TRITIUM BREEDING REQUIREMENTS

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ANL

FIGURE OF MERIT FOR TBR

$$F = \frac{T_C - (1 + G_0)}{\sqrt{\Delta_G^2 + \Delta_S^2 + \Delta_P^2}}$$

T_C = NET TBR CALCULATED FOR THE BLANKET UNDER CONSIDERATION IN 3D GEOMETRY FOR REFERENCE REACTOR CONDITIONS (E.G., MARS WITH A SET OF ASSUMPTIONS ABOUT DESIGN CHOICES; OR STARFIRE WITH SPECIFIED LIMITER, LOWER HYBRID, ETC.)

G_0 = EXPECTED (MEAN) VALUE OF DOUBLING TIME GAIN REQUIRED UNDER REFERENCE CONDITIONS AND ASSUMPTIONS

Δ_G = UNCERTAINTY IN PREDICTING REQUIRED DOUBLING TIME MARGIN

Δ_S = UNCERTAINTY ASSOCIATED WITH SYSTEM DEFINITION

Δ_P = UNCERTAINTY IN PREDICTING TBR FOR A GIVEN SYSTEM

NOTES

IN RIGOROUS STATISTICAL TREATMENT:

- THE NUMERATOR SHOULD HAVE PART OF THE UNCERTAINTY SUBTRACTED TO ACCOUNT FOR MAXIMUM ACCEPTABLE RISK. (THIS IS IGNORED HERE.)

- THE VARIANCES IN THE DENOMINATOR HAVE COEFFICIENTS THAT ARE FUNCTIONS OF THE PARTIAL DERIVATIVES WITH RESPECT TO UNCERTAINTY VARIABLES. (THESE COEFFICIENTS ARE ASSUMED CONSTANT AND EQUAL HERE.)

SCORING OF TBR

- Based on normal distribution

F	Score (Evaluation Index, I)
0	0
0.25	0.20
0.50	0.38
0.75	0.55
1.00	0.68
1.25	0.79
1.50	0.87
1.75	0.92
2.00	0.95
2.25	0.98
2.50	0.99
3.00	1.0

REQUIRED TBR

$$T_R = 1 + G_0 + \Delta_G$$

MODEL

- A DETAILED MODEL WAS WRITTEN FOR ANALYSIS OF TRITIUM FLOW IN ALL KEY COMPONENTS OF THE REACTOR PLANT.
- EXACT MATHEMATICAL FORMULATION WAS USED.
- A COMPUTER PROGRAM CAN NOW CALCULATE (A) THE TIME-DEPENDENT TRITIUM INVENTORY IN EACH COMPONENT, AND (B) THE REQUIRED TRITIUM BREEDING RATIO AS A FUNCTION OF REACTOR PARAMETERS.

RESULTS

- THE MODEL HAS BEEN USED TO CALCULATE THE REQUIRED TBR $(1 + G_0)$ AT A SET OF REFERENCE CONDITIONS.
- SENSITIVITY ANALYSIS IS UNDERWAY TO COMPUTE STATISTICALLY CORRELATED (RIGOROUS) Δ_G.
- DIRECT SENSITIVITY ANALYSIS COMPLETED. PERMITS AN ESTIMATE OF Δ_G USING SOME EXPERT JUDGEMENT.

KEY PARAMETERS FOR REFERENCE CASE FOR ESTIMATING G_0

Note 1: Rigorous Analysis would use expected (mean) values for the reference case. However, we used expert judgement on the most probable values. These most probable values used are much more optimistic than the mean values as evident from the results shown later.

Note 2: Changing the reference case values to more optimistic values will not affect the BCSS results. It will only reduce the credibility of the reference case.

Tritium Consumption (Burn in Plasma) = 0.5 kg/day

Doubling Time = 5 yr

Tritium Fractional Burnup in Plasma = 5%

Non-Radioactive Losses (Chemical Inefficiences, Etc.) = 0.1%
(Plasma Exhaust Processing, Coolant Processing, Breeder Processing)

Tritium Reserve = 2 Days of Tritium Flow to Plasma

Equilibrium Tritium Inventory in Blanket = Variable

Tritium Inventory in Other Components ≡ practically ignored

TRITIUM FRACTIONAL BURNUP

- THERE ARE GOOD REASONS TO EXPECT IT TO BE HIGH IN MIRRORS

- THERE ARE EQUALLY GOOD (BUT DIFFERENT) REASONS TO EXPECT IT TO BE HIGH IN TOKAMAKS

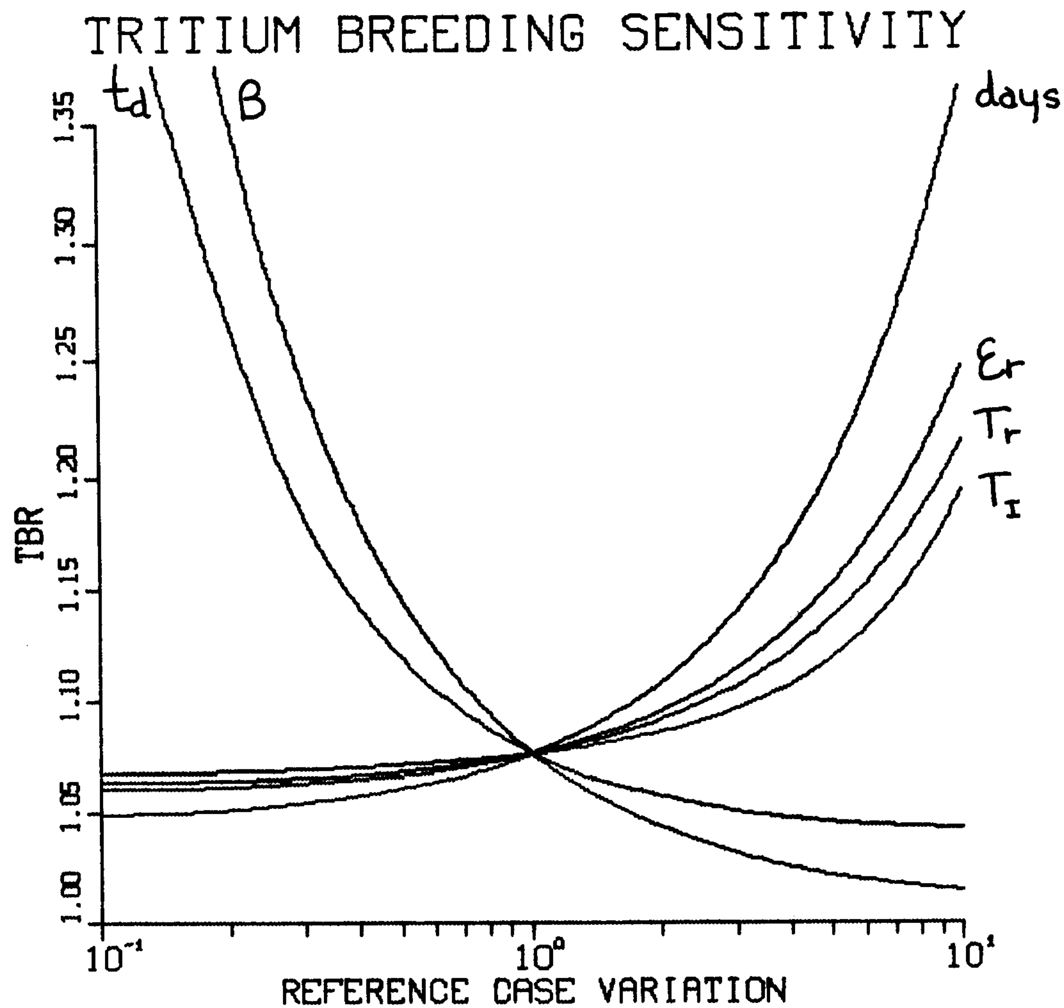
- IF THE ONLY WAY TO SUSTAIN THE FUEL CYCLE SELF SUFFICIENCY IS TO HAVE A TRITIUM FRACTIONAL BURNUP OF 10 TO 20%, WE CAN ASSUME THAT IT CAN BE DONE WITH ACCEPTABLE RISK.

