

VNS
A Volumetric Neutron Source Fusion Facility to Test, Develop
and Qualify Fusion Nuclear Technology Components and
Material Combinations

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VENUS Study

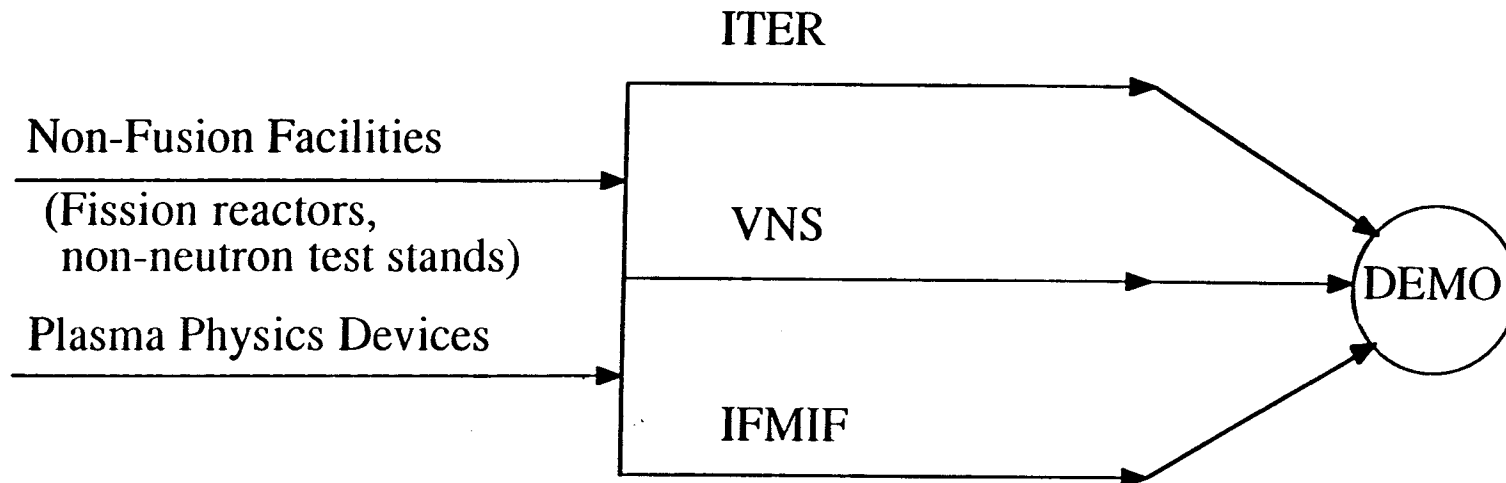
- Initiated by OFE, May '93.
- Participating organizations: UCLA, ORNL, LLNL, etc..
- Focus of VENUS: Evaluation of VNS as a dedicated facility for testing fusion nuclear components and material combinations. VNS will operate in parallel to ITER to achieve the US national strategy goal of DEMO operation by the year 2025.

- VENUS Present Phase: Concept Definition Study.
 - Determine testing requirements.
 - Define an envelope of key features within which VNS must fit (size, power, cost, etc.).
 - Identify promising design concepts.

- VENUS serves as a mechanism for providing technical input to international VNS discussions.

- VENUS Progress
 - Technical progress on VNS test requirements and design concepts.
 - Provided information to international community
 - * IEA Workshop, Moscow, July '93
 - * Briefings in Japan: JAERI, Japanese Universities, Fusion Council Subcommittees, Industrial Forum
 - * Scheduled IAEA Workshop at UCLA, Sept. '93

Prudent and Optimum Path to DEMO Requires
Three Parallel Facilities



ITER

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

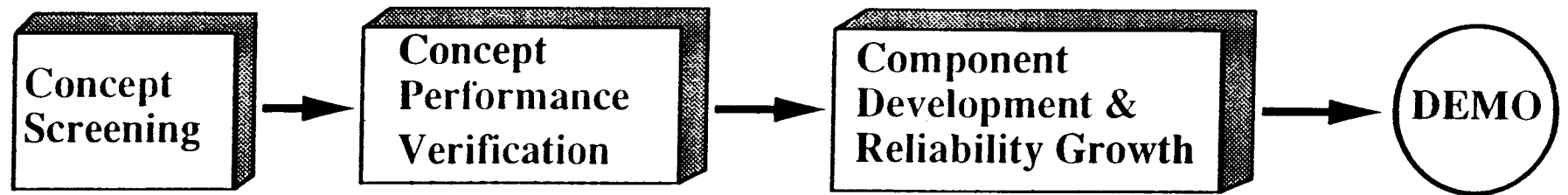
VNS [Volumetric Neutron Source]

