Role and Requirements for Volumetric Neutron Source (VNS)

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Briefing to Dr. M. Yoshikawa,
Vice President, JAERI, August 19, 1993
Tokyo, Japan

What is the present focus of the World Fusion R&D Program?

- DEMO is the goal of the present world fusion R&D program

Do we have a comprehensive plan to address R&D needs for DEMO?

- It is crucial that we examine the major R&D needs for DEMO and develop R&D strategy that results in:
  - successful development of all key components for DEMO
  - lower overall risk
  - timely development (DEMO operation by the year 2025)
  - cost effective

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**
    [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.

DEMO Characteristics

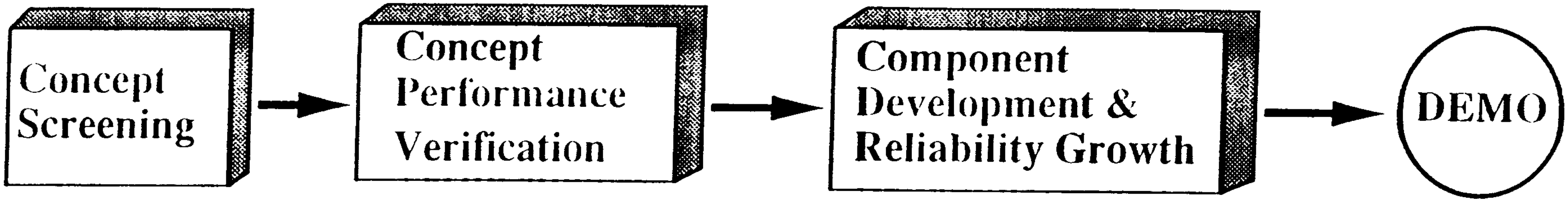
A DEMO Plant is one that demonstrates dependability and reliability. The size, operation and performance of DEMO must be sufficient to demonstrate that there are no open questions about the economics of prototype/first commercial reactor.

Neutron Wall Loading	2-3 MW/m^2
Fluence	10-20 $MW.y/m^2$
Fuel Cycle	Self sufficient, demonstrate doubling time requirements
Plasma Mode of Operation	Steady state (or very long burn, short dwell)
Net Plant Availability	> 50% (Demonstrate reliability and maintainability)

Availability Requirements

- To achieve net plant availability of 50% means that :
  Availability per blanket module > 99%
- Such high availability requirements for blanket module imply that prior to DEMO, there would be aggressive development program for blanket that includes component reliability growth

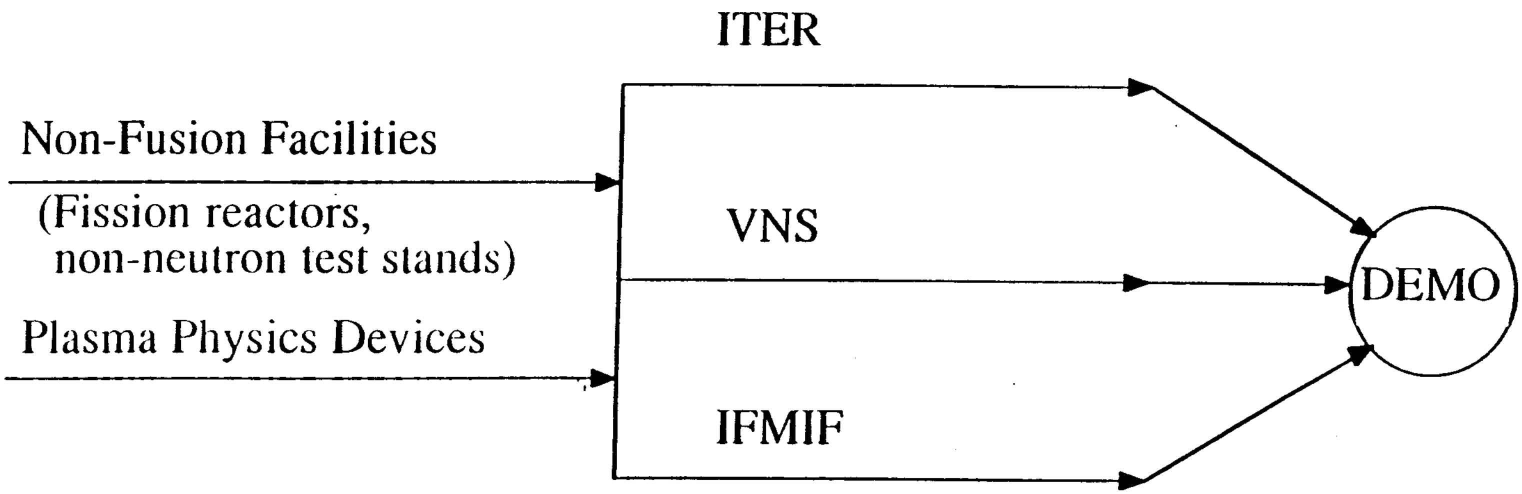
Testing in Fusion Devices For Fusion Nuclear Development Can Be Classified Into a Number of Stages



	Concept Screening	**Concept Performance Verification**	**Component Development & Reliability Growth**	**DEMO**
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 an aggressive design/test/fix iterative program
  - Requires many test modules and high fluence in fusion facility

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 m3 test volume]

IFMIF ["Point" Neutron Source]

Small volume (<0.01 m3), high availability facility to address radiation effect life time issues

VNS Mission and Objectives

VNS Mission

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

FNT components and materials have the highest impact on the economic, environmental and safety attractiveness of fusion energy and they require extensive testing in an integrated fusion environment.

VNS Objectives

Parallel and Sequential Tests of FNT Components and Materials in Submodules, Modules and Sector in Fusion Environment
[neutrons, gamma-rays, surface heat flux, volumetric nuclear heating, magnetic field, tritium, etc.]

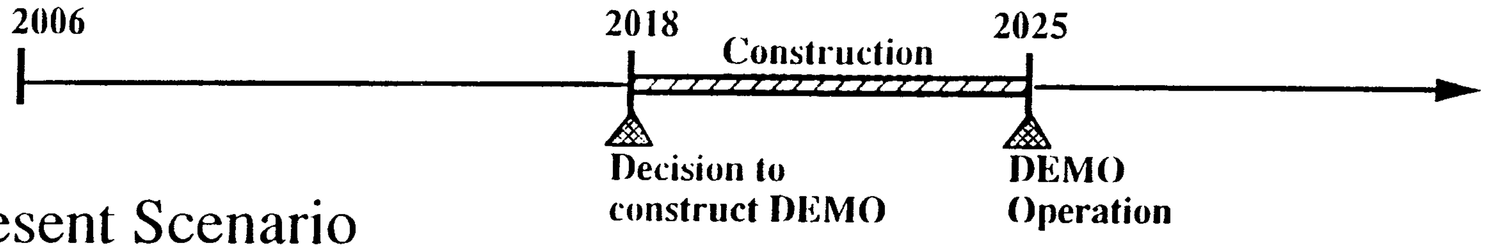
- Calibrate non-fusion tests against performance in the fusion environment
  Check/Validate Codes and Data

- Screen FNT Concepts and Material Combinations

- Performance Verification
  Select Reference Concepts
  Optimize Designs, Verify Performance
  Performance Specific Safety-Related Tests
  Response to off-normal events, operational margin