- HOWEVER, IF TWO BLANKET CONCEPTS ARE EQUAL EXCEPT IN VIABILITY AT LOWER FRACTIONAL BURNUP THEY SHOULD GET DIFFERENT MARKING BECAUSE OF THE DIFFERENT IMPLICATIONS ON SUCCESS IN PLASMA OPERATION AND PLASMA IMPURITY CONTROL AND EXHAUST PHYSICS AND TECHNOLOGY.

- THE TBR FIGURE OF MEERIT IS WHERE BLANKET CONCEPTS GET HIGHER POINTS FOR BEING ABLE TO ACCOMODATE LOWER FRACTIONAL BURNUP.

DEPENDENCE OF $1 + G_0$ ON BLANKET INVENTORY

	Parameter Value	$(1+G_0)$ TBR	Blanket Inventory (g)
	1.0	1.068	534
	2.0	1.069	1060
	3.0	1.070	1600
	4.0	1.071	2140
	5.0	1.072	2670
	6.0	1.073	3210
	7.0	1.073	3750
	8.0	1.074	4290
	9.0	1.075	4830
BASE CASE	10.0	1.077	5370
	20.0	1.086	10800
	30.0	1.096	16300
	40.0	1.107	22000
	50.0	1.119	27700
	60.0	1.132	33600
	70.0	1.146	39700
	80.0	1.161	45900
	90.0	1.177	52200
	100.0	1.194	58700



TRITIUM BREEDING SENSITIVITY
TBR
1.35
1.30
1.25
1.20
1.15
1.10
1.05
1.00
t_d
β
days
ε_r
T_r
T_I
10^{-1}
10^{0}
10^{1}
REFERENCE CASE VARIATION

TBR SENSITIVITY TO THE PARAMETER DOUBLING TIME (DAYS)

	Parameter Value	TBR
	182.5	1.464
	365.0	1.266
	547.5	1.181
	730.0	1.142
	912.5	1.119
	1095.0	1.105
	1277.5	1.094
	1460.0	1.087
	1642.5	1.081
BASE CASE	1825.0	1.077
	3650.0	1.057
	5475.0	1.050
	7300.0	1.047
	9125.0	1.045
	10950.0	1.044
	12775.0	1.043
	14600.0	1.043
	16425.0	1.042
	18250.0	1.042

TBR SENSITIVITY TO THE PARAMETER H^3 BURN FRACTION

	Parameter Value	TBR
	5.0E-03	1.670
	1.0E-02	1.354
	1.5E-02	1.238
	2.0E-02	1.180
	2.5E-02	1.145
	3.0E-02	1.122
	3.5E-02	1.106
	4.0E-02	1.094
	4.5E-02	1.084
BASE CASE	5.0E-02	1.077
	0.10	1.043
	0.15	1.031
	0.20	1.025
	0.25	1.022
	0.30	1.019
	0.35	1.018
	0.40	1.016
	0.45	1.016
	0.50	1.015

TBR SENSITIVITY TO THE PARAMETER PLASMA CLEANUP LOSS FRACTION

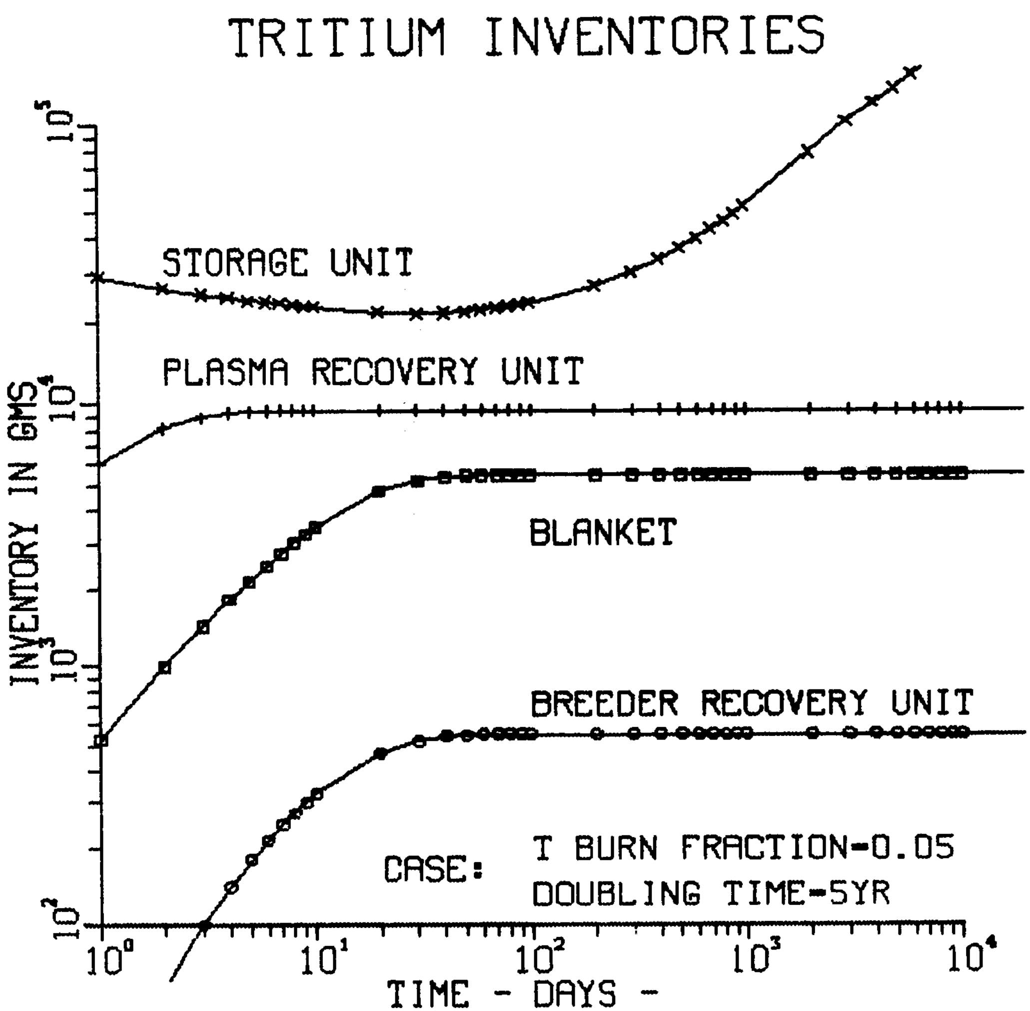
	Parameter Value	TBR
	1.0E-04	1.060
	2.0E-04	1.061
	3.0E-04	1.063
	4.0E-04	1.065
	5.0E-04	1.067
	6.0E-04	1.069
	7.0E-04	1.071
	8.0E-04	1.073
	9.0E-04	1.074
BASE CASE	1.0E-03	1.077
	2.0E-03	1.095
	3.0E-03	1.114
	4.0E-03	1.133
	5.0E-03	1.152
	6.0E-03	1.171
	7.0E-03	1.190
	8.0E-03	1.209
	9.0E-03	1.228
	1.0E-02	1.247

