DETERMINATION OF THE REQUIRED TRITIUM BREEDING RATIO FOR THE NEXT FUSION EXPERIMENTAL REACTOR

Yoichi Watanabe, Mohamed A. Abdou, Mahmoud Z. Youssef
University of California, Los Angeles
Los Angeles, CA 90024, USA
(213) 825-8627

ABSTRACT

The next fusion experimental reactor such as ITER requires tritium breeding because of the high tritium cost and its limited availability from non-fusion sources, in addition to demonstrating breeding capability of commercial D-T reactors. A tritium fuel cycle model was developed to compute the required tritium breeding ratio(TBR) by taking into account reactor down-time. The results show that TBR should be unity to achieve 3 MW • Year/m^2 of neutron fluence in 10 years for a steady-state reactor with 600 MW fusion power and 25% system availability provided 5 kg of initial tritium supply. If the external tritium supply is increased to 20 kg, the required TBR is 0.9. The estimated TBR is very sensitive to the variation of the tritium burn-up fraction in plasma and the tritium residence time in the tritium processing system. For example, decreasing the burn-up fraction from 5% to 1% leads to a 25% increase in the required TBR. Thus these parameters must be carefully examined in future work.

I. INTRODUCTION

Deployment of controlled thermonuclear fusion reactor power plants utilizing deuterium and tritium fuels for meeting world's energy needs will require a large amount of deuterium(D) and tritium(T). Deuterium exists in nature; but, tritium does not exist and decays with a half life of 12.3 year. The most economic way to provide tritium is to breed a sufficient amount of tritium in fusion reactors. The self-sufficiency of tritium must be validated before D-T fuel economy for fusion is seriously considered as an option for commercial reactors. Next generation reactors (ETRs) which are being planned as a next step toward realization of fusion energy as a practical energy source will use D-T fuels. Although an ETR needs not produce tritium as much as a commercial reactor does, the tritium breeding in blankets is still necessary for two reasons. First, it must be proved that we can design a workable blanket that can achieve a sufficiently large tritium breeding ratio(TBR) and have technology required for extracting and processing a large amount of tritium at a reactor site reliably, safely, and economically. Second, a certain amount of self-production inside a plant is needed because of limited availability of tritium from external suppliers and the high cost of the commercially available tritium. Even if D-T fusion will not be accepted for economical or safety reasons, an ETR or devices currently being planned as ignition testing machines or neutron sources will utilize D-T fuel because of its ease to achieve the fusion reaction condition.

Consequently, we ask how much of tritium breeding in blankets is required in an ETR and how much tritium must be purchased to complete the mission of the reactor. This paper tries to answer these questions. Once the size of fusion power of a reactor is decided, it is easy to compute the amount of tritium consumed by the reactor; however, this value is not equal to the amount of tritium actually needed by the reactor if the reactor breeds tritium to some extent and the tritium is recirculated in the reactor. After a discussion on availability of tritium from existing facilities, therefore, in Section III we create a model suitable for assessing the tritium breeding requirement in an ETR. The model, in particular, includes the availability of system. This is necessary because an ETR is expected to have very low availability. In Section IV, the model is applied to analyze the international thermonuclear energy reactor (ITER). The required TBR is estimated and its uncertainty is clarified.

II. REQUIREMENTS AND AVAILABILITY OF TRITIUM

A reactor with fusion power, P [MW], burns the amount of tritium $\dot{M}_T$ kg per one full power year (FPY) operation. Here, $\dot{M}_T$ can be given by

$$\dot{M}_T = 0.056\,P \text{ (kg/FPY)} \tag{1}$$

ITER, for example, will produce about 600 MW of fusion power in steady state. Thus, the reactor will require 100 kg of tritium for a three-year period of full-power operation. Even if 25% system availability is assumed, 8.4 kg of tritium is still needed every year.

