OVERVIEW OF TRITIUM BREEDING PROBLEMS AND EFFORTS

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Presented at the
6th Topical Meeting on the Technology of Fusion Energy
San Francisco
March 3-7, 1985

REQUIRED TBR

$$\Lambda_r = 1 + G_o + \Delta_G$$

G_o = doubling time margin for a reference conceptual design

Δ_G = uncertainty associated with G

Model

- Model was formulated and used to evaluate dependence of Λ_r on reactor parameters.

- Methods for estimating Δ_G are under development. Initial results are available.

TRITIUM BREEDING PROBLEM

- A part of DT fuel self-sufficiency issue
- Self-sufficiency condition:

  Λ_r = Required tritium breeding ratio

  Λ_a = Achievable breeding ratio

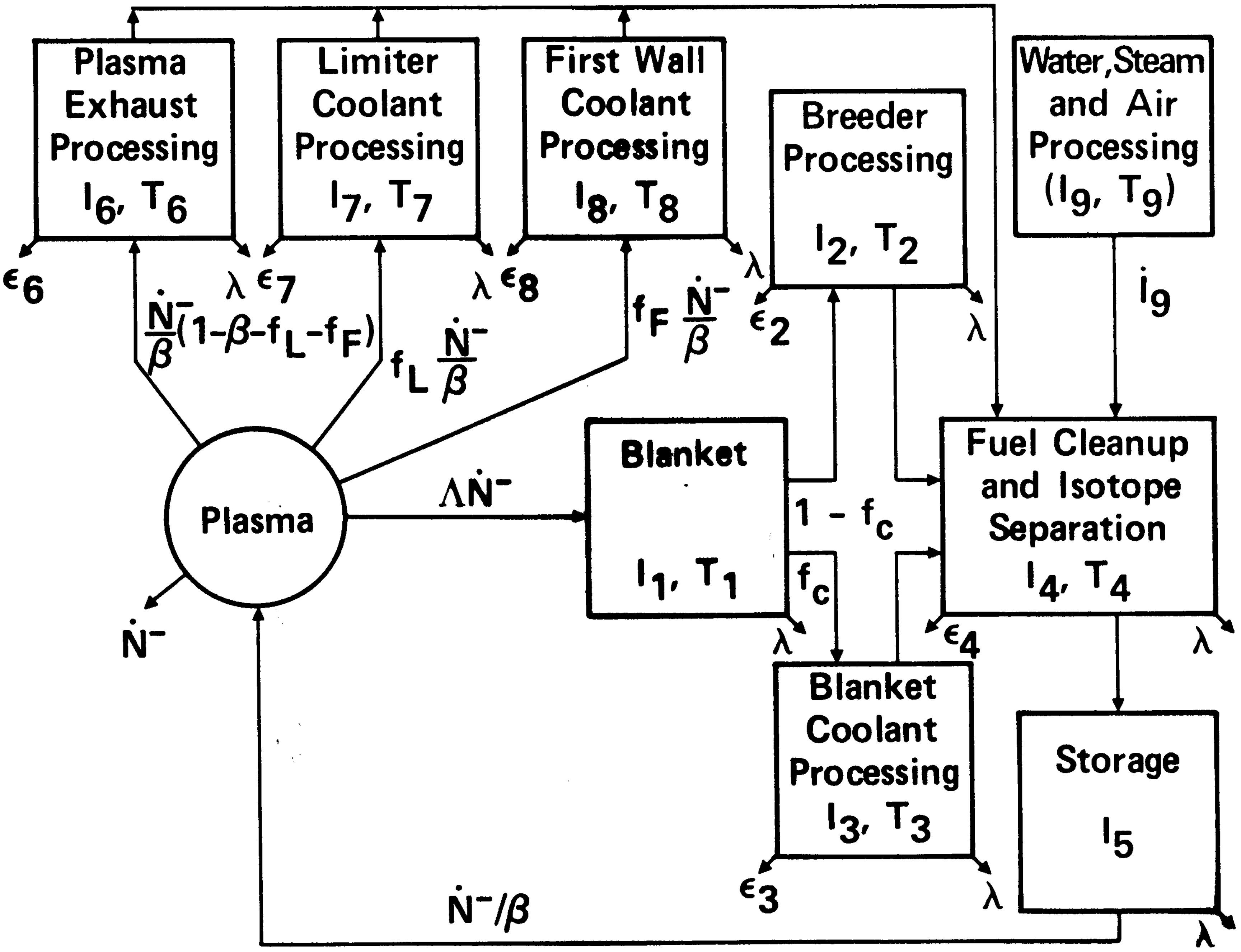
  $\Lambda_r > \Lambda_a$

- Key question:

