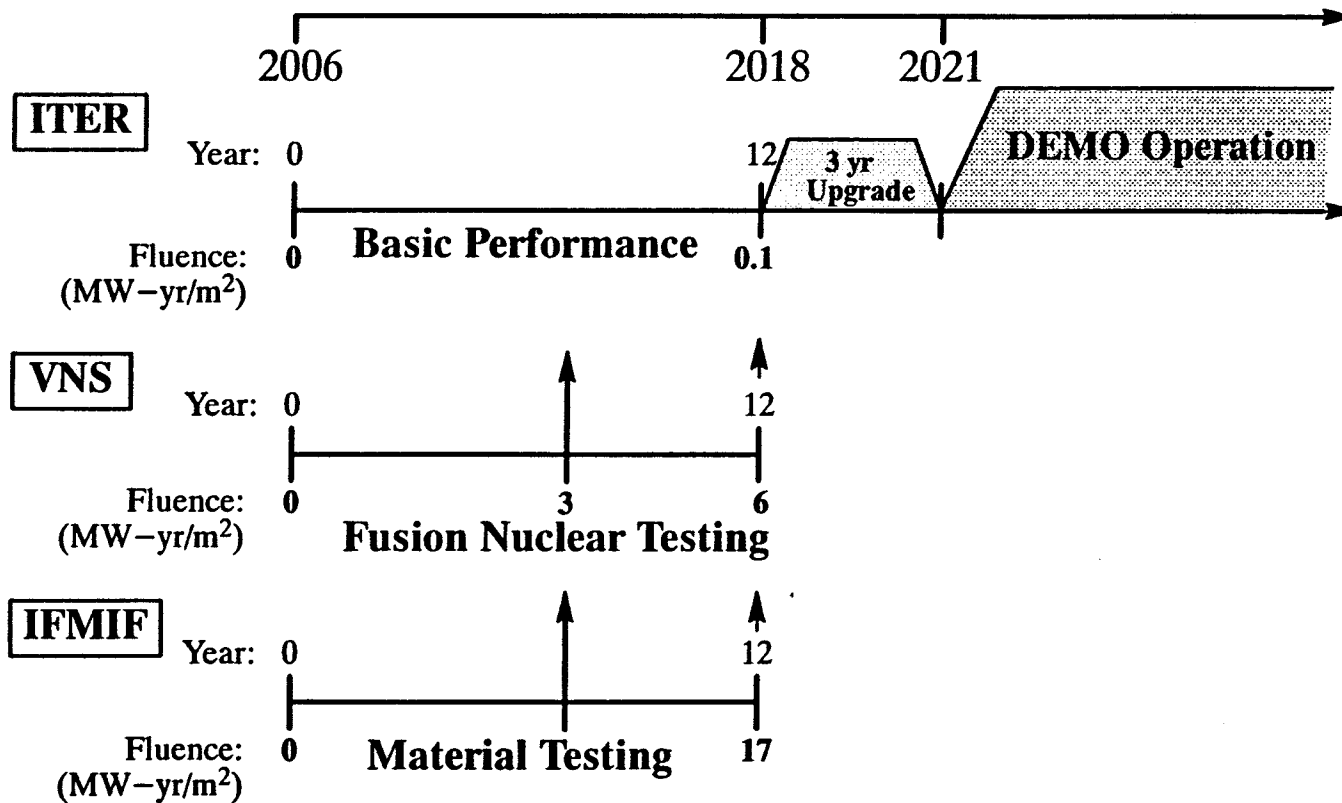
32

CAN ITER BECOME A DEMO ?

VNS Can Also Help A High Success Scenario

If Results Are Better Than Expected:

VNS Makes it Possible to Convert ITER EPP to DEMO



33

VNS Mission

To Complement ITER as a Dedicated fusion facility to test, develop and qualify those advanced fusion nuclear components and materials combinations that are required for DEMO operation by the year 2025

Design Concepts for VNS

Suggested Ground Rules for Evolving Design Concepts

- Plasma Steady State Operation
- Low Fusion Power 100-200 MW
 - To keep cost low
 - To avoid need for breeding blanket
- Surface Area at First Wall for testing >10m²
- Wall Load 1-2 MW/m²
- Design for Maintainability and Higher Availability
 - Duty Cycle x Availability >0.3
- No Breeding Blanket
 - Avoid Use of Unproven Technologies
- Maximum Site Power Requirements <500MW
- Cost: <0.3 ITER