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

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



Required
Fluence
MW.Y/m²

0.3

> 1.0

> 4 - 6

Size of
Test
Article

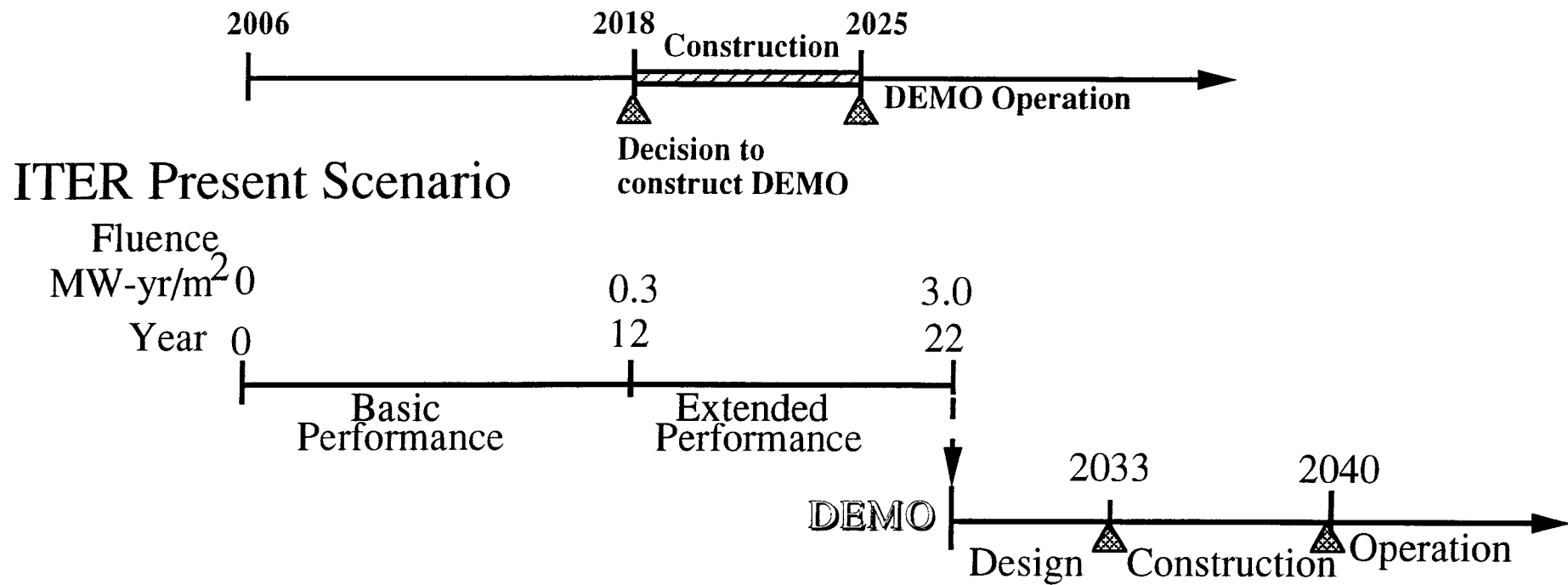
Submodules

Modules

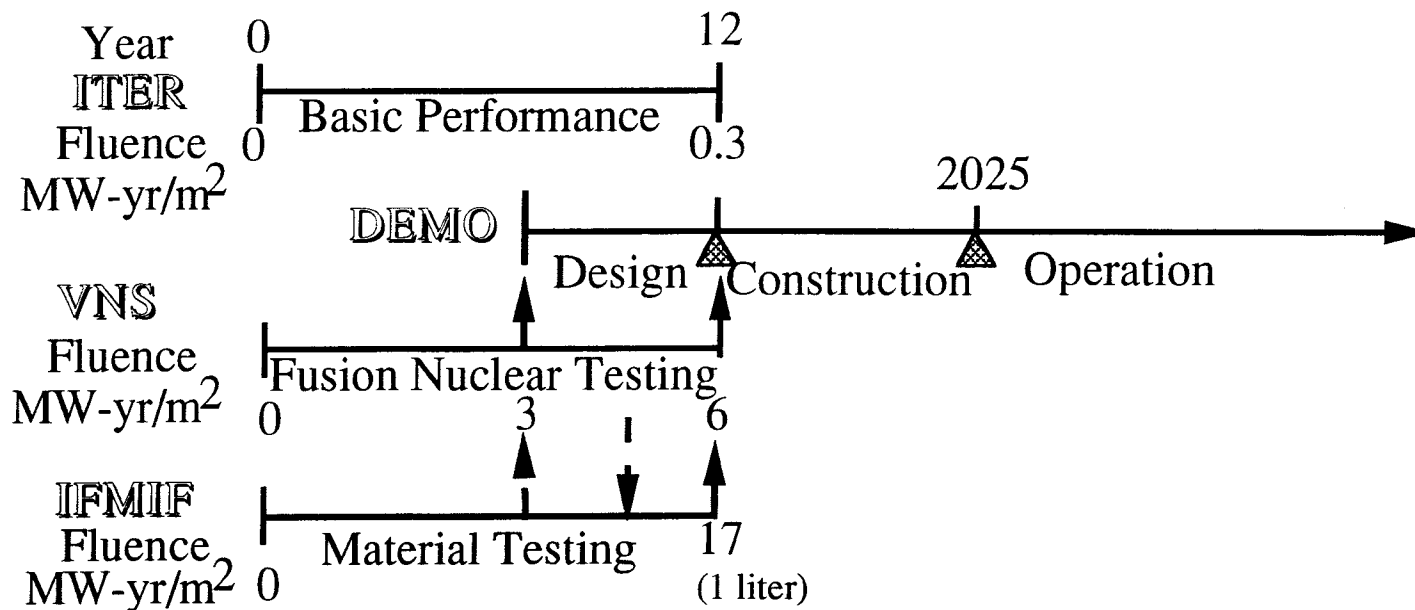
Modules/Sectors

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- Reliability Growth Testing is Most Demanding
 - Requires an aggressive design/test/fix iterative program