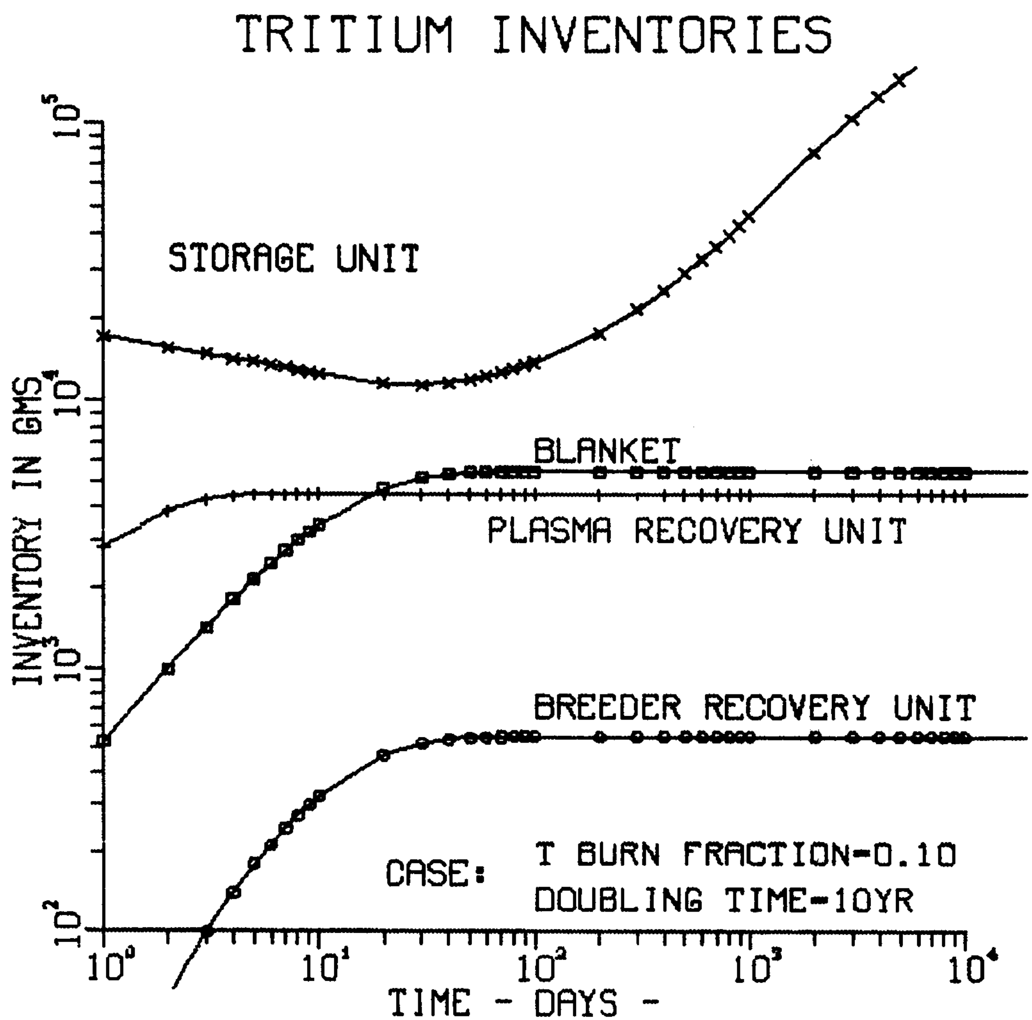
TBR SENSITIVITY TO THE PARAMETER
PLASMA CLEANUP RESIDENCE TIME
(DAYS)

	Parameter Value	TBR
	0.1	1.063
	0.2	1.064
	0.3	1.066
	0.4	1.067
	0.5	1.069
	0.6	1.070
	0.7	1.072
	0.8	1.073
	0.9	1.075
BASE CASE	1.0	1.077
	2.0	1.091
	3.0	1.107
	4.0	1.122
	5.0	1.137
	6.0	1.153
	7.0	1.168
	8.0	1.184
	9.0	1.200
	10.0	1.215

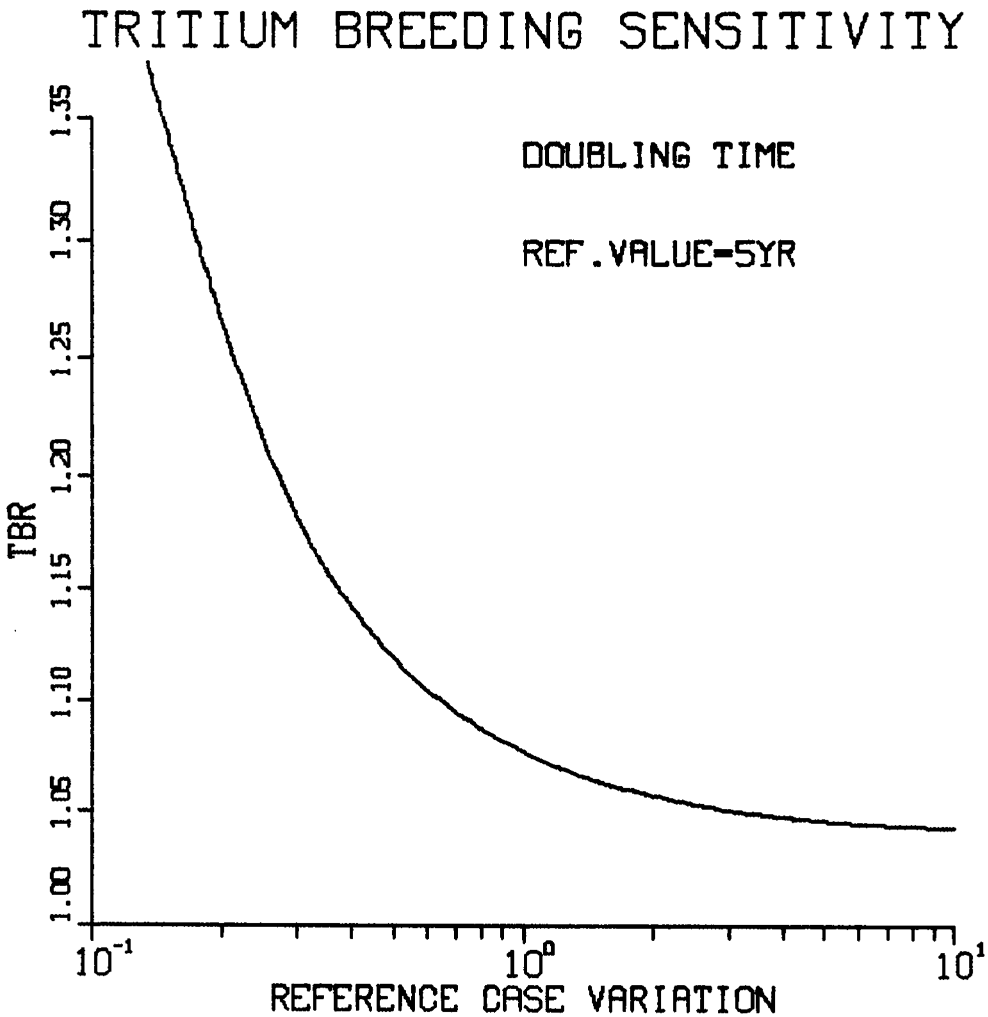
TBR SENSITIVITY TO THE PARAMETER
DAYS OF H^3 FUEL RESERVE