Types of Confinement Concepts for VNS

1. Mirrors

A. Gas Dynamics Trap (GDT)

- Max. Test Area $<0.75\text{m}^2$
- Not Suitable for VNS
- Can Play a Role if Inexpensive
- More Suitable for IFMIF

B. "Conventional" Mirrors with Large Surface Area

- Physics Feasibility Issues

2. Tokamaks

- Driven (Q approx. 1-3)
- JET Type Physics with Current Drive and Other Capabilities
- Three Types
 - Superconducting TF Magnets (Standard A)
 - Normal Conducting TF Magnets with Standard A
 - Normal Conducting TF Magnet with Very Low A

Key Parameters Proposed for Mirrors

	Gas Dynamic Trap ^a		FEF II ^b
	GDT-2	GDT-3	
Neutron Wall Load (MW/m ²)	3.9	2.5	3.5
Equivalent Major Radius L _p /2π(m)	10/2π	10/2π	3/2π
Plasma (minor) radius, a(m)	0.06	0.07	0.1
Magnetic Field at Plasma B _{min} /B _{max} (T)	1.25/25	1.8/26	4.16
Plasma Drive Power (MW)	20	15	36
Fusion Power (MW)	3.0	2.0	5
Site Power Required	50	50	84
Direct Access Test Area (m ²)	0.5	0.75	1

a - E.P. Kruglakov, et.al.

b - T. Kawabe

Tokamak VNS Design

- Attractive Design Envelope Exists
- Normal Versus Superconducting TF Coil?
 - S/C Leads to Larger Size
 - Lower Power Consumption
- VNS Capital Cost Relative to ITER

S/C VNS	approx.	0.4	ITER
N/C VNS	approx.	0.25	ITER
N/C, low A	approx.	0.1	ITER
- Key Issues For VNS Design
 - Must Design for High Availability 25-30 %
 - Divertor Heat Load
 - Current Drive

Options for Tokamak VNS

	ITER	VNS		
		Super Conductor	Normal Conductor	Low A
Wall Load, MW/m ²	1	1	1-2	1-2
Inboard Shield, m	1.2	0.72	0.23	0.03
Major Radius, m	7.75	4.6	1.5-1.6	0.79-0.81
Minor Radius, m	2.8	1.05	0.6	0.6
Plasma Current, MA	24	6.4	6-7.1	9.4-10.4
Toroidal Field, T	6	7.7	4.3-5.5	2-2.4
Drive Power, MW	0	140	30-46	19-29
Fusion Power, MW	1500	360	82-172	32-65
Power Consumption, MW	400	370	540-700	130-180
First Wall Area, m ²	1300	290	62-65	30-31