- Reliability Growth
  - Identify Failure Modes and Effects
  - Iterative design/test/fix programs aimed at improving reliability and safety
  - Failure Rate Data; Obtain Data Base sufficient to predict mean time between failure (MTBF) and component lifetime with sufficient confidence
  - Obtain data base to predict mean time to replace (MTTR) with remote maintenance
  - Obtain sufficient data to predict overall availability of FNT components in DEMO

VNS Is Necessary to Meet DEMO Time Schedule



2006

2018

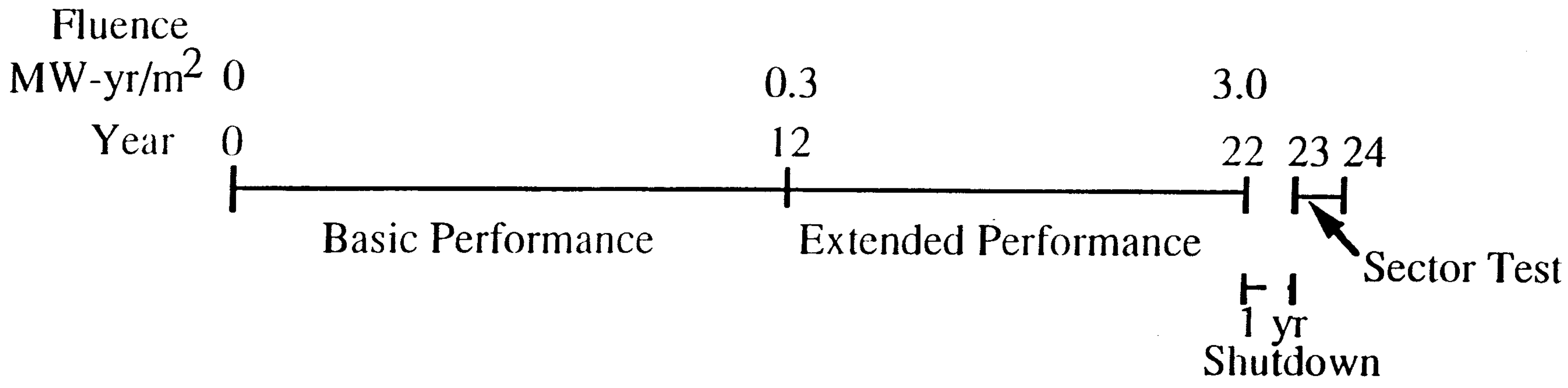
2025

Construction

Decision to construct DEMO

DEMO Operation

ITER Present Scenario



Fluence MW-yr/m^2 0 0.3 3.0

Year 0 12 22 23 24

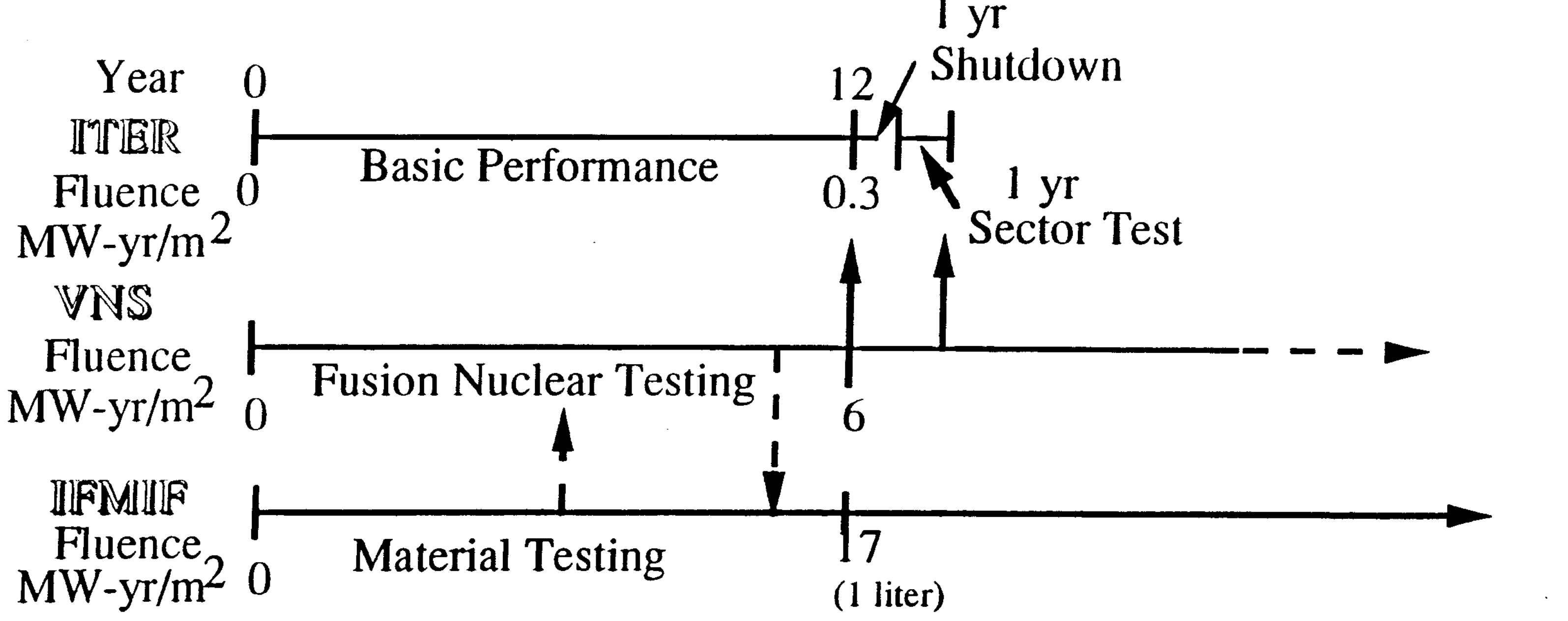
Basic Performance

Extended Performance

Sector Test

1 yr Shutdown

Complementary Approach (Reduced Technology Burden on ITER)



Year 0 12

1 yr Shutdown

ITER

Basic Performance

Fluence MW-yr/m^2 0 0.3

1 yr Sector Test

VNS

Fluence MW-yr/m^2 0 6

Fusion Nuclear Testing

IFMIF

Fluence MW-yr/m^2 0 7 (1 liter)