	Parameter Value	TBR
	0.2	1.049
	0.4	1.051
	0.6	1.054
	0.8	1.057
	1.0	1.060
	1.2	1.063
	1.4	1.067
	1.6	1.070
	1.8	1.073
BASE CASE	2.0	1.077
	4.0	1.108
	6.0	1.140
	8.0	1.172
	10.0	1.204
	12.0	1.236
	14.0	1.268
	16.0	1.300
	18.0	1.332
	20.0	1.364

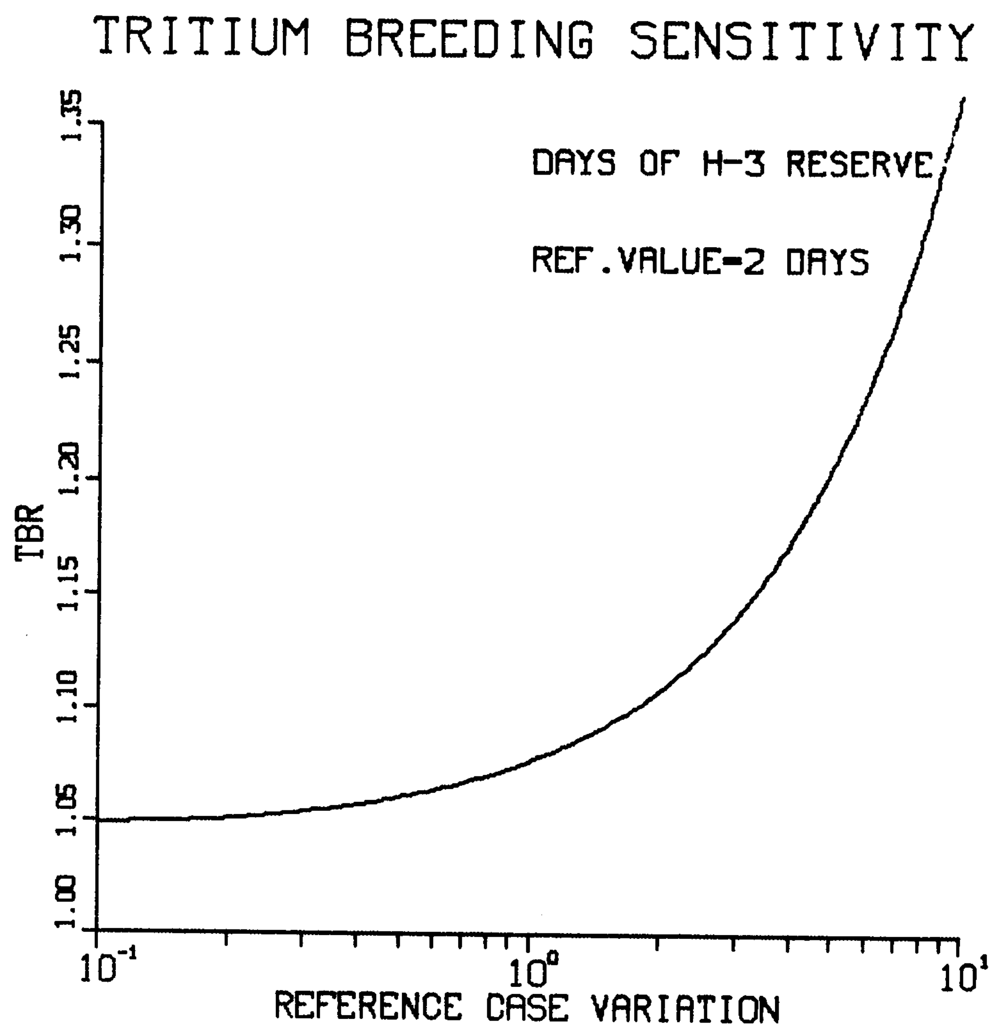

TRITIUM INVENTORIES
STORAGE UNIT
PLASMA RECOVERY UNIT
BLANKET
BREEDER RECOVERY UNIT
CASE: T BURN FRACTION=0.05
DOUBLING TIME=5YR
INVENTORY IN GMS
TIME - DAYS -