  Magnitude of uncertainties in Λ_r, Λ_a

  - Conventional types of uncertainties
  - Unconventional type

Schematic model of the fuel cycle for a DT fusion reactor used in the present work



Λ = tritium breeding ratio

$\dot{N}^-$ = tritium burn rate in the plasma

I_i = tritium inventory in compartment i

T_i = tritium mean residence time in compartment i

ε_i = nonradioactive loss of tritium in compartment i

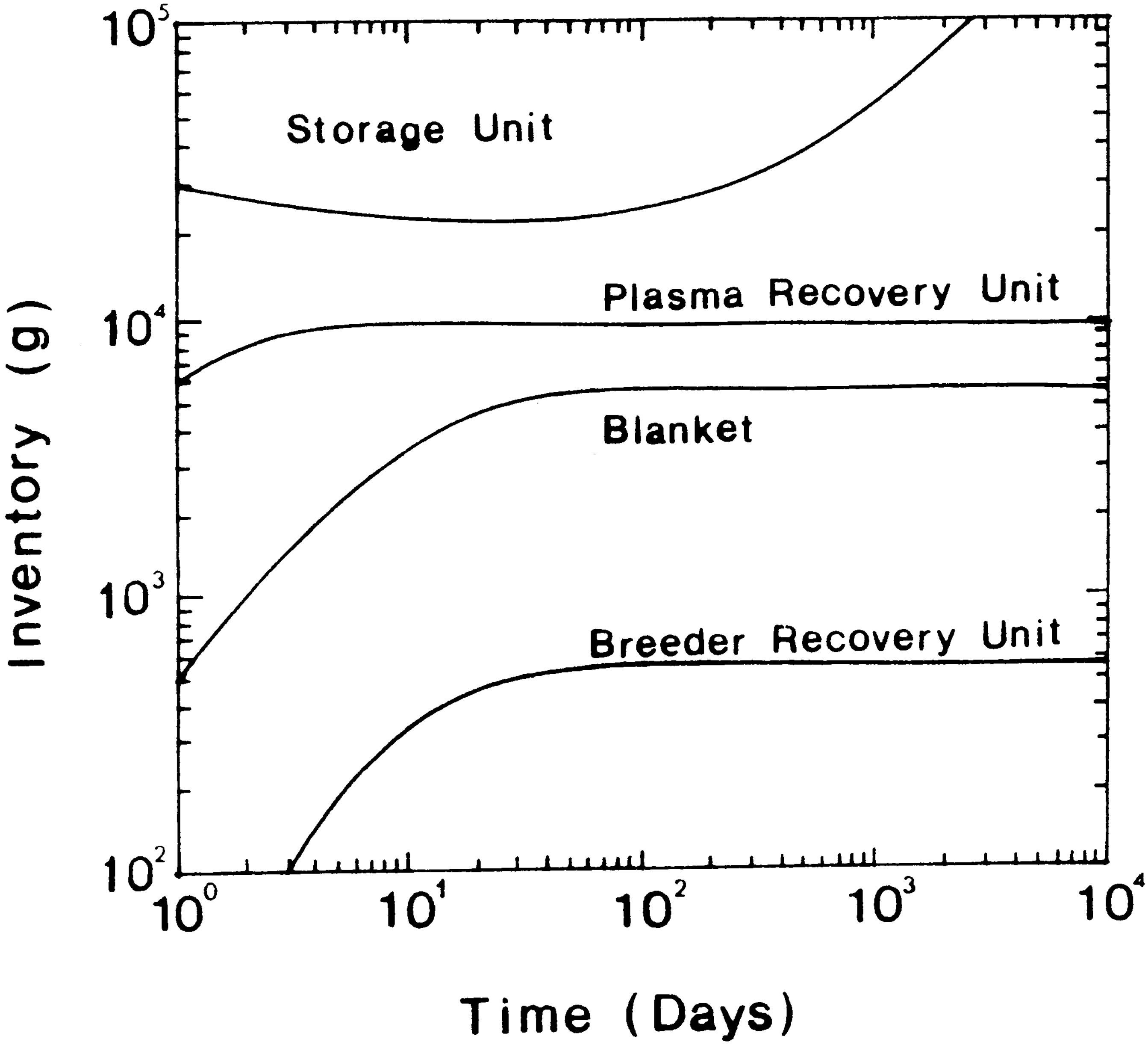
λ = tritium decay constant

β = tritium fractional burnup in the plasma

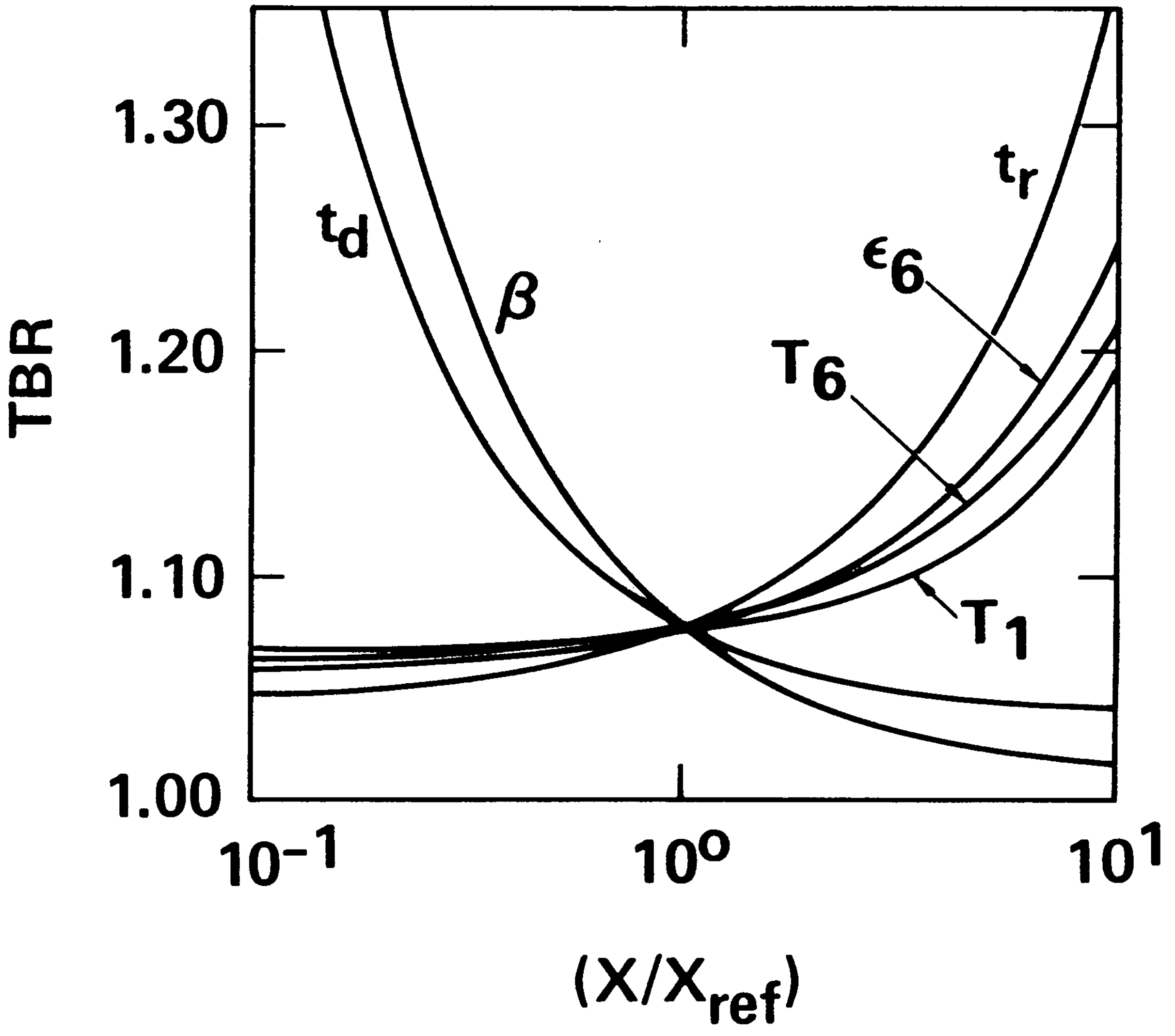
f_i = tritium fractional leakage in compartment i