Material Testing

Physics and Nuclear Technology Requirements for Testing Are Very Dissimilar

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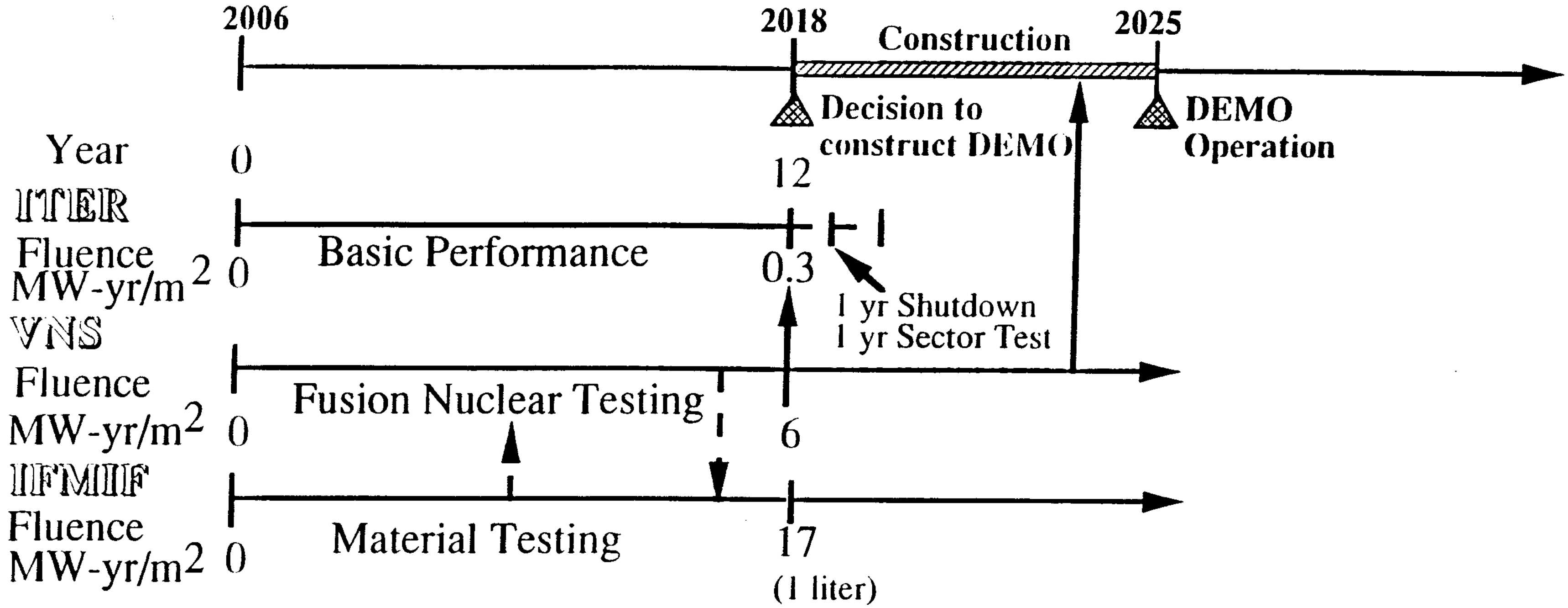
	Fusion Power	Integrated Burn Time	Tritium Consumption
A. Physics and Plasma Support	3500 MW	15 days	8.0 kg
B. Fusion Nuclear Technology	20 MW	5 yr	5.6 kg

Combined * A and B	3500 MW	5 yr	976 kg

* Combining large power and high fluence leads to large tritium consumption requirements

VNS Increases Confidence in Successful Timely DEMO

Possibility 1



2006
2018
Construction
2025
Decision to construct DEMO
DEMO Operation

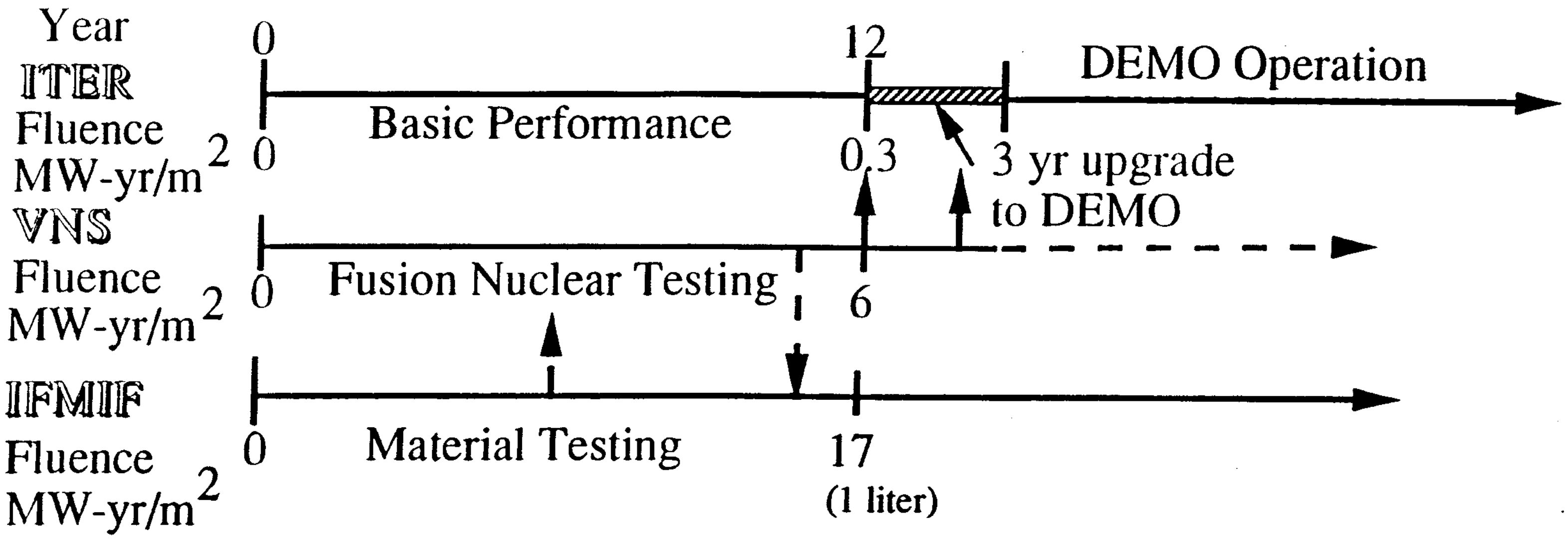
Year 0 12

ITER Fluence MW-yr/m^2 0
Basic Performance
0.3
1 yr Shutdown
1 yr Sector Test

VNS Fluence MW-yr/m^2 0
Fusion Nuclear Testing
6

IFMIF Fluence MW-yr/m^2 0
Material Testing
17
(1 liter)

Possibility 2 (Very High Success Scenario)



Year 0 12

ITER Fluence MW-yr/m^2 0
Basic Performance
0.3
DEMO Operation
3 yr upgrade to DEMO

VNS Fluence MW-yr/m^2 0
Fusion Nuclear Testing
6

IFMIF Fluence MW-yr/m^2 0
Material Testing
17
(1 liter)

MAJOR DEVICE PARAMETERS OF FUSION FACILITIES

	ITER	**VNS**	**IFMIF***
Availability	10 %	30%	>70%
Wall Load, (MW/m^2)	2	1–2	2$^{(a)}$
Fluence @12yr, (MW·yr/m^2)	0.3	6	17
Test Area [Volume)]	TBD	>30m^2 [15m^3]	<0.02m^2 [0.001m^3]$^{(b)}$
Cost Goal (relative units)	1	0.3	0.1

*Source: IAE Workshops (1989, 1992)

(a): 2 at 1 liter; 5 at 0.1 liter; 10^{15} n/cm^2–s; E_n>0.1MeV
(b): at 2MW/m^2

Benefits of VNS

Primary

Makes it possible to develop with reasonable confidence FNT Components and Material Combinations that meet the DEMO Performance Technical Requirements (particularly reliability/availability) with a self-consistent time schedule