 - Requires many test modules and high fluence in fusion facility

VNS Is Necessary to Meet DEMO Time Schedule



ITER, VNS, IFMIF Scenario (Reduced Technology Burden on ITER)



Physics and Nuclear Technology Requirements for Testing Are Very Dissimilar

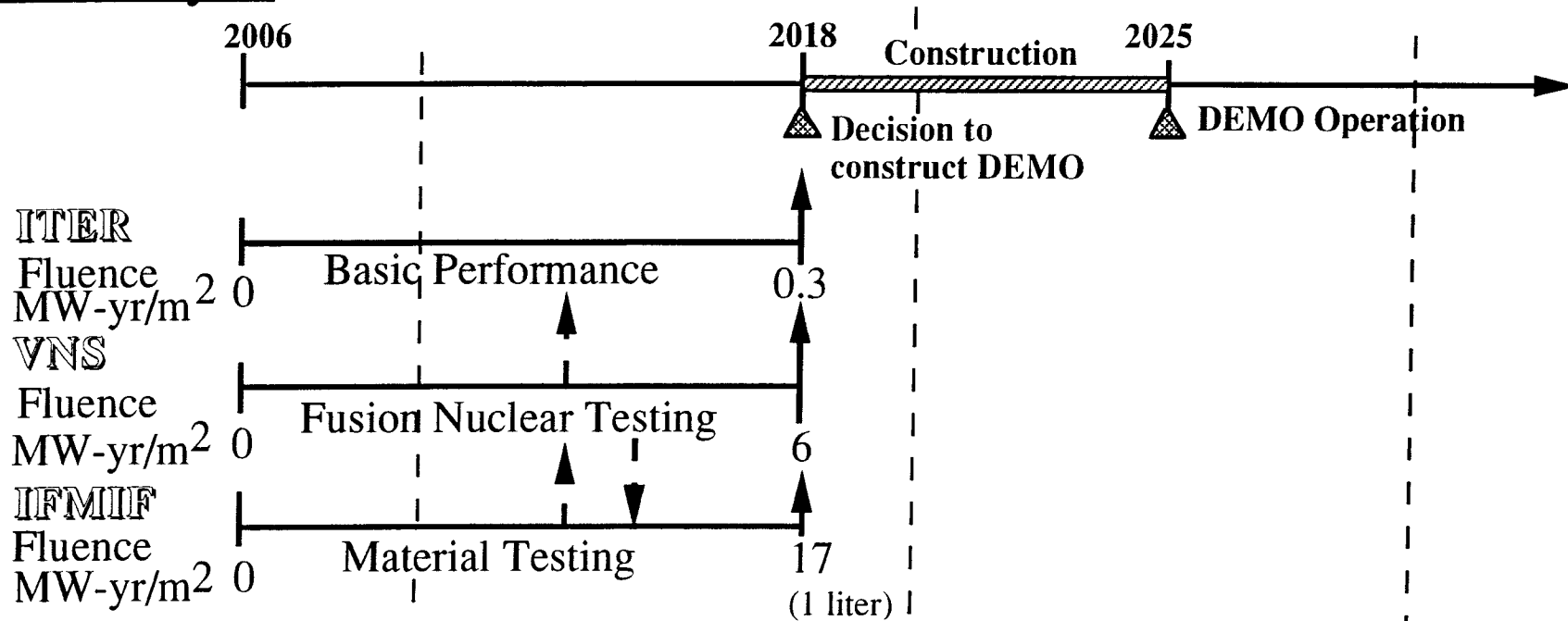
	Fusion Power	Integrated Burn Time	Tritium Consumption
A. Physics and Plasma Support	3500 MW	15 days	8.0 kg
B. Fusion Nuclear Technology	20 MW	5 yr	5.6 kg