$\dot{I}_9$ = constant flow rate of tritium recovered from waste, steam, and air processing units

TRITIUM INVENTORY VARIATION WITH TIME FOR THE BASE CASE PARAMETER VALUES USING $\beta = 0.05$ and $t_d = 5$ YR



Dependence of Required TBR on Plasma, Engineering Parameters



Reference Case (X_{ref})

β = 5%	t_d = 5y
T_1 = 10d	T_6 = 1d
t_r = 2d	ϵ_6 = 0.1%

REQUIRED TBR IS FOUND TO BE STRONGLY DEPENDENT ON SIX KEY PARAMETERS

β = tritium fractional burnup in plasma

t_d = doubling time

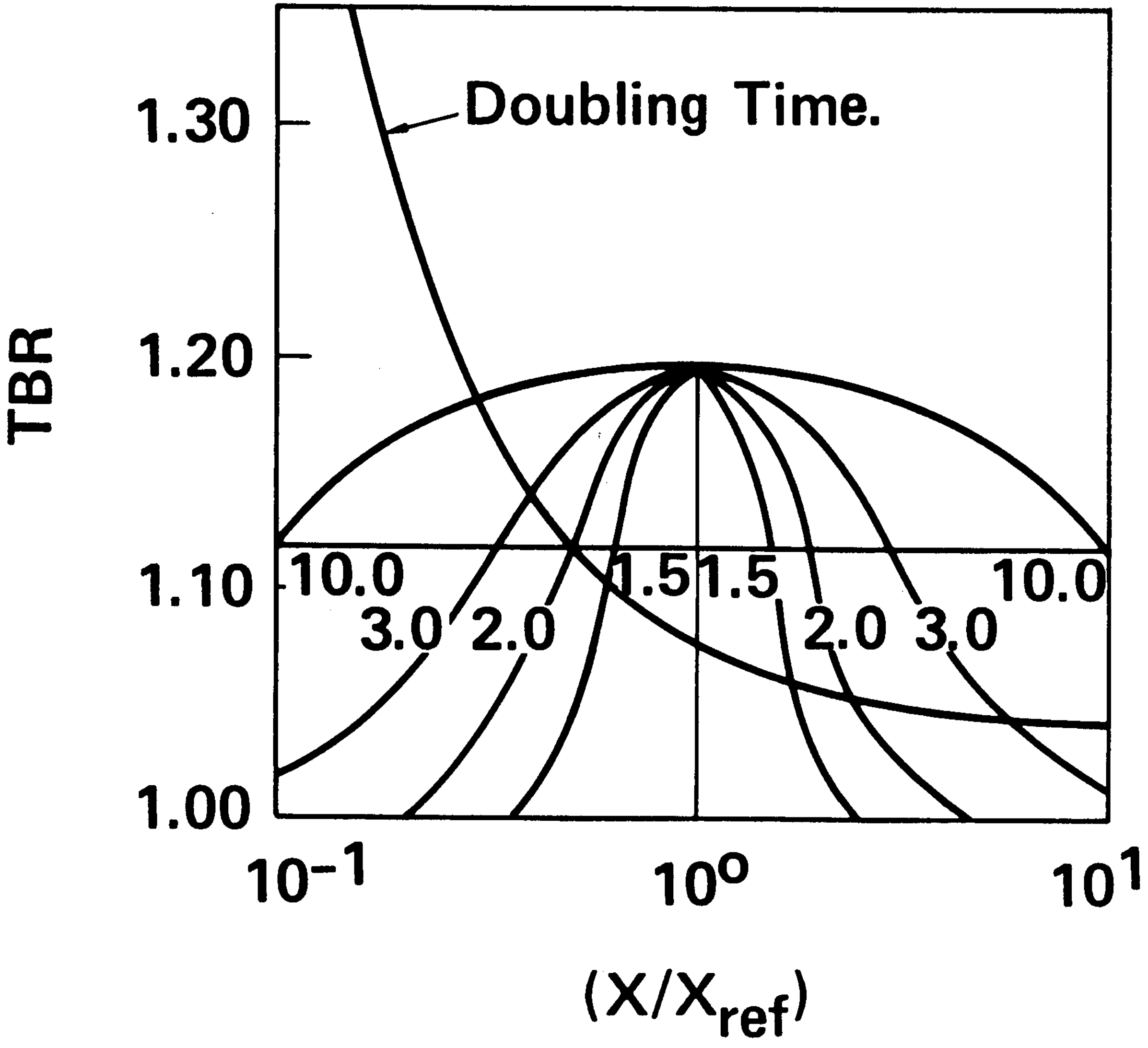
T_1 = tritium mean residence time in blanket