Other Benefits

- Reduced Technological Risk and Cost to ITER
  - -Reduce Fluence need
  - -Eliminate Need for Breeding Blanket
- Provides additional experience in design, construction and licensing of a fusion device
- Forcing Function to developments concerned with remote maintenance and component reliability

Nuclear Testing Requirements

- ## Engineering Scaling Requirements

	Minimum	Highly Desirable
Neutron Wall Load (MW/m^2)	1	2
Plasma Burn Time	> 1000 s	Steady State (or long burn, hours)
Dwell Time	a	< 20 s
Continuous Test Duration (steady state or back-to-back cycle 100% availability)	> 1 week	2 weeks
Average Availability	10 - 15 %	25 - 35 %
Total Neutron Fluence (MW-a/m^2)	1.5	4 - 6
<u>Test Port Size</u> (m^2 x m)		
Module	0.5 x 0.3	1 x 0.5
Outboard Sector	2 x 0.5	4 x 0.8
<u>Total Test Area</u> (m^2)		
Module Only	5	10 - 20
Including Outboard Sectors	7	20 -30

- ## Programmatic Constraints

Test Time	12 yr
Fluence	6 MW-yr/m^2
Neutron Wall Load	2 MW/m^2

Duty Cycle x Availability	30 %

Achieving A High Plant Availability Requires A Very High Blanket Availability

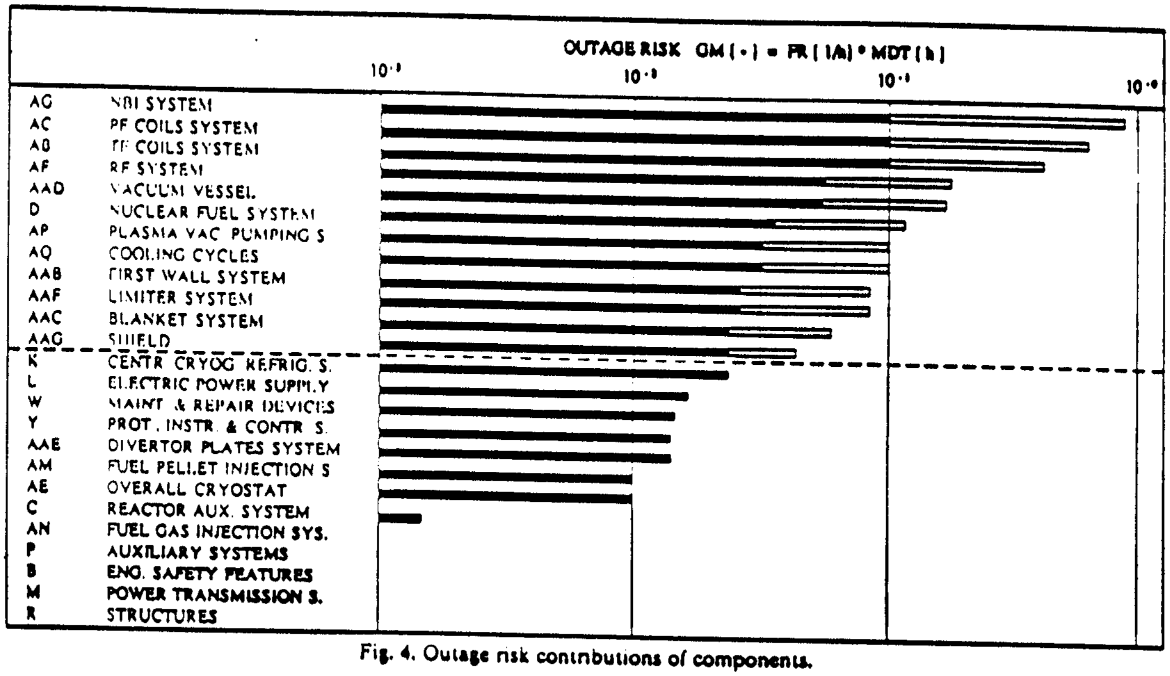


Fig. 4. Outage risk contributions of components.

- The outage risk is defined as, failure rate x mean down time, which gives the availability being equal to $\frac{1}{1+\text{outage risk}}$
  Plant outage risk = 0.717; Plant availability = 58%
  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 Availability as a Function of Plant Availability

Plant Availability	Blanket Availability
75 %	> 99 %
58 %	97.6 %
55 %	90 %
51 %	80 %
37%	50 %

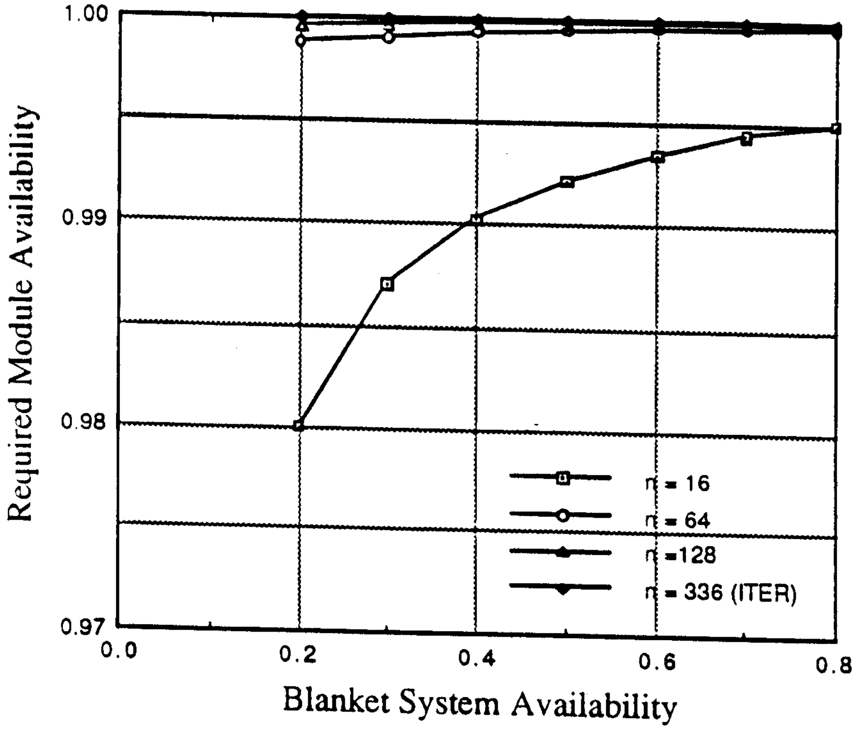
Achieving a High Blanket Availability Requires A Very High Module Availability

- A Blanket System Availability (A_{BS})

$$A_{BS} = \frac{A_n}{A_n(1-n^2)+n^2} \approx \frac{A_n}{n^2(1-A_n)} \qquad (n^2 >> 1)$$

