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TRITIUM INVENTORIES AND ASSOCIATED TRITIUIM BREEDING REQUIREMENT FOR FUSION POWER REACTORS*

J. Jung
Fusion Power Program
Argonne National Laboratory
Argonne, Illinois 60439

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TRITIUM INVENTORIES AND ASSOCIATED TRITIUIM BREEDING REQUIREMENT FOR FUSION POWER REACTORS

J. Jung

Fusion Power Program
Argonne National Laboratory
Argonne, Illinois 60439

This paper presents an assessment of tritium-breeding requirement for fusion power reactors. The analysis is based on an evaluation of time-dependent tritium inventories in the reactor system. The method presented can be applied to any fusion systems in operation on a steady-state mode as well as on a pulsed mode. The effect of reactor-parameter changes on the required tritium breeding ratio is analyzed for a variety of reactor operation scenarios.

Consider a fusion power plant consisting of a reactor complex and a system external to it. The reactor complex is assumed to include a tritium breeding blanket, vacuum-pumping system, tritium processing system, etc., while the external system (labeled as "storage system") is composed of tritium storage and fueling systems. The tritium flow in this power plant can be described, during reactor operation, as

$$\frac{dI_m}{dt} = Q_m - \frac{I_m}{\Lambda_m}, \qquad (m = 1,\ 2,\ \ldots\ M) \tag{1}$$

$$\frac{dI_p}{dt} = \sum_{m=1}^{M} \frac{I_m}{\lambda_m} - \frac{I_p}{\Lambda_p}, \tag{2}$$

$$\frac{dI_s}{dt} = \frac{I_p}{\lambda_p} - \frac{I_s}{\tau} - \frac{N^+}{f_b}, \tag{3}$$

or combining all the equations,

$$\frac{dI_T}{dt} = (N^+ - N^-) - \frac{I_T}{\tau} \quad . \tag{4}$$

The following explains the nomenclature used in the above equations:

$I_m(t)$: Tritium inventory in component other than the processing system in the reactor complex ($m = 1, 2, \ldots, M$).

$I_p(t)$: Tritium inventory in the processing system.

$I_s(t)$: Tritium inventory in the storage system.

$I_T(t)$: Total tritium inventory in the plant $\left(= \sum_m I_m + I_p + I_s\right)$.

ε: Tritium loss rate into environment.

τ_o: Decay half life of tritium (= 12.3 y/ℓn 2).

λ_m: Mean residence time of tritium in components other than the processing system in the reactor complex ($m = 1, 2, \ldots, M$).

N^-: Tritium burnup rate in the plasma.

N^+: Tritium production rate in the blanket.

f_b: Fractional tritium fuel burnup rate.

TBR: Tritium breeding ratio $\left(= N^+/N^-\right)$.

$$\frac{1}{\Lambda_m} = \frac{1}{\lambda_m} + \frac{1}{\tau} , \qquad (m = 1,\ 2,\ \ldots,\ M), \tag{5}$$

$$\frac{1}{\Lambda_p} = \frac{1}{\lambda_p} + \frac{1}{\tau} , \tag{6}$$

$$\frac{1}{\tau} = \frac{1}{\tau_o} + \varepsilon , \tag{7}$$

$$\sum_{m=1}^{M} Q_m = N^- \left(TBR + \frac{1 - f_b}{f_b} \right) . \tag{8}$$

During operation the inventory solutions can be written as

$$I_m(t) = I_{mc}(\infty)\left[1 - K_n(\Lambda_m)e^{-t/\Lambda_m}\right] , \quad (m = 1, 2, \ldots, M) , \tag{9}$$

$$I_p(t) = \sum_{m=1}^{M}\left[\frac{I_{mc}(\infty)}{\lambda_m}\right]\Lambda_p\left\{\frac{\Lambda_p}{\Lambda_p - \Lambda_m}\left[1 - K_n(\Lambda_p)e^{-t/\Lambda_p}\right] - \frac{\Lambda_m}{\Lambda_p - \Lambda_m}\left[1 - K_n(\Lambda_m)e^{-t/\Lambda_m}\right]\right\}, \tag{10}$$

$$I_T(t) = I_T(0)e^{-t/\tau} + I_{Tc}(\infty)\left[1 - K_n(\tau)e^{-t/\tau}\right] , \tag{11}$$

and

$$I_s(t) = I_T(t) - \sum_m I_m(t) - I_p(t) , \tag{12}$$

where

$$K_n(x) = G(x) + \left[1 - G(x)\right]e^{n\Delta/x} , \tag{13}$$

and

$$G(x) = \frac{\left(1 - e^{-\Delta_0/x}\right) \cdot e^{-\Delta_D/x}}{1 - e^{-\Delta/x}} \tag{14}$$

with operation duration Δ_0, downtime Δ_D and one complete cycle time $\Delta = \Delta_0 + \Delta_D$.

By finding the time t_o at which the storage inventory takes the minimum value, $I_{s,min}$, the startup inventory $I_s(0)$ or $I_T(0)$ can be calculated as follows:

$$I_T(0) = I_{Tc}(\infty)K_{n_0}(\tau) - \sum_{m=1}^{M} I_{mc}(\infty)K_{n_0}(\Lambda_m)\, e^{-t_0/\lambda_m} - \left(\frac{\lambda_p}{\Lambda_p}\right)\left[I_{sc}(\infty) - I_{s,min}\right]e^{t_0/\tau} . \tag{15}$$

where n_0 is the cycle number that contains the time t_o.