40

41

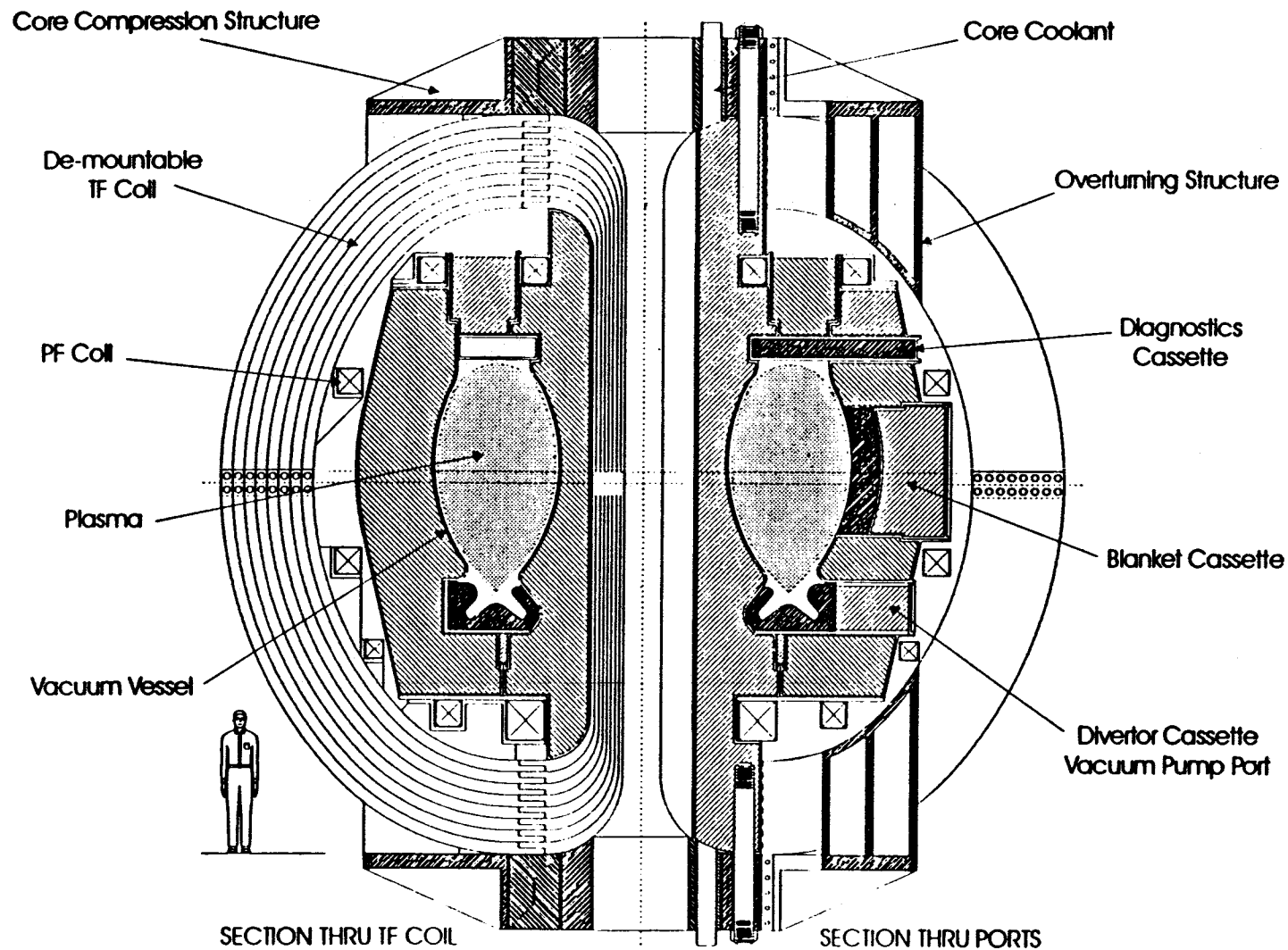
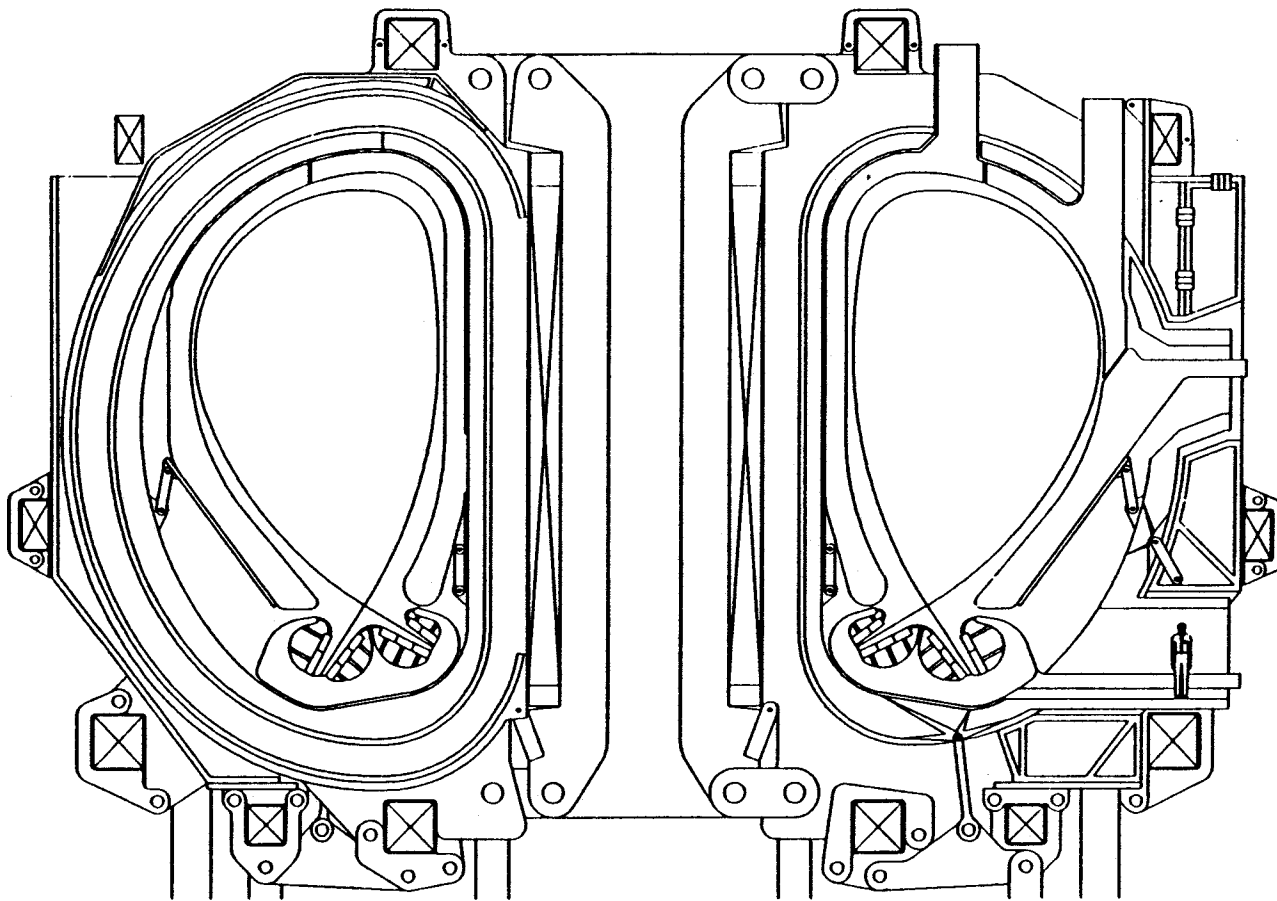
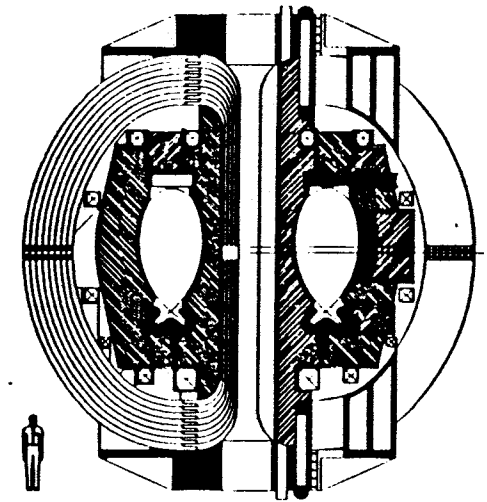