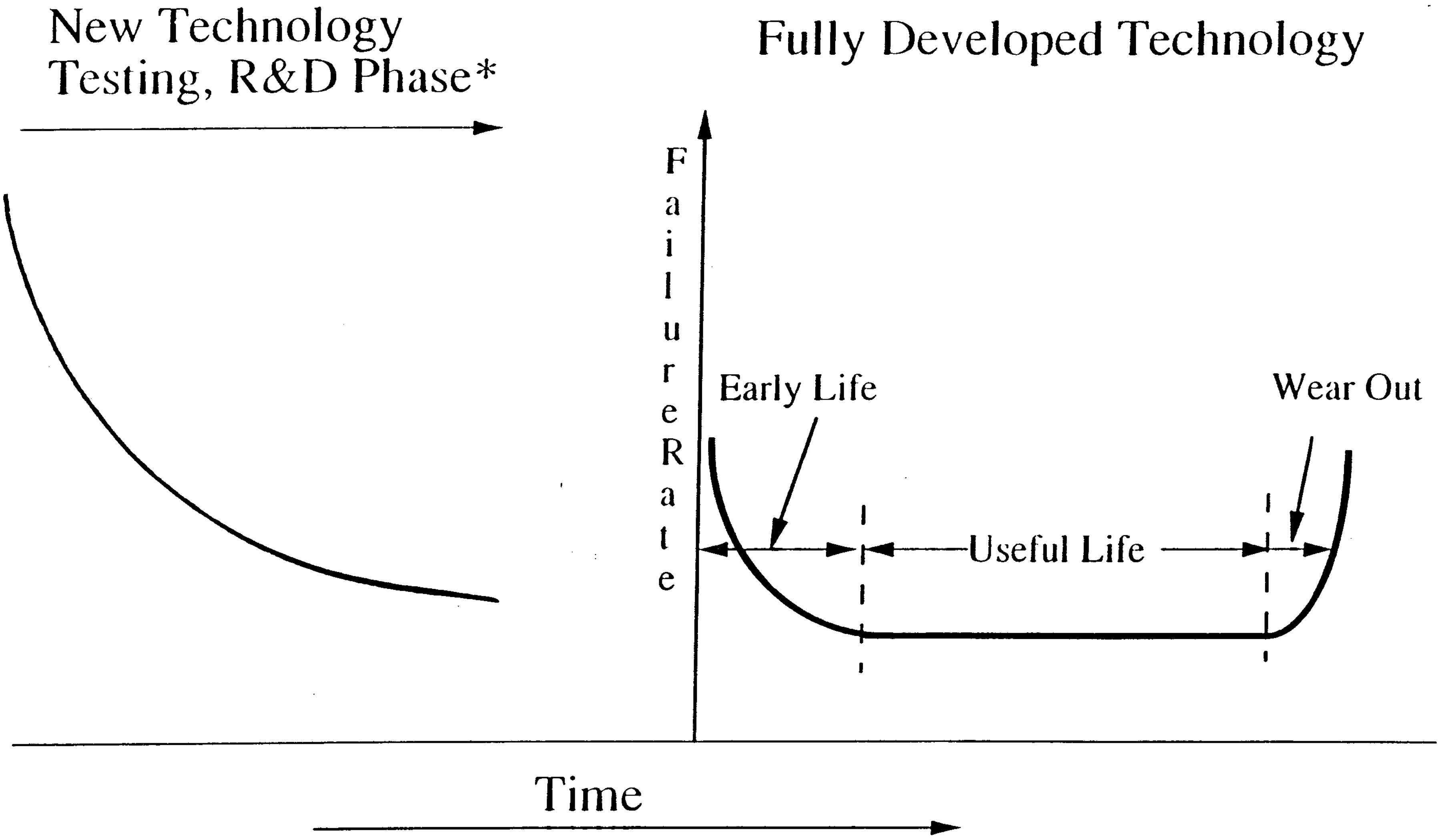
or

$$A_n \approx \frac{1}{1 + \frac{1}{n^2 A_{BS}}}$$



MTTRn	Required MTBF (Years)			
	ABS = 0.5		ABS = 0.8	
	n = 16	n = 336	n = 16	n = 336
1 day	0.35	155	0.56	247
1 week	2.5	1084	3.9	1728

Schematic Failure Rate vs Time
During Development and After Development



*The curve shown is for an aggressive development program.

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.

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

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Estimated Failure Frequencies for ITER In-Vessel Blanket System

Event/Failure Mode	Failure Rate	Length or Number of Welds	Failure rate /hour	MTBF	Frequency per FPY
In-Vessel LOCA	[1a] 5E-08 /(h-m)	[2] Tube length close to the FW = 46 km	2.3E-3	431 hours	20
	[1b] 3.3E-08/(h-m)	[3] Overall blanket tube length= 159 km	5.3E-3	189 hours	46
Butt Welds of Pipes [4]	[a]1E-07/(h-weld)	[5]158,976 welds	1.59E-02	63 hours	139
	[b]1E-08/(h-weld)		1.59E-03	629 hours	14
	[c]1E-09/(h-weld)		1.59E-04	6290 hours	1-2

1 From L. Cadwallader, "Investigation of Selected Accident Frequencies for Helium, Water, and Liquid Metal ITER Coolants," ITER/US/93/EN/SA-3.

- Estimated leak failure rate for copper tubes (including brazes) was about 5E-07/hour-m in the first wall and divertor areas.

a - For steel pipe failure rate, the above number is reduced by a factor of 10. This gives a steel pipe leak failure rate of 5E-08/hour-m.

b - This failure rate is about 1/3 lower than the failure rate estimated for the FW to account for less radiation effect.

2. The total tube length close to the first wall is estimated as: 12 m/tube x 7 tubes near the FW/module x 552 modules = 46368 m.

3. This tube length is estimated as: 12 m/tube x 24 tubes per module x 552 modules = 1.59E5 m.

4. From R. Bünde et al., "Reliability of Welds and Brazed Joints in Blankets and Its Influence on Availability," Fusion Engineering and Design, 16 (1191) 59-72.(a. upper value b. reference value c. upper value). Note that these failure rates were estimated for the useful life period, the failure rate during the infant mortality period would be much higher.

5. Number of welds was estimated for the ITER JCT He-Cooled blanket (duplex tubing) design by V. D. Lee. The assumption was 1 weld for tube entering blanket at top, 1 for tube turning down blanket, 1 for tube turnaround at bottom and 2 manifold welds at top.

FAILURE RATE

References (extremely limited)

- R. Bünde, et. al ISFNT-1 (Fus. Eng. & Design 1989)
  ISFNT-2 (Fus. Eng. & Design 1991)
  Other (unpublished work)
- L. Cadwallader, INEL (LOCA and LOFA, ITER memo Jan. 1993)

- Data in these and other references are based on well established technologies (mostly fission reactors and steam generators) for the bottom of the bathtub failure rate curve (i.e. after all learning in hundreds to thousands of units and "unit•time" equivalent to thousands of years of operating experience).

- Based on this data, a representative First wall/Blanket in the present ITER design is estimated to have (see detailed estimate)

"Base" Failure Rate ~ 10-50 per year of operation (per FPY)

- However, for ITER as the first fusion device (new technology), the failure rate during the first several years of operation can be higher by one to two orders of magnitude (or more depending on design and prior testing).