T_6 = tritium mean residence time in plasma exhaust processing

t_r = number of days of tritium reserve

ε_6 = tritium extraction inefficiency in plasma exhaust processing

Log-Normal Probability Distributions Used as Weighting Functions, Superimposed on the Variation of the Breeding Ratio with Doubling Time.



REQUIRED BREEDING RATIO UNCERTAINTY
(95% CONFIDENCE LEVEL)

Parameter	x_g	σ_g	$\Lambda_{ex,i}$	Δ_{Gi} (%)
Doubling time	5 yr	2	1.120	4
Burn fraction	.05	2.5	1.18	9.6
Days of T reserve	2 d	2	1.108	3
Plasma recovery loss fraction	0.001	5	1.153	7
Plasma recovery time	1 d	2	1.092	1.4
Blanket inventory	5 kg	3	1.097	2

ACHIEVABLE TBR

- Problem - We cannot predict precisely Λ_a because:
    - We do not know the exact specifications of what to build
    - For given reactor specifications, we cannot predict precisely the performance
- We can only calculate a TBR for a reference system with assumptions about its specifications

$$\Lambda_a = \Lambda_c - \sqrt{\Delta_s^2 + \Delta_p^2}$$

Λ_c = TBR calculated (the best we know how today, 3D, etc.) for a specified blanket in a specified reactor

Δ_s = Uncertainty associated with system definition [changes in calculated TBR resulting from changes in the reference reactor system (e.g., reference reactor system has limiter and reactor to be built could have a divertor)]

Δ_p = Uncertainties in predicting TBR for a given system

$$\Delta_p = \sqrt{\Delta_m^2 + \Delta_d^2 + \Delta_c^2}$$

Δ_m = Uncertainties associated with geometric modeling

Δ_d = Uncertainties associated with nuclear data

Δ_c = Uncertainties associated with calculational methods

TYPES OF UNCERTAINTIES IN PREDICTING ACHIEVABLE TBR

Uncertainties Associated with System Definition (Δ_s)