On the other hand, the amount of available tritium is limited. Any nation that owns thermonuclear explosives is capable of producing a certain amount of tritium, but no information is available regarding the size of production capability of tritium for military usage. According to Ref. 1, three thermal fission reactors are being used for tritium production in the U.S. A quick and rough calculation suggests that these reactors can produce hundreds of kg of tritium per year. This value is in fact, in good agreement with the amount of tritium required for nuclear arsenals.[2] Thus, if needed, tritium for an ETR can be purchased from military suppliers. To avoid sensitive issues in politics, however, non-military sources should be pursued.

Canada deuterium uranium reactors utilize heavy water as a neutron moderator. Upon absorbing a neutron, deuterium is transmuted into a triton; hence, tritium is an inevitable sub-product in a CANDU reactor. Ref. 3 describes the amount of tritium produced from CANDU reactors for the next 20 years. A figure is reproduced here as Fig. 1, where the unit of tritium production rate has been changed to kg/year from MCi/year by using the conversion factor 10 MCi = 1 kg of tritium. The figure shows that at average 2.8 kg of tritium per year will be produced. The tritium production curve in Fig. 2 is now integrated with respect to time. Tritium accumulation was calculated by taking into account radioactive decay loss of tritium. The result is given in Fig. 2. One can see from Fig. 2 that in the year 2000, more than 25 kg of tritium can be available from the Ontario Hydro tritium removal facilities TRF's), where tritiated heavy water from CANDU reactors is processed. One must bear in mind that the current price of tritium is approximately $10,000 per gram.[4] 25 kg of tritium, thus, would cost 250 million dollars.

III. TRITIUM FUEL CYCLE MODEL

The TBR in a blanket is usually computed by using neutron transport codes with an adequate nuclear cross-section library for a given geometry and material composition. This TBR is called *achievable*

TBR and is donated by Λ_A. The predicted value is associated with uncertainty, δ_Λ. Meanwhile, systems analysts can obtain a value for TBR required to achieve the mission of the reactor that they are

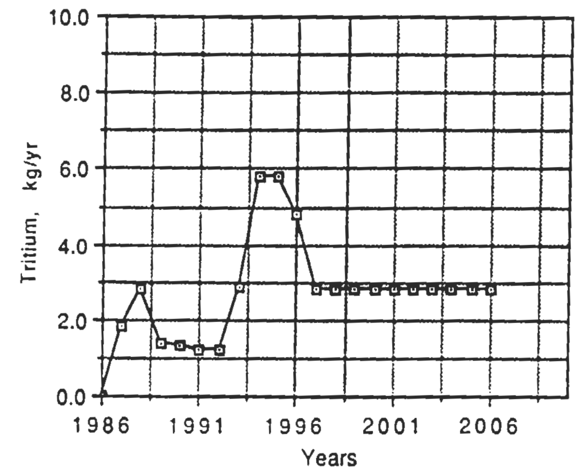

Fig. 1 Annual tritium supply from Ontario Hydro TRF's

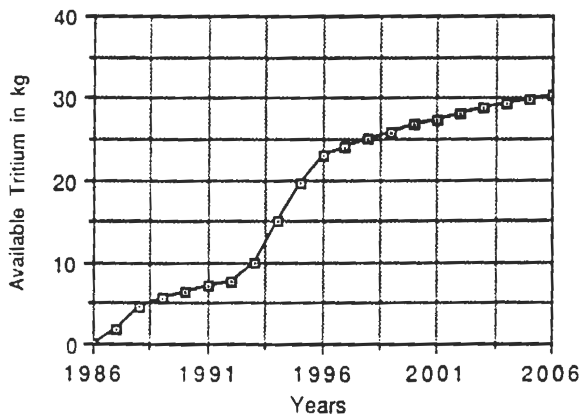

Fig. 2 Availability of tritium for next 20 years

analyzing. For this estimation they take into account the loss of tritium, the flow rate of tritium in subsystems, and so on. This TBR is called *required TBR* and is denoted by Λ_R. This value is also associated with uncertainty, δ_R. To assure completion of the predetermined mission of a reactor, therefore, the following inequality must be satisfied[5]:

$$\Lambda_A \geq \Lambda_R + \sqrt{\delta_2^R + \delta_2^A} \qquad (2)$$

where statistical independence of Λ_A and Λ_R is assumed.