Expected Failure Rate in FW/B can be on the order of 100-500 per FPY

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WHY EXPECTED FAILURE RATE IN ITER FW/B DURING EARLY YEARS OF OPERATION COULD BE MUCH HIGHER THAN BASE CASE ESTIMATES

Base Estimate Failure Rate (FR) Assumptions

- Mature well developed technology (fission reactors, steam generators, etc.)
- Bottom of bathtub of FR vs. operating time curve

Expected FR Estimate for ITER Early Years

Failure rate could be much higher because:

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

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REMARKS ON FAILURE RATE AND RELIABILITY GROWTH

- Capability to replace first wall and blanket (individual modules as well as the entire FW/B system) in a reasonable time MUST be a design goal for fusion devices

- Design concepts for FW/B (and other components) must aim at improving reliability. One of the most effective directions is to minimize features that are known to have high failure rate (e.g. minimize or eliminate welds, brazes, tube length)

- A serious reliability and availability analysis must be an integral part of the design process

- R&D program must be based on quantitative goals for reliability (type of tests, prototypicality of test, number of tests, test duration)

- Reliability growth testing in fusion devices will be the most demanding (particularly on number of tests and time duration of tests). Reliability testing should include:
  - Identification of failure modes and effects
  - Aggressive iterative design/test/fix programs aimed at improving reliability
  - Obtain failure rate data sufficient to predict MTBF

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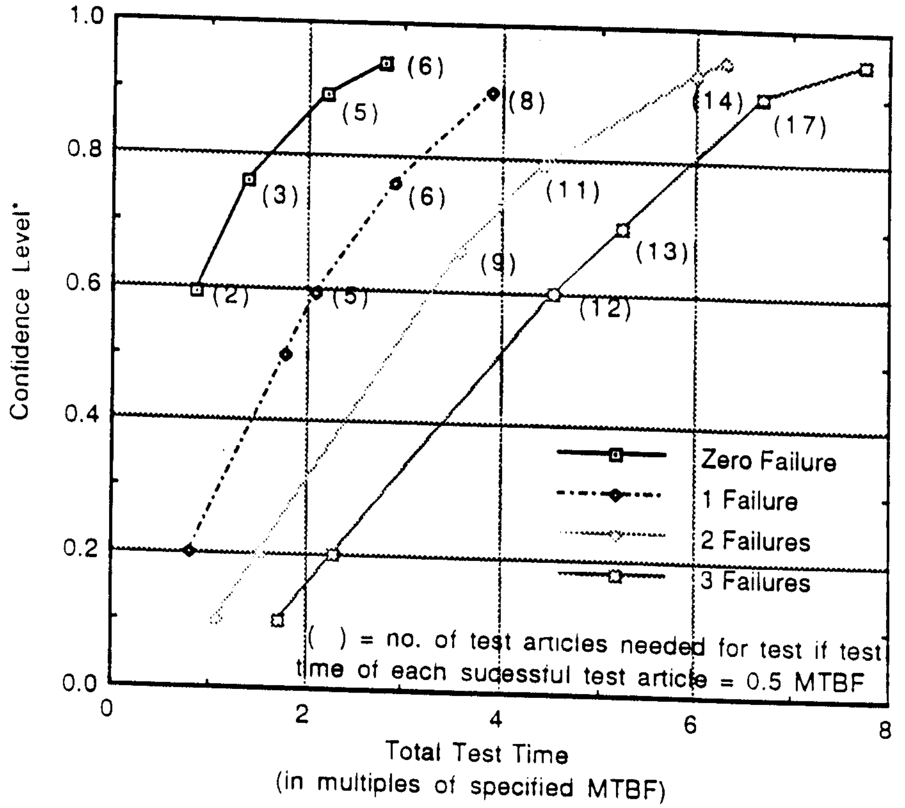
Test Time and Number of Test Articles vs Confidence Level

- For MTBF tests, the minimum test time per component = 0.5 MTBF (assuming that the component useful operating time is equal to the MTBF)
- This requirement implies that 6 test components are needed for achieving a 90% confidence level, if the number of failure is zero.
- 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%.

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

- The MTBF at the end of the development process will be somewhat higher than M_c because the early design has been modified to reduce the probability of certain failure modes that manifested themselves early on.

- 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

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

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

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 Development Factors and A*

Target MTBF (M_i) for DEMO Blanket	Further Testing Time,Hours (Years) A = 100	
	$\alpha = 0.5$	$\alpha = 0.3$
4.38x10^4 hours (5 yrs)	4.8x10^4 (5.5)	1.9x10^8 (2.2x10^4)

* MTBF of Blanket at 1 hour of testing

Design Concepts For VNS

- VNS must be a Magnetic Fusion Device
  Plasma is the only credible means at present to generate 14 MeV neutrons at a rate $>10^{19}$n/s

- A Tokamak: Appears to offer the best potential for VNS

  - Driven, Low Q, Plasma based on present data base
  - Experience from Large Physics Devices
    (e.g. JET, TFTR, JT-60 U, D-IIID)
  - Additional Technology data base required is part of what is being developed under ITER R&D

- Trade off studies have been carried out in the US for a Tokamak VNS. Attractive Design Envelope to meet VNS mission/objectives at a reasonable cost exists.

Cost depends on:
  - Desired Wall Load
  - Normal Conducting Versus Superconducting Magnets
  - Current Drive Capability

Suggested Ground Rules for Evolving VNS Design Concept

- Cost < 0.5 ITER
  (lower cost is encouraged)

- Low Fusion Power (< 400 MW)

- Surface Area at First Wall for testing
  $> 10\ m^2$

- Higher Wall Load
  $> 1 MW/m^2$ (prefer 2 if possible)

- Design for Maintainability and Higher Availability
  Duty Cycle x Availability > 0.3

- No Breeding Blanket
  Avoid use of unproven technologies

- Maximum Site Power Requirements < 700MW

Example of VNS Tokamak Design

[Examples only Based on Conservative Assumptions; Trade off Studies are Presented Later; More Effort is Necessary to Select an optimum design]

	Normal Conducting	Superconducting
Average Neutron Wall Load (MW/m^2)	1.0	1.0
Major Radius, M	2.83	5.52
Aspect Ratio	3.4	4.2
Axial Magnetic Field, T	7.1	7.2
Plasma Current, VA	6.2	7.9
Total Fusion Power, MW	160	500
Current Drive Power, MW	60	110
Inboard Shield thickness, m	0.2	0.9
Q	2.7	4.9
TF Resistive Power, MW	500	N/A
Power Operating Cost (M$/yr) (at 30% availability)	90	35
Direct Cost (B$)	1.9	2.5

SMALL TOKAMAK VNS ENVELOPE ENCOMPASSES A RANGE OF REASONABLE EXTRAPOLATIONS AND COSTS (6/93)

	ITER EDA	S/C Shield	N/C Multi-Turn Shield/Support	N/C Multi-Turn No Inner Shield		N/C Single-Turn No Inner Shield	
Neutron wall load ($MW{\cdot}m^{-2}$)	2.0	1.1	1.0	1.0	2.0	1.0	2.0
Major radius, R_0 (m)	7.75	4.64	2.6	1.52	1.74	0.91	0.97
Minor radius, a (m)	2.8	1.05	0.84	0.6	0.64	0.6	
Plasma current, I_p (MA)	25	6.4	6.8	6.3	7.3	6.0	6.8
External toroidal field, B_{t0} (T)	6.0	7.7	6.7	6.8	8.0	3.6	4.7
Drive power, P_{drive} (MW)	0	155	60	35	67	24	33
Fusion power, P_{fusion} (MW)	3170	400	150	65	158	42	90
Site power, peak/s.s. (MW)	800/400	400	700	690	700	230	330
Direct-access test area (m)	TBD	110	52	21	23	17	17
Direct cost relative to ITER	1.0	~0.48	~0.45	~0.25	~0.40	~0.14	~0.16

BASED ON A COMMON SET OF PHYSICS AND ENGINEERING ASSUMPTIONS.