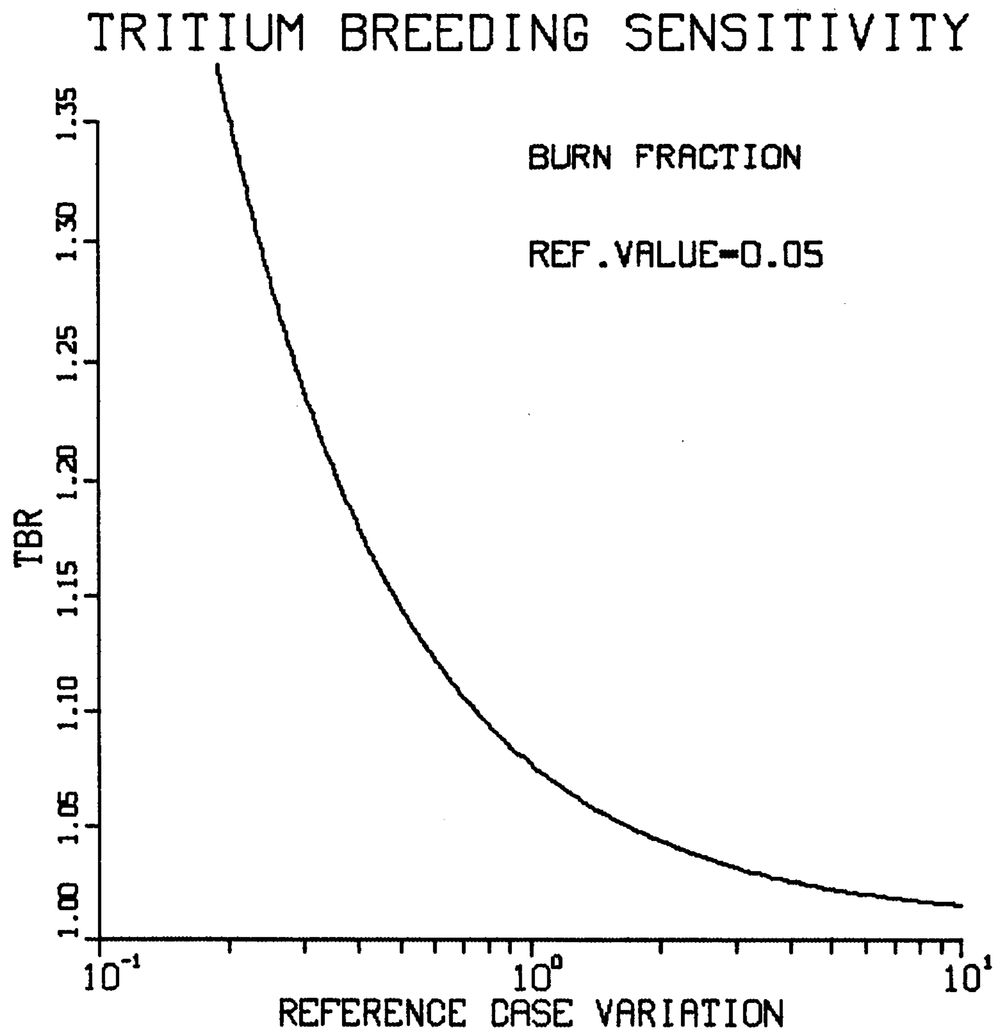
TRITIUM INVENTORIES
STORAGE UNIT
BLANKET
PLASMA RECOVERY UNIT
BREEDER RECOVERY UNIT
CASE: T BURN FRACTION=0.10
DOUBLING TIME=10YR
INVENTORY IN GMS
TIME - DAYS -



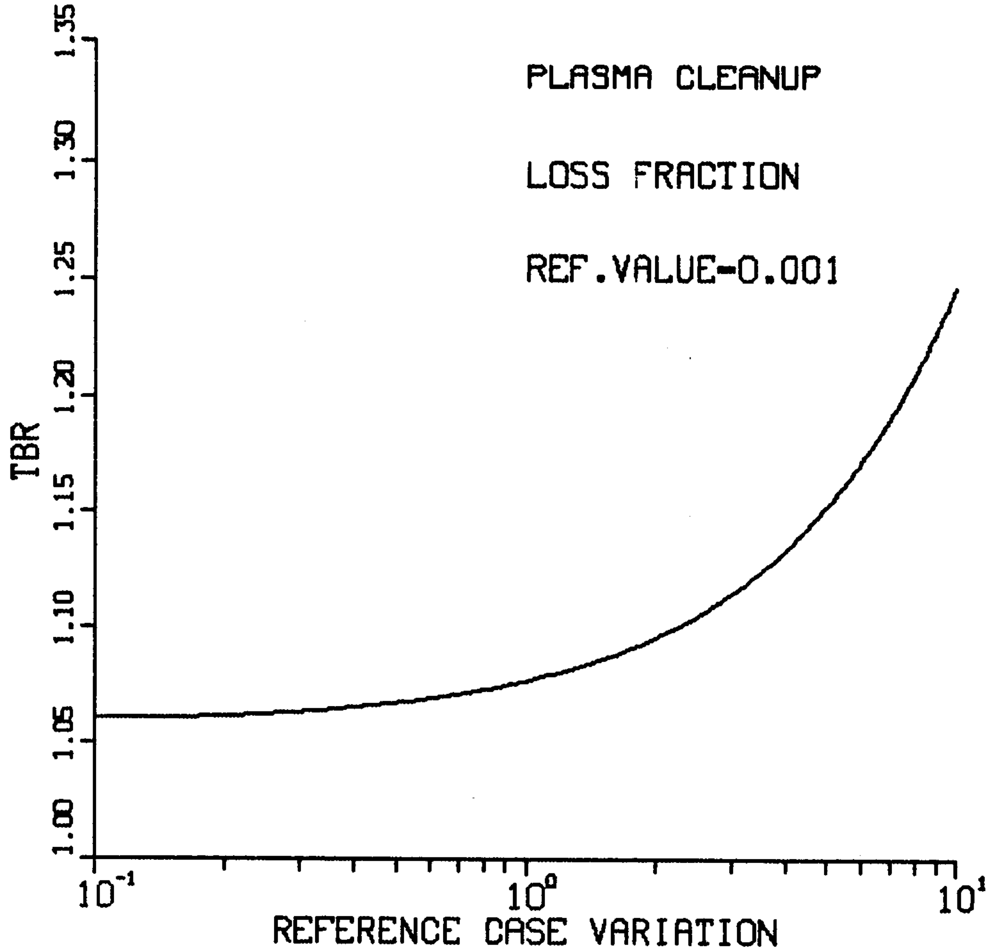
TRITIUM BREEDING SENSITIVITY
DOUBLING TIME
REF.VALUE=5YR
TBR
1.35
1.30
1.25
1.20
1.15
1.10
1.05
1.00
10^{-1}
10^{0}
10^{1}
REFERENCE CASE VARIATION