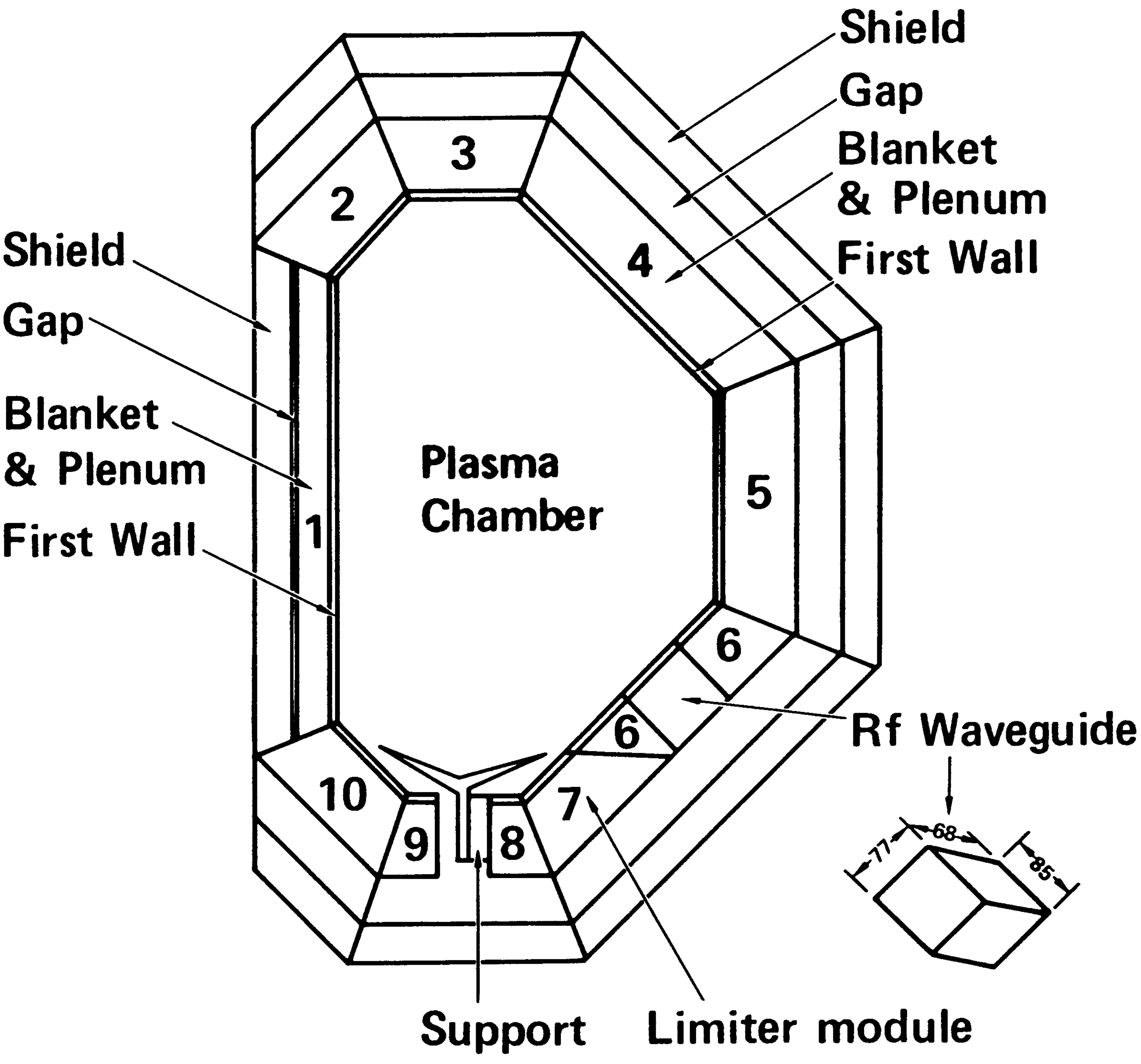
- First Wall/Blanket Definition
  - Configuration details, structure, coolant, manifolds, form and porosity of solid breeders, thermophysical property variations, etc.

- Reactor Definition
  - Technology choices (type of rf vs. neutral beams, limiter vs. divertor, etc.)
  - Requirements and specifications for specific technology choices (e.g., size and configuration of penetrations for limiter, material choices for limiter)
  - Presence of yet undefined components (e.g., penetrations for diagnostics and fueling, I&C)
  - Possible need for components to satisfy yet undefined requirements (e.g., passive copper coils in the blanket for plasma stabilization, sector to sector electrical joints, etc.)

Δ_p = UNCERTAINTIES ASSOCIATED WITH PREDICTING TBR FOR A GIVEN SYSTEM

- Approximations in Geometrical Modeling (Δ_m)
  - Approximating engineering 3D surfaces and volumes by traditional mathematically convenient shapes (intersection of cones, cylinders, spheres, cubes, etc.)
  - Approximating discrete by continuous geometric zones
  - Approximating the details of heterogenity
- Nuclear Data (Δ_d)
  - Uncertainties in basic nuclear data
  - Approximations in data processing
  - Approximations in final data libraries (number of energy groups, weighting functions, etc.)
- Calculational Methods (Δ_c)
  - Inherent in methods and codes
  - Introduced by analyst (e.g., order of S_n, P_n, etc.)