Combined * A and B	3500 MW	5 yr	976 kg
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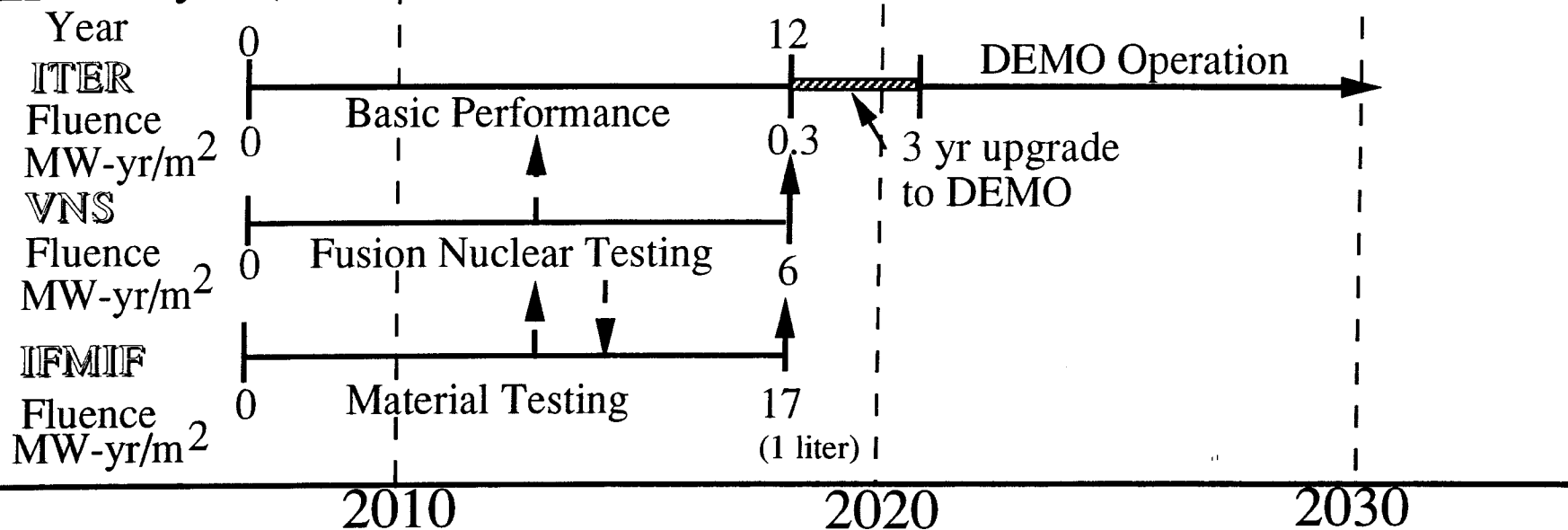
* Combining large power and high fluence leads to large tritium consumption requirements

VNS Increases Confidence in Successful Timely DEMO

Possibility 1



Possibility 2 (Success-Oriented Scenario)



Benefits of VNS

- Provide the fusion facility needed for testing, and developing nuclear components and material combinations for DEMO to adequate testing parameters (e.g. fluence). Test options for attractive economic, safety and environmental features.
- Strengthens Fusion Energy Development Plan and makes it more attractive.
 - Self consistent technical logic.
 - DEMO operation by the year 2025 is defensible.
 - Reduces risk.
 - Eliminates need for another device between ITER and DEMO.
 - VNS operation in parallel to ITER Basic Performance Phase, may enable ITER to operate as a DEMO during Second Phase (under high success-oriented scenario).
 - Fusion energy becomes nearer term option.
 - Reduce cost.
 - Keep industry and governments' interest high.

