Required Tritium Breeding Ratio of ITER

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ANNUAL TRITIUM SUPPLY FROM ONTARIO HYDRO TRFS

Drolet et al.
Nucl. Tech./Fus.
5 (1984) 19
AVAILABILITY OF TRITIUM FOR NEXT 20 YEARS

Available Tritium in kg

Years

The Calculational Model

- Model includes plasma downtime

- Time is discretized with interval $\Delta$. In an interval, the device is up during $r\Delta (0 \leq r \leq 1)$ and down during $(1-r)\Delta$

- Rate Equations are derived for the 4 subsystems in both $[n\Delta, n\Delta + r\Delta]$ and $[n\Delta + r\Delta, (n+1)\Delta]$, where $n$ is a positive integer or zero

- The equations are analytically solved with an initial condition

- The required TBR, $\Lambda_R$, is calculated by assuming an initial external tritium supply that is consumed during reactor operation such that a minimum pre-specified amount is left in the storage at the end of a given reactor lifetime.

- The model assumes that the tritium recovery mechanism is the same regardless of whether the plasma is on or off
Tritium Fuel Cycle Model

\[ \Lambda \dot{N} \]

\[ \tau_b \]

\[ \tau_v \]

\[ \frac{1}{1 - f_B} \dot{N} \]

\[ \lambda \]

Notes:

\( \lambda \) = Tritium decay constant

\( \tau_b \) = Tritium residence time in blanket

\( \tau_v \) = Tritium residence time in plasma exhaust system

\( \tau_p \) = Tritium residence time in tritium processing system

\( \dot{N} \) = Tritium burning rate

\( \Lambda \) = Tritium breeding ratio

\( f_B \) = Burnup fraction
Base Parameters used in the Analysis

Fusion Power, $P_{\text{fus}}$, 608.6 MW

Neutron wall load (average) 1.148 MW/m$^2$

Tritium Burnup Fraction, $f_b$, 5%
Tritium Residence Time in Blanket, $\tau_b$, 10 days
Tritium Residence Time in Vacuum System, $\tau_v$, 2 hours
Tritium Residence Time in Tritium Processing System, $\tau_p$, 1 day

Interval of Failure, $\Delta$ 30 days
Availability, $r$, 25%
Reactor Lifetime, 6 years

(accumulated neutron fluence = 1.72 MW·year/m$^2$)

Initial Tritium Requirement, $I_S(0)$ 5 kg
Tritium at the End of Plant Life, $I_{S,\text{min}}$ 0 kg
Definition

Externally supplied tritium, EST (Kg), for a given operation time, T, is:

$$\text{EST (Kg)} = \dot{N}T - \Lambda \dot{N} T + \sum_{i} I_i(\infty)$$

Where

- \(\dot{N}\) = Tritium burning rate (Kg/yr)
- \(\Lambda\) = TBR
- \(I_i(\infty)\) = Amount of saturated tritium in subcomponent i other than storage

Note:

\(I_i(\infty)\) depends on parameters such as \(\Lambda\), \(\tau_i\), \(\lambda\), \(\dot{N}\)
TRITIUM REQUIREMENT AS A FUNCTION OF TBR

- Full Operation Time
  - 1 year
  - 2.5 years

\[ P_{\text{fus}} = 608.6 \text{ MW} \]
REQUIRED TBR VS FUSION POWER

- Availability
  - 5%
  - 15%
  - 25%

Life Time = 6 Years

- \( \tau_b = 10 \text{ days} \)
- \( \tau_v = 2 \text{ hrs.} \)
- \( \tau_p = 1 \text{ day} \)
- \( f_b = 5\% \)
- \( I_s(0) = 5 \text{ Kg} \)
- \( \Delta = 30 \text{ days} \)
- \( I_{s,\text{min}} = 0 \text{ Kg} \)
Impact of Fusion Power and System Availability on the Required TBR

- The required TBR increases with fusion power.
  - The percentage increase in TBR is larger for smaller fusion power (< 400MW)
  - Changes in required TBR are small for fusion power > 600 MW with availability > 15% (required TBR ~1.0)
  - Larger fusion power devices are more demanding on external supply to compensate for uncertainty in achievable TBR
NEUTRON FLUENCE VS. AVAILABILITY