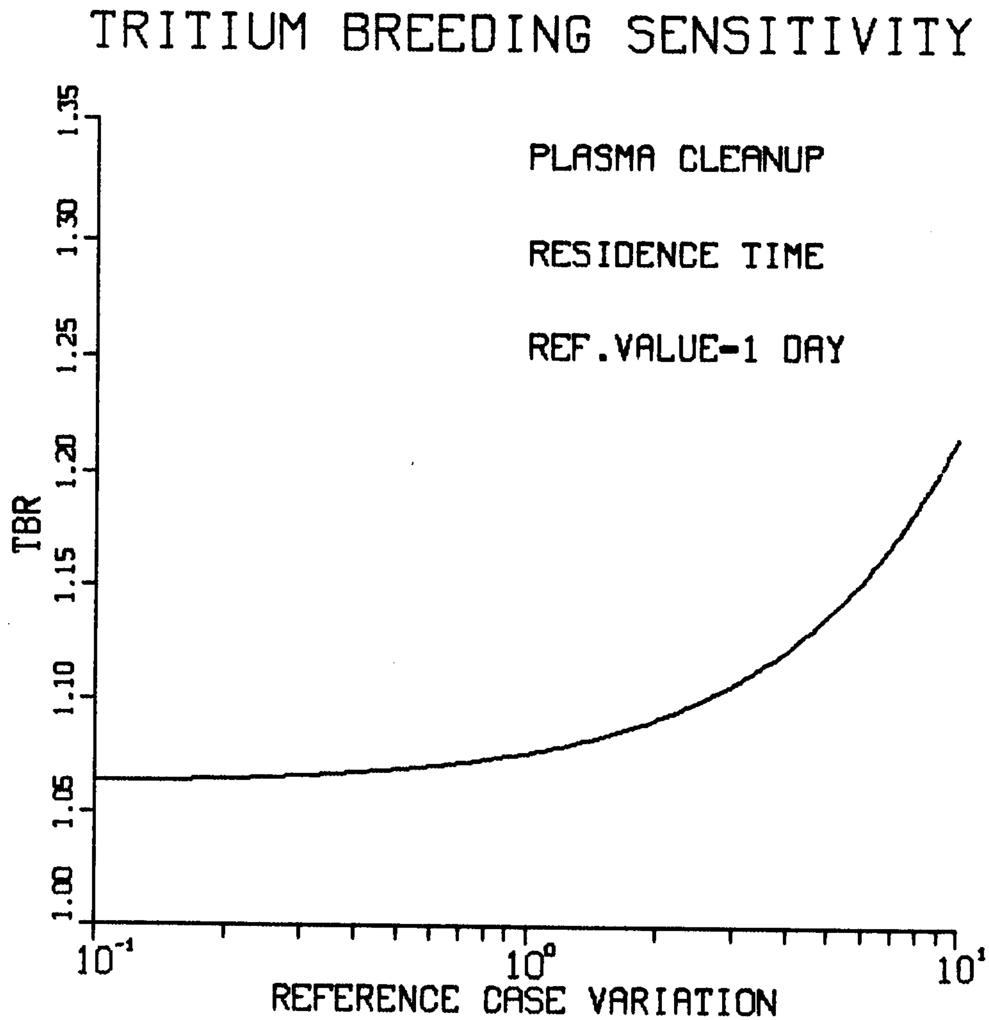


TRITIUM BREEDING SENSITIVITY
DAYS OF H-3 RESERVE
REF.VALUE=2 DAYS
TBR
1.00
1.05
1.10
1.15
1.20
1.25
1.30
1.35
10^-1
10^0
10^1
REFERENCE CASE VARIATION

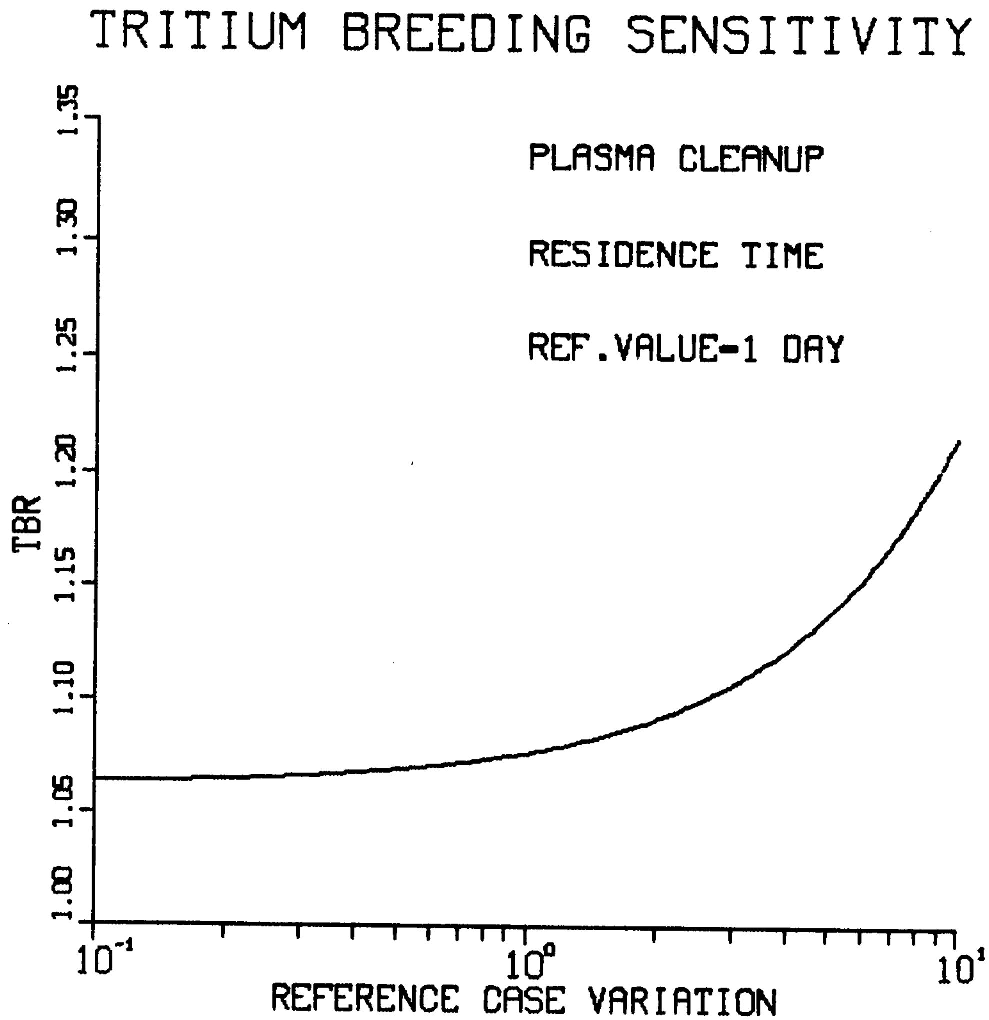

TRITIUM BREEDING SENSITIVITY
BURN FRACTION
REF.VALUE=0.05
TBR
1.00
1.05
1.10
1.15
1.20
1.25
1.30
1.35
10^{-1}
10^{0}
10^{1}
REFERENCE CASE VARIATION