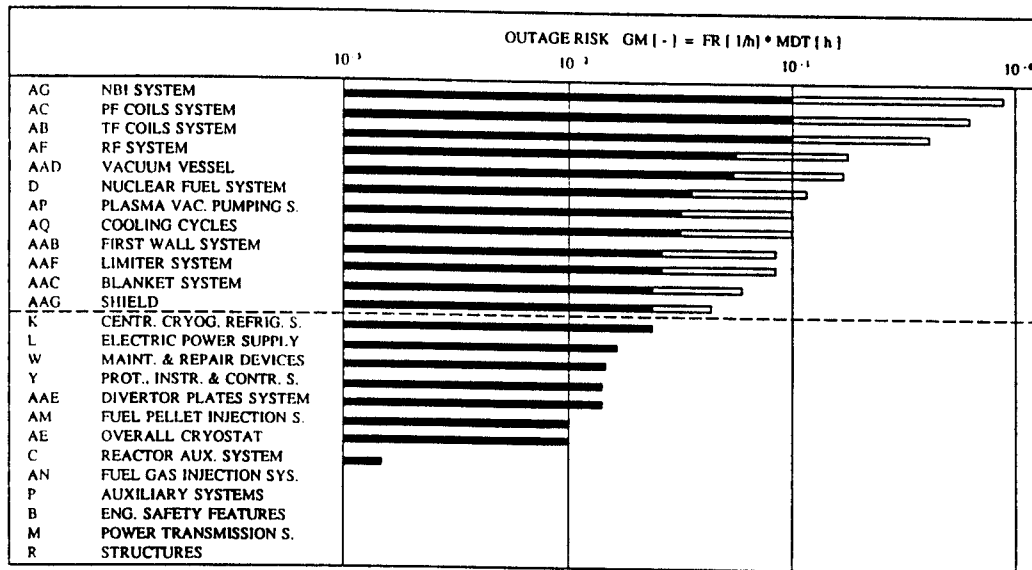
Benefits of VNS (cont'd)

- Reduce technological risk and cost to ITER
 - Reduce fluence need.
 - Eliminate need for breeding blanket during Phase 1.

- Provides additional experience in design, construction and licensing of a fusion device.

- VNS, parallel to ITER, enhances interest of the parties, particularly government's and industry's.