Life Time Length
- 6 years
- 9 years
- 12 years

Fusion Power = 608.6 MW
Wall Load = 1.148 MW/M²
REQUIRED TBR VS. FLUENCE (fixed availability)

Fluence, MW*year/m**2

Fusion Power = 608.6 MW
Wall load = 1.141 MW/M²
Availability = 25%

τ_b = 10 days  \quad \Delta = 30 \text{ days}

τ_v = 2 \text{ hrs.}  \quad I_s(0) = 5 \text{ Kg}

τ_p = 1 \text{ day}  \quad I_{s,\text{min}} = 0 \text{ Kg}

f_b = 5 \%
REQUIRED TBR VS. NEUTRON FLUENCE

Fluence, MW*year/m**2

Required TBR

Availability
- 5%
- 15%
- 25%

Fusion Power = 608.6 MW
Wall load = 1.148 MW/M^2

τ_b = 10 days       \quad I_s(0) = 5 Kg
τ_v = 2 hrs.        \quad I_s, min = 0 Kg
τ_p = 1 day         \quad f_b = 5%
REQUIRED TBR VS. FLUENCE (FIXED LIFE TIME)

- Life Time Length
  - 6 years
  - 12 years

Fusion Power = 608.6 MW
Wall Load = 1.148 MW/M2
\(\tau_b = 10 \text{ days}\)
\(\tau_v = 2 \text{ hrs.}\)
\(\tau_p = 1 \text{ day}\)
\(I_s(0) = 5 \text{ Kg}\)
\(\Delta = 30 \text{ days}\)
\(I_{s,\text{min}} = 0 \text{ Kg}\)
\(f_b = 5\%\)
REQUIRED TBR VS. INTERVAL OF FAILURE

Fusion Power = 608.6 MW
Availability = 25%

τ_b = 10 days
τ_v = 2 hrs.
τ_p = 1 day
f_b = 5%

I_s(0) = 5 Kg
I_s,min = 0 Kg
REQUIRED TBR VS. INITIAL INVENTORY

Required TBR

Initial Storage Inventory, Kg

- Life time
  - 3 years
  - 6 years

Fusion Power = 608.6 MW
Availability = 25%

\[ \tau_b = 10 \text{ days} \]
\[ \tau_v = 2 \text{ hrs.} \]
\[ \tau_p = 1 \text{ day} \]
\[ f_b = 5\% \]

\[ I_s(0) = 5 \text{ Kg} \]
\[ \Delta = 30 \text{ days} \]
\[ I_{s,\text{min}} = 0 \text{ Kg} \]
REQUIRED TBR VS. FINAL STORAGE INVENTORY

Fusion Power = 608.6 MW
Availability = 25%

\( \tau_b = 10 \text{ days} \quad \Delta = 30 \text{ days} \)
\( \tau_v = 2 \text{ hrs.} \quad \text{Lifetime} = 6 \text{ years} \)
\( \tau_p = 1 \text{ day} \)
\( f_b = 5 \% \)
VARIATION OF TRITIUM INVENTORY

Total In-System Inventory, kg

Variation

TBR = 1.03
Power = 608.6 MW
Lifetime = 6 Years
Availability = 25%

$\Delta = 30$ days
TBR = 1.03
$I_{s,min} = 0$ Kg
Remarks

- With 5 kg of tritium at the beginning of ITER operation, the required tritium breeding ratio (TBR) for a reactor with a range 600 ~ 800 MW fusion power is about unity (0.986 at 608.6 MW.)

- If the availability of the reactor is lower than 25%, the required TBR could be much smaller (i.e., 0.82 for a 608.6 MW fusion power reactor with 5% availability)

- The 608.6 MW reactor will achieve an accumulated neutron fluence 1.8 MW year/m² after 6 years of operation with 25% availability, and a required TBR=0.986.

- If more than 5 kg of tritium is externally available to operate the reactor, the required TBR for the same fusion power can be decreased; for example if 10 kg of tritium is available, the required TBR is 0.956

- Since there is at least 5% uncertainty in the estimation of the achievable TBR, the required TBR (i.e., the design value for TBR) must be larger than 0.986 + 0.986 x 0.05 = 1.035

- There is a large uncertainty in tritium burn-up fraction and tritium residence time. For the TBR obtained in this study, the unexpected shortage of TBR due to these and other uncertainties can be overcome by supplying more tritium externally.