TRITIUM BREEDING SENSITIVITY

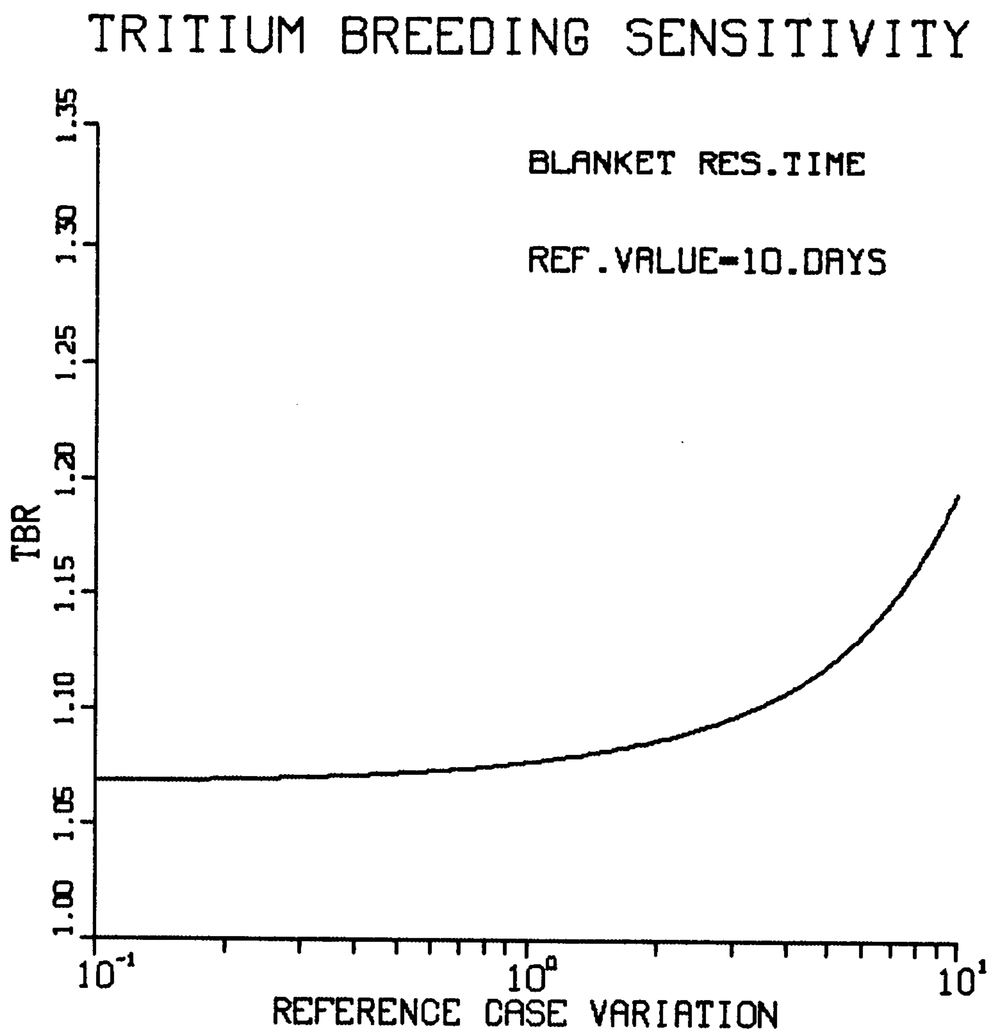


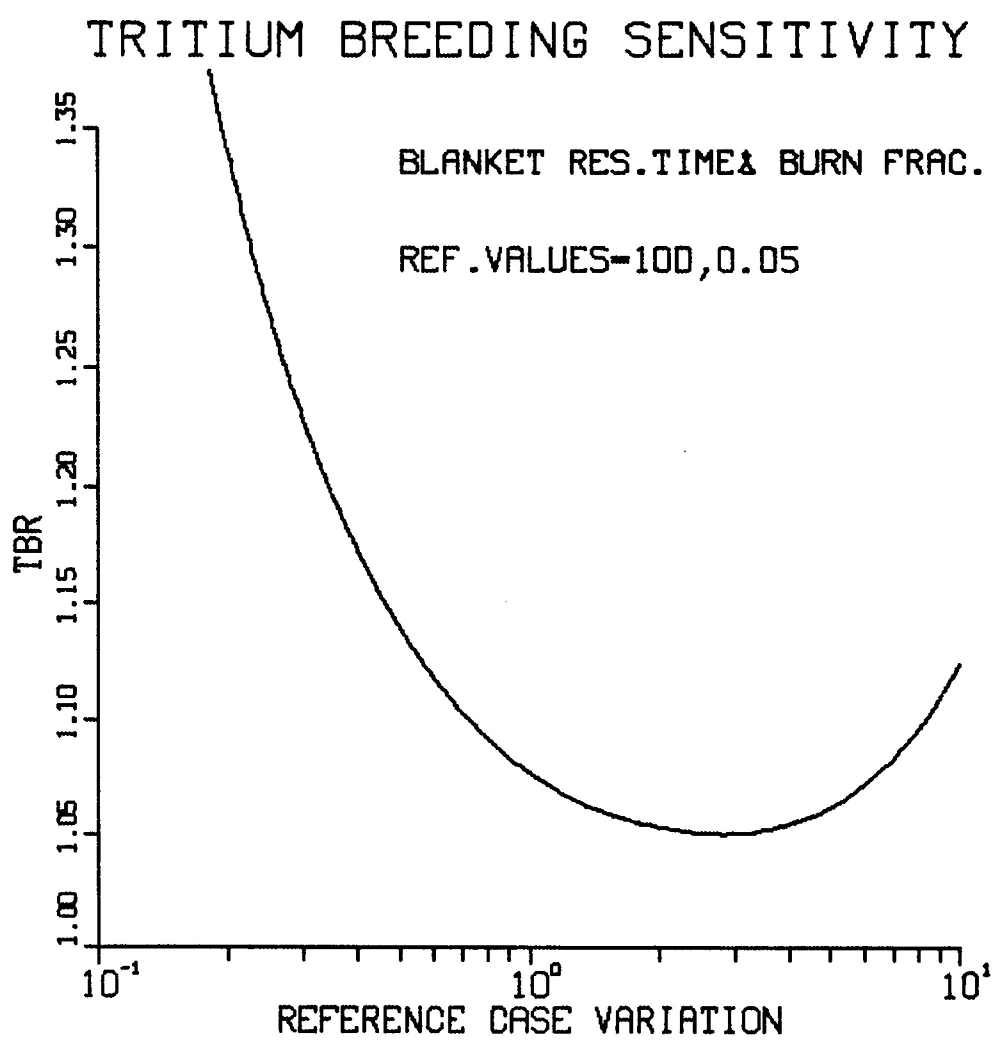


TRITIUM BREEDING SENSITIVITY
PLASMA CLEANUP
RESIDENCE TIME
REF.VALUE=1 DAY
TBR
1.00
1.05
1.10
1.15
1.20
1.25
1.30
1.35
10⁻¹
10⁰
10¹
REFERENCE CASE VARIATION