Achieving A High Plant Availability Requires A Very High Blanket Availability



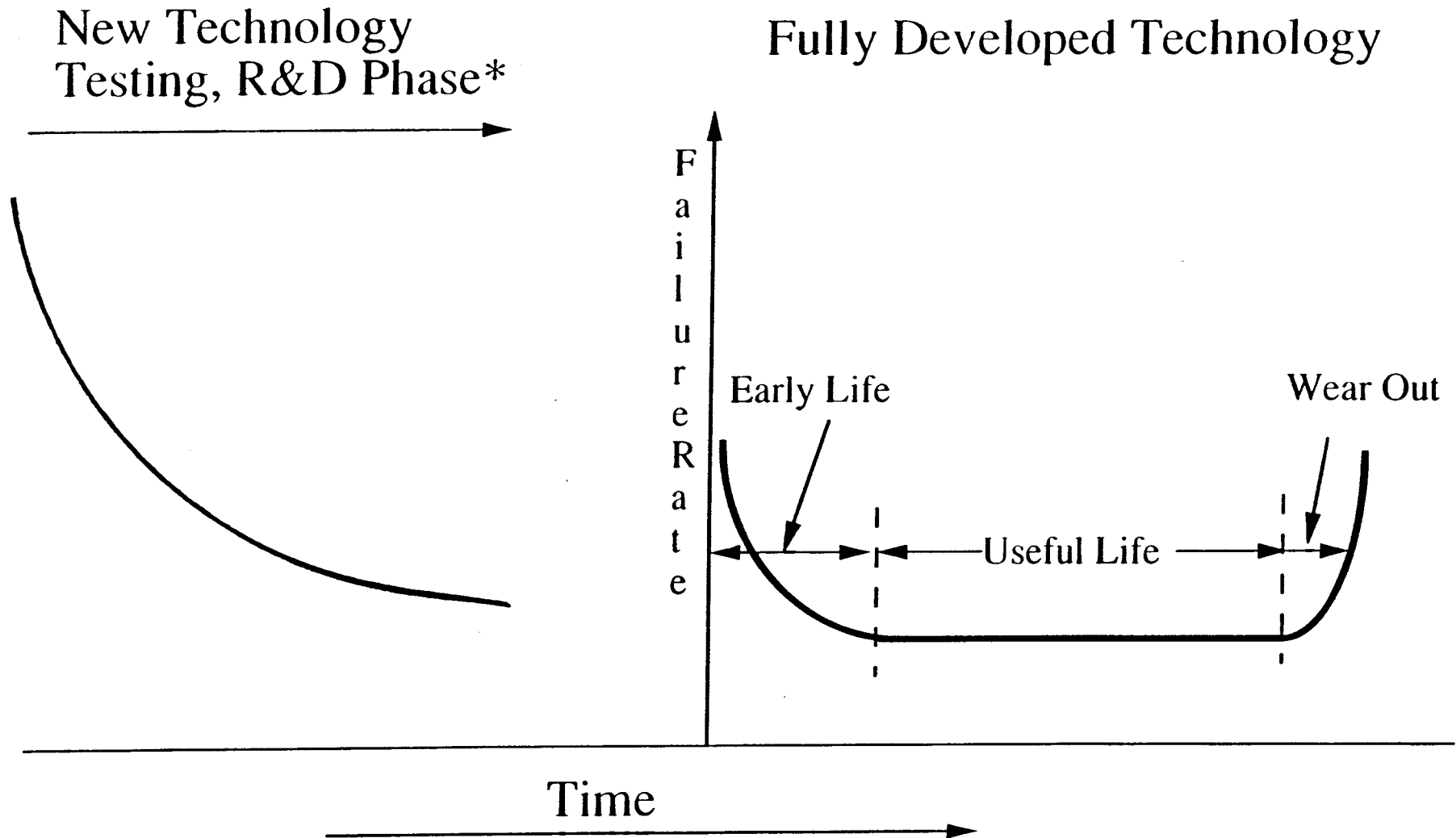
- The outage risk is defined as, failure rate x mean down time, which gives the availability being equal to $\frac{1}{1 + \text{outage risk}}$
 Plant outage risk = 0.717; Plant availability = 58%
 Blanket outage risk = 0.024 ; Blanket availability = 97.6%
- Failure rates for various components were from 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 %

Schematic Failure Rate vs Time During Development and After Development



*The curve shown is for an aggressive development program.

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.

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

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

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 m²
- Higher Wall Load
 > 1 MW/m² (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 < 700 MW

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 ($\text{MW}\cdot\text{m}^{-2}$)	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_{10} (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.

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 of Discussions on VNS in Japan

- Briefings to Drs. Yoshikawa, Shikazono, other JAERI management, Profs. Miya, Ishino, other university people, industry.
- Considerable support for VNS on technical and programmatic basis.
- Policy Issue:
 - Third Phase of Fusion Power Program Policy of AEC does not explicitly mention VNS.
 - Request to form a Fusion Council Subcommittee on Fusion Projects and Program Planning was accepted and implemented (to be chaired by Prof. Miya). Subcommittee will discuss VNS among other projects.
- Japanese Industrial Forum will consider VNS based on industry strong recommendation for fusion facility "before or parallel to ITER."

Summary of Discussions in Russia

- Very strong support at all levels.
- They are working on several tokamak (and mirror) concepts.

What is needed during the next 4-6 months?

- 1) Continue effort to discuss VNS with fusion technical communities in EC, Japan, RF, and USA.
- 2) Continue VENUS effort to evolve VNS design concepts and provide technical basis.
 - VNS technical concept is feasible, an attractive design envelope exists.
 - There are important technical issues that need to be addressed, larger effort is needed to establish credibility.
- 3) OFE Initiative

Effort to initiate an International Study on VNS through:

 - IEA: FPCC implements Executive Committee recommendations.
 - IAEA.
 - Exploration discussion may evolve other mechanisms.

Suggestions for VNS International Study

- The study will consist of 3 phases with decisions to proceed or terminate at the end of each phase
 - Phase 1: Concept Definition (2 years)
 - Phase 2: Conceptual Design (2 years)
 - Phase 3: Engineering Design (3years)

Scope of Phase I: Concept Definition

- Develop detailed statement of mission and objectives for VNS.
- Develop detailed requirements on machine major parameters (e.g. wall load, fluence, plasma burn mode) and design features necessary to test, develop and qualify fusion nuclear components and material combinations.
- Identify envelope of design concepts for VNS; study critical issues and develop design solutions; perform trade off studies to optimize cost/benefit /risk.
- Select design concept.