[From Summary of IEA Workshop; Moscow July 12-18, 1993]

TABLE 3. VNS Options and Key Parameters Based on Tokamak

CONCEPT	ITER EDA[f]	S/C Shield[g]	N/C Shield[g]	H-I_{bs}[h] (Efremov)	N/C No Shield[g]	TK-T[i] (TSP-PPD)	N/C Single-Turn[g]	MTF[j] (Culham)
Neutron wall load (MW/m^2)	2.0	1.1	1.0	0.7 - 1.0	1.0 - 2.0	0.8 - 1.2	1.0 - 2.0	1.4
Major radius, R_0 (m)	7.75	4.64	2.6	2.5	1.52 - 1.74	1.5	0.91 - 0.97	0.53
Minor radius, a (m)	2.8	1.05	0.84	0.63	0.6 - 0.64	0.5	0.6	0.33
Plasma current, I_p (MA)	25	6.4	6.8	4.1 - 4.5	6.3 - 7.3	3.0 - 3.5	6.0 - 6.8	6.9
Magnetic field, B_{t0} (T)	6.0	7.7	6.7	6.8 - 7.5	6.8 - 8.0	3.5 - 4.2	3.6 - 4.7	2.4
Drive Power, P_{drive} (MW)	0	155	60	50	35 - 67	30 - 40	24 - 33	20
Fusion power, P_{fusion} (MW)	3170	400	150	90 - 130	65 - 158	35 - 45	42 - 90	20
Site power, peak/s.s. (MW)	800/400	400	700	500 - 700	690 - 700	TBD	230 - 330	100
Direct access test area (m^2)	TBD	110	52	30	21 - 23	TBD	17	6
Tritium consumption[k] (kg/yr)	TBD	5.0	1.7	1.3 - 1.9	0.8 - 2.0	TBD	0.4 - 1.0	0.2

[f] ITER-EDA information as of May 1993.

[g] "Initial Design Boundaries and Parameters of Small Tokamak VNS Envelope," presented by M. Peng, Oak Ridge National Laboratory, USA.

[h] "VNS on the basis of the High Bootstrap Fraction Tokamak," presented by A. B. Mineev, D. V. Efremov Scientific Research Institute of Electrophysical Apparatus, St. Petersburg, Russia.

[i] "The Compact Volumetric Neutron Source on the Tokamak Basis (TRINITI – "Kurchatov Institute" Version)," presented by S. V. Mirnov, Troitsk-Kurchatov Institute, Russia.

[j] "Tight Aspect Ratio Tokamak Neutron Source," presented by T. C. Hender, Culham Laboratory, Abingdon, UK.

[k] Assuming tritium a breeding ratio of unity for test blanket modules covering the entire test area for an achieved availability of 30%.

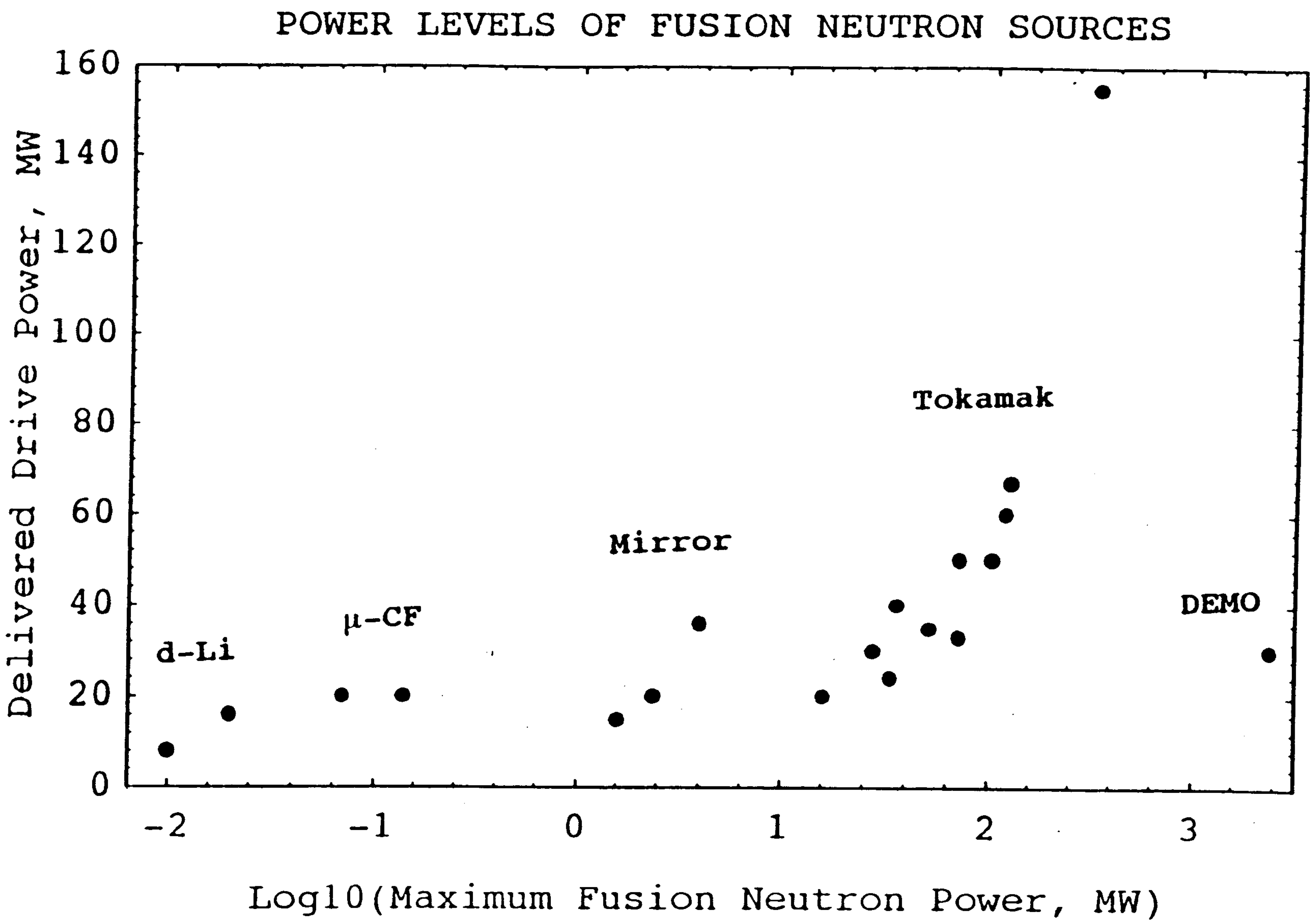


Figure 1. Maximum fusion neutron power produced and the required drive power delivered to the plasma target for the VNS concepts presented at the workshop ("•" representing values from Tables 2 and 3). The values for a DEMO, and the high-flux neutron sources based on d-Li target and μCF are included for contrast.