Vertical Cross Section of Reference Tokamak Reactor



UNCERTAINTIES IN ACHIEVABLE BREEDING RATIO DUE TO UNCERTAINTIES IN SYSTEM DEFINITION

Type of Change	Change in TBR (%)
No inboard blanket	14
Limiter:	
Non-breeding limiter module	6
Doubling limiter duct width	2
Strong absorber coating	4
Divertor replaces limiter	7
Other penetrations:	
Auxiliary heating	1
Fueling, diagnostics, etc.	1
Other materials in blanket (e.g., passive copper coils)	3
Blanket first wall specification details (configuration, structure, coolant, manifolds)	2

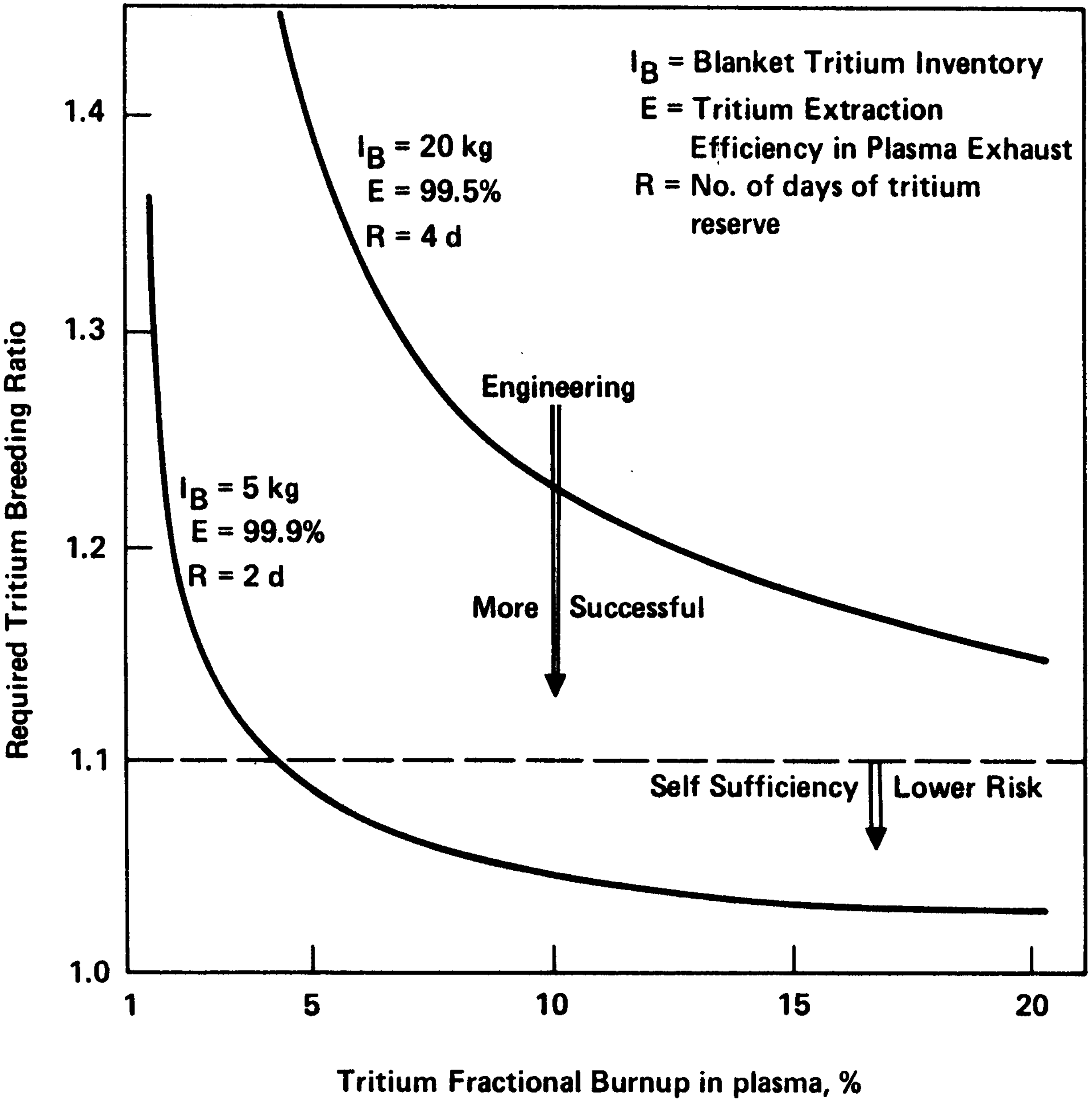
Δ_d, ESTIMATE OF UNCERTAINTY IN TBR DUE TO UNCERTAINTIES IN NUCLEAR DATA

Blanket Concept	Δ_d(%)
Li/Li/HT9	5.5
LiPb/LiPb/V	4.4
Li/Li/V	6
Li_2O/He/HT9	4.9
$LiAlO_2/H_2O$/HT9/Be	2.1

ACHIEVABLE AND REQUIRED TRITIUM BREEDING RATIOS AND UNCERTAINTIES FOR LEADING BLANKETS IN TOKAMAKS

	Achievable Λ_a		Required Λ_r		
Concept	Δ_c	Δ_a	$1 + G_o$	Δ_g	$\epsilon = \Lambda_a - \Lambda_r$
$LiAlO_2$/DS/HT9/Be	1.24	0.22	1.077	0.143	-0.20
LiPb/LiPb/V	1.30	0.24	1.072	0.142	-0.15
Li/Li/V	1.28	0.24	1.072	0.142	-0.17
Li_2O/He/HT9	1.11	0.21	1.077	0.143	-1.32
$LiAlO_2$/He/HT9/Be	1.04	0.19	1.077	0.143	-0.37
Li/He/HT9	1.16	0.22	1.072	0.142	-0.27
$LiAlO_2$/H_2O/HT9/Be	1.16	0.21	1.077	0.143	-0.27

Attaining DT Fuel Self Sufficiency Requires Success in Both Physics and Engineering



PRESENT EFFORT ON TRITIUM BREEDING

- Efforts to Reduce Uncertainties in:

  Required TBR

  Achievable TBR

- Efforts to Improve Predictability of Uncertainties

REDUCING UNCERTAINTIES IN REQUIRED TBR