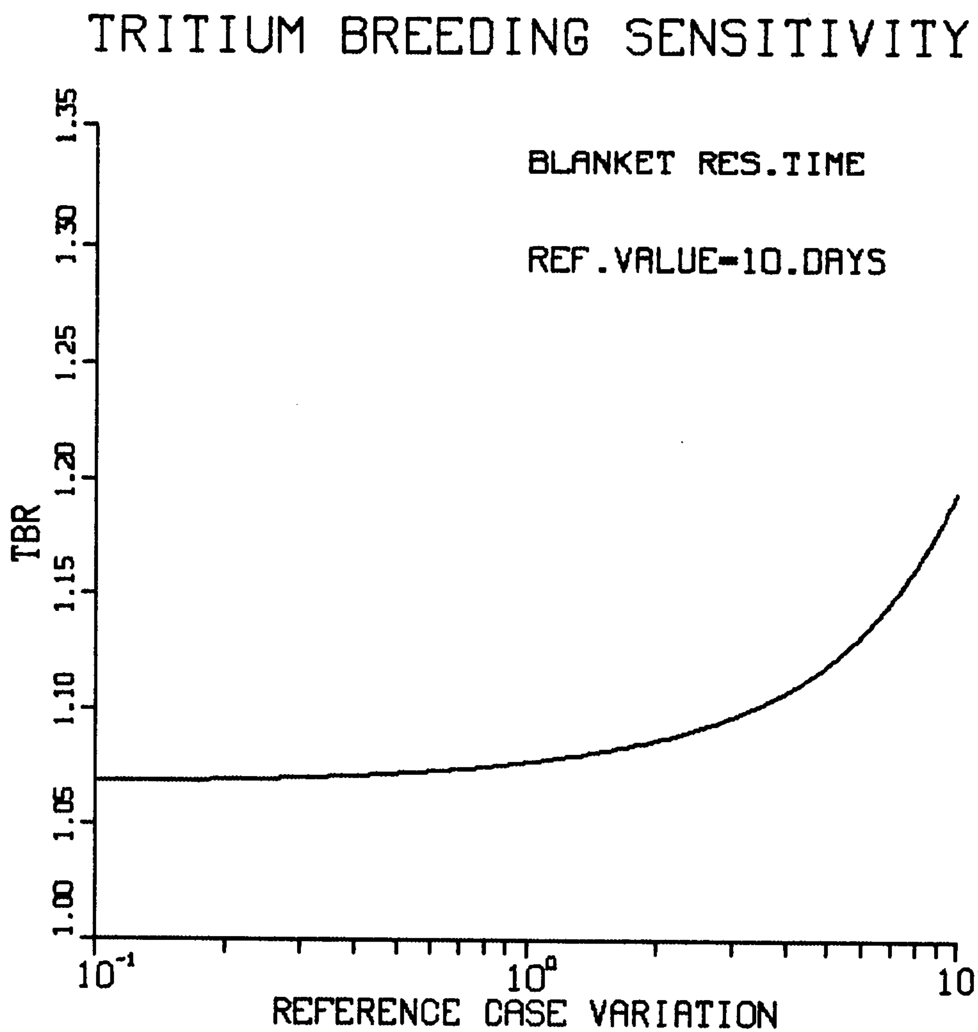


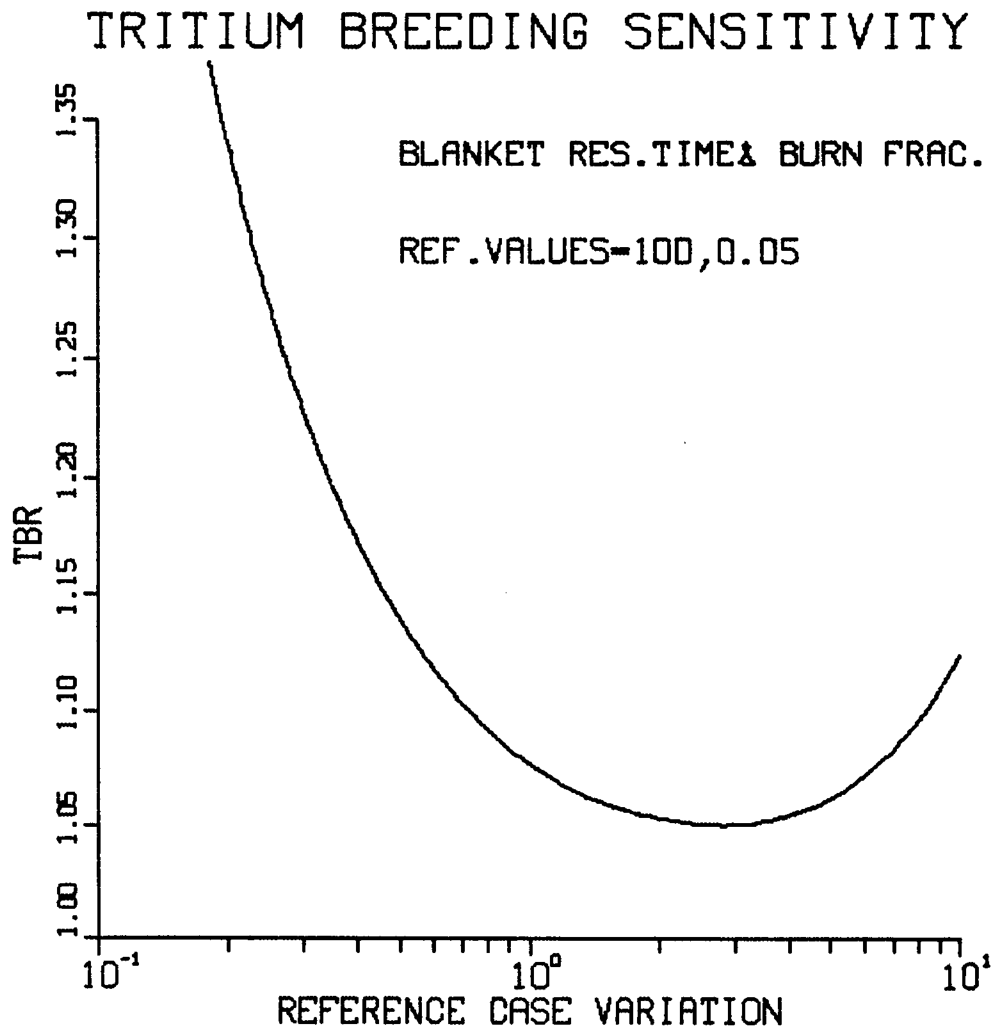
TRITIUM BREEDING SENSITIVITY
PLASMA CLEANUP
RESIDENCE TIME
REF.VALUE=1 DAY
TBR
1.00
1.05
1.10
1.15
1.20
1.25
1.30
1.35
10^{-1}
10^{0}
10^{1}
REFERENCE CASE VARIATION


TRITIUM BREEDING SENSITIVITY
BLANKET RES.TIME
REF.VALUE=10.DAYS
TBR
1.00
1.05
1.10
1.15
1.20
1.25
1.30
1.35
10^-1
10^0
10^1
REFERENCE CASE VARIATION



TRITIUM BREEDING SENSITIVITY
BLANKET RES.TIME& BURN FRAC.
REF.VALUES=100,0.05
TBR
1.35
1.30
1.25
1.20
1.15
1.10
1.05
1.00
10⁻¹
10⁰
10¹
REFERENCE CASE VARIATION


TRITIUM BREEDING SENSITIVITY
BLANKET RES.TIME
REF.VALUE=10.DAYS
TBR
1.00
1.05
1.10
1.15
1.20
1.25
1.30
1.35
10^{-1}
10^{0}
10^{1}
REFERENCE CASE VARIATION



TRITIUM BREEDING SENSITIVITY
BLANKET RES.TIME& BURN FRAC.
REF.VALUES=100,0.05
TBR
1.00
1.05
1.10
1.15
1.20
1.25
1.30
1.35
10^{-1}
10^{0}
10^{1}
REFERENCE CASE VARIATION

Δ_G ≡ UNCERTAINTY IN ESTIMATING $1 + G_\theta$

- MOST DIFFICULT TO ESTIMATE. NEED PROBABILITY DISTRIBUTIONS FOR MANY PLASMA AND REACTOR COMPONENT PARAMETERS.

- WE ASSUMED SEVERAL HYPOTHETICAL PROBABILITY DISTRIBUTORS (ALBEIT SOME EXPERT JUDGEMENT WHEREVER POSSIBLE) AND CALCULATED Δ^2_G. RESULTS ARE SENSITIVE TO PROBABILITY DISTRIBUTION.

- VALUE RECOMMENDED IN THE PREVIOUS MEETING IS AS GOOD AS ANY ($\Delta^2_G = 0.15$)

Δ_S ≡ UNCERTAINTY DUE TO SYSTEM DEFINITION

Δ_P = UNCERTAINTY IN PREDICTION

- Δ_S AND Δ_P REMAIN AS RECOMMENDED IN THE LAST MEETING.