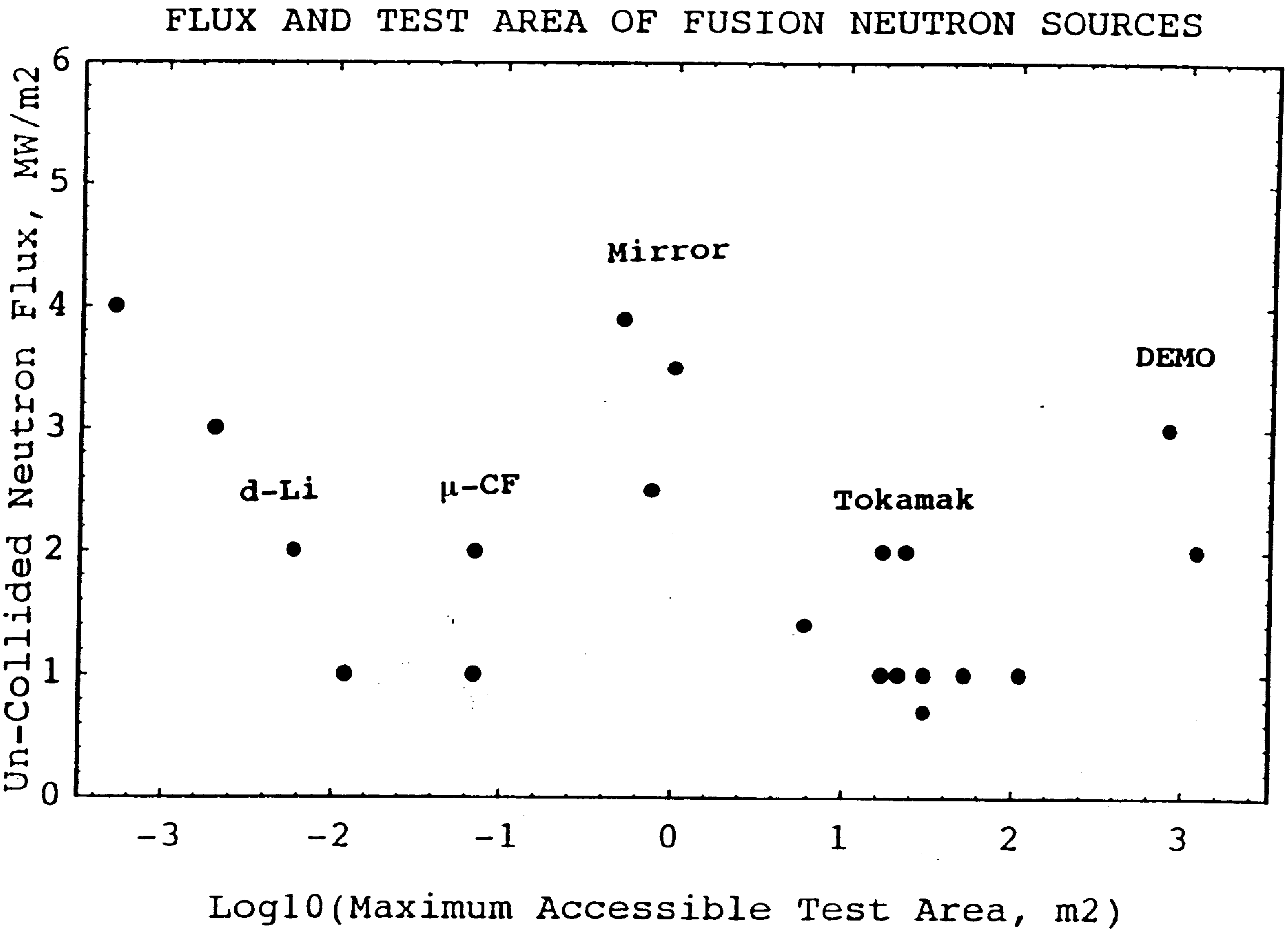


Figure 2. Maximum accessible test area and the un-collided neutron loading averaged over the test area for the VNS concepts presented at the workshop ("•" representing values from Tables 2 and 3). The values for a DEMO, and the high-flux neutron sources based on d-Li target and μCF are included for contrast.

List of Issues for VNS Design

- Must design for high availability
  25-35%
- Normal versus superconducting TF coil?
  - Inboard shield requirements
  - Ceramic insulators in N/C coils?
  - Demountable N/C TF coils?
  - Radiation limits
- Divertor heat load
- Current drive

VENUS Study

- DOE's Office of Fusion Energy in USA has initiated in May 1993 a new study called VENUS.

- The focus of the study is evaluation of VNS (Volumetric Neutron Source) as a dedicated facility for testing fusion nuclear components and material combinations. VNS will operate in parallel to ITER to achieve the US National Energy Strategy Goal of DEMO operation by the year 2025

- The first phase of VENUS is Concept Definition Study to
    - determine VNS requirements for fusion nuclear component and material testing
    - define an envelope of key features within which VNS must fit (size, power, duty cycle, availability, cost, etc.)
    - Identify promising design concepts for VNS that fit within the envelope

- Participating Organizations: UCLA, ORNL, LLNL and Others

- VENUS will serve as a mechanism for providing the USA technical input to International VNS activities such as IEA

IEA Activity on VNS

- The Fusion Power Coordinating Committee (FPCC) requested the IEA Executive Committee on Fusion Materials to study and make recommendations regarding:
  - IFMIF: an accelerator-based international fusion materials facility
  - VNS: high volume source
- A workshop was held in Moscow July 12-18, 1993 with participants from EC, Japan, Russia, USA
- Conclusions from workshop
  i) A volumetric neutron source (VNS) fusion facility is needed to test, develop and qualify fusion nuclear components and material combinations for DEMO
  ii) An attractive range of design options exists for VNS
- Recommendations from workshop
  Recommend IEA initiate VNS study activity with 3 phases (with decisions to proceed or terminate at the end of each phase)

Phase 1: Concept definition (2 years)
  - Develop detailed statement of mission and objectives
  - Elucidate detailed test requirements
  - Identify envelope of design concepts, evolve the concepts to a level sufficient for making selection
  - Select design concept

Phase 2: Conceptual Design (2 years)

Phase 3: Engineering Design (3 years)

Summary

- VNS (Volumetric Neutron Source) is a fusion facility, which operates parallel to ITER, for testing, developing and qualifying fusion nuclear components and materials for DEMO

- VNS, together with ITER and IFMIF, provide an optimum cost effective path for timely development of DEMO

- Requirements on VNS to effectively perform testing of nuclear components and materials have been identified. Examples are:
  - Neutron Wall Load: 1-2 MW/m^2
  - Neutron Fluence: 4-6 MW• y/m^2
  - Plasma Burn Mode: Steady State (or long pulse)
  - Availability: 25-35%
  - Test Area at first wall: 10-30 m^2

- Programmatic constraints suggest that VNS capital cost be kept below one third to one half of ITER

- Fusion Power in VNS should be kept below 400 MW to minimize tritium consumption and avoid the need for breeding blanket

- VNS should rely on present day physics and technology

- VNS will help reduce the Technological Burden on ITER; e.g. eliminating the need for high fluence (operating ITER 3500 MW to high fluence is costly)

- An attractive design envelope for a Tokamak VNS that satisfies the technical and programmatic requirements exists

- Serious International effort is needed to further evaluate the testing requirements and to identify attractive design options for VNS