The doubling time is defined as the time at which an excess tritium in the overall system becomes equal to the startup inventory, i.e., $I_T(t_d) = 2\ I_T(0)$.

By inserting Eq. (11) into the above equation, the required tritium breeding ratio, TBR, can be written as

$$\mathrm{TBR} = 1 + \frac{I_T(0)}{\tau N^-} \cdot \frac{2 - e^{-t_d/\tau}}{1 - K_{n0}(\tau)e^{-t_d/\tau}} . \quad (16)$$

Figure 1 presents the results of a sensitivity study of required TBR with respect to possible parameter changes. We consider a reactor complex consisting of three components, viz., blanket, vacuum system, and tritium processing system. The operating mode is assumed to be steady state.

It is found that the impact of λ_b, ε, and $I_{s,min}$ variations on the TBR requirement is relatively small compared to other parameter variations. Note that these variations cover the entire range of practical interest. The most important parameters in terms of determining the required TBR are the vacuum-system time constant, λ_v, the processing-system time constant, λ_p, the fractonal tritium burnup rate, f_b, and the doubling time requirement, t_d.

In order to realize a fusion blanket which requires a reasonably small TBR one has to assure that

$$\lambda_p \lesssim 1\ \mathrm{d}$$

$$\lambda_v \lesssim 1\ \mathrm{d}$$

$$f_b \gtrsim 5\%$$

$$t_d \gtrsim 5\ \mathrm{yr}$$

For such a system, even a factor of two uncertainty in these parameters leads to only a few percent variation at most, in the estimated TBR requirement.

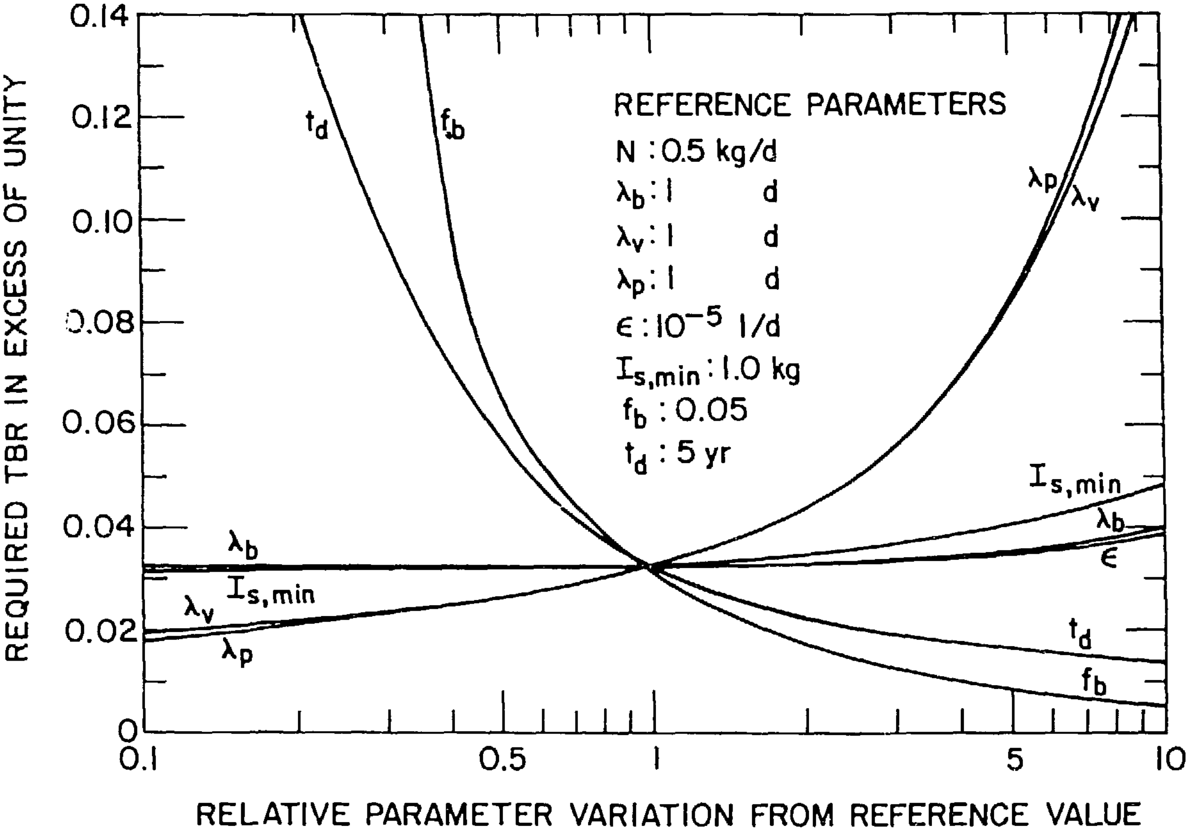

Fig. 1. Effect of parameter variation on required tritium breeding ratio.