- Models to predict required TBR as a function of reactor plasma and engineering parameters

- Identifying allowable range of parameter space to guide R&D
  - Plasma, plasma support systems
  - Blanket
  - Tritium processing system
  - Other components
  - Early stage of fusion commercialization (short doubling time)

REDUCING UNCERTAINTIES IN ACHIEVABLE TBR

- Design Definition
    - Narrow materials and design concepts
    - Greater engineering detail
- Calculations
    - Modest improvement in methods
    - More detailed geometrical modeling
- Nuclear Data
    - Measurements
    - Evaluation
    - Data representation and processing

IMPROVING PREDICTABILITY OF UNCERTAINTY IN TBR

- Uncertainty in Required TBR
  - Probability distributions for reactor parameters
  - Methods to evaluate Δ_g
- Uncertainty in Achievable TBR
  - Integral experiments with point neutron source
  - Sensitivity analysis
    - Improve methods
    - Perform sensitivity studies
  - Benchmark calculations
  - Identifying requirements for integral experiments in fusion testing devices

PRESENT INTEGRAL NEUTRONICS EXPERIMENTS RELATED TO TRITIUM BREEDING (contd.)

- LOTUS: Switzerland
  - Led by IGA, EPFL, EIR in Switzerland
  - Cooperation with US, India
  - Emphasis on fissile material and tritium production in hybrid modules

- LBM: Supported by EPRI
  - PPPL, GA
  - Li_2O module for insertion in TFTR
  - Delays in using tritium in TFTR
  - Other uses being explored

- Others
  - OKTAVIAN: Osaka University
    Focus on clean, single material sphere
  - Special Experiments
    e.g., Pulsed Beryllium Sphere, LLNL