Figure 1. Elevation View Depicting a VNS Using Multi-Turn Normal Conducting Toroidal Field Magnets That Require Some Inboard Shielding.

1/2



ITER 93



TOKAMAK VNS

Figure 4. Elevation views for ITER [5] and a typical tokamak VNS with multi-turn normal conducting toroidal field coils (M-T N/C, Figure 1), depicted in same scale.

Arguments Against VNS? Cost?

- Total Cost from now to DEMO

VNS actually provides substantial cost savings

A) ITER without VNS lengthens time to DEMO by 17 years

17 year x \$1B/yr (world program) = \$17B
Much Larger Cost than VNS

$$\text{VNS Cost} = (\$3\text{B} + 12\text{yr} \times 0.2/\text{yr}) = \$5.4\text{B}$$

B) ITER EPP Operating Cost

= 12 yr x 0.4/yr + cost of tritium
= \$4.8B + cost of tritium

VNS Reduces Risk and REDUCES TOTAL COST

Arguments Against VNS? Cost? (Cont'd)

- Expenditure NOW?

Increase in Expenditures in early years to build VNS Parallel to ITER is modest

- Consider Host Party X
(Assume Host Party Pays 50%)

44

	Total Cost (\$B)	ITER at X Site (\$B)	VNS at X Site (\$B)
ITER	10	5	1.67
VNS	3	0.5	1.50
IFMIF	1	0.17	0.17
Other	2	0.50	0.50
	16	6.17	3.84

- If Party X wins ITER site, VNS will add \$500M over many years
- If Party X loses ITER and wins VNS, it will get Substantial Benefits at lower cost

Summary

- **The development of Fusion Nuclear Technology, particularly blanket is**
 - critical to realizing the promise of fusion
 - difficult: facilities, time
- **VNS is a facility to test, develop and qualify FNT Components for DEMO**
- **A Technically and Programmatically Sound World Strategy for Fusion R & D should include 3 Parallel Facilities**
 - ITER
 - VNS
 - IFMIF
- **VNS is Necessary**
 - To meet DEMO Operations Schedule by the year 2025
 - To have reasonable confidence in successful DEMO

Summary (Cont'd)

- **Confidence in DEMO FNT Components:**

With VNS: > 60%

With ITER alone : < 1%

- **Adding VNS reduces total cost to DEMO**

- Near Term Cost is not an issue if ITER and VNS are not sited in one country

- **There are attractive design options for VNS**

- **A small size ($R < 2\text{m}$) driven tokamak ($Q = 1-3$) with steady state capabilities appears a particularly attractive option for VNS**