When the time variation of the amount of tritium stored in the tritium storage unit in a reactor is examined, one finds that at the beginning the inventory rapidly decreases and some time after this it begins increasing.[5] Initially it decrease because some amount of tritium must be kept in the subsystems of a reactor to reach a steady-state flow among subsystems. Once the inventories in subsystems get saturated, the extra amount of tritium due to breeding in a blanket starts coming into the storage unit, leading to an accumulation. This scenario is, however, true only for a reactor with a TBR greater than a certain critical value, which is larger than unity. Let us call it *critical TBR*.

Commercial reactors must have a sufficiently large TBR so that a large amount of tritium should be generated for starting new reactors in addition to providing its own need. This type of operation is called *super-breeding mode*. On the other hand, an experimental reactor is not supposed to supply tritium to other usages than its own fuel. Thus, the reactor can be designed so that it uses up all the tritium supplied from external sources by the time of completion of its mission (or at the end of the reactor lifetime). This type of operation is called *sub-breeding mode*. Modes of operation are, therefore, classified into either super-breeding or sub-breeding, depending on whether or not the TBR exceeds the critical TBR.

In the past, models for tritium fuel cycle analysis were developed by various people.[5-10] All these analysis were performed to obtain the required TBR for a commercial reactor; their models are different from each other mostly in the number of subsystems. The model adopted in this work includes only four subsystems: blanket, plasma exhaust system, tritium processing system and tritium storage unit. The interrelationships among these are illustrated in Fig. 3, where tritium flow paths are explicitly shown.

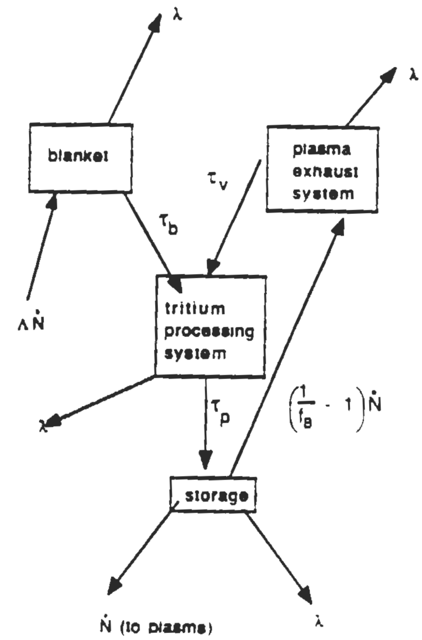

Fig. 3 Tritium fuel cycle model

Tritium stored in the storage unit flows into plasma with a flow rate $\dot{N}/f_B$ [kg/day]. Only a fraction of the injected tritium is actually burned in the plasma before it leaves the plasma chamber. The fraction factor called burn-up fraction is denoted by f_B. The tritium burning rate is $\dot{N}$ [kg/day]. Consequently $(1/f_B-1)N$ of tritium is trapped in the plasma exhaust system through vacuum pumping ducts. With the tritium residence time τ_v, the tritium in this system flows out to the tritium processing system. Meanwhile $\Lambda\dot{N}$ of tritium is generated in the blanket, which is capable of achieving a TBR Λ. The tritium in the blanket then, flows into the tritium processing system with the residence time τ_b. The tritium processing system extracts, separates and purifies the tritium coming from the blanket and plasma exhaust system. The processed tritium is returned back into the storage unit with residence time, τ_p. In our model, tritium loss due to radioactive decay is considered, but leakage loss is not taken into account. One should be aware of the assumption that the tritium flow rate from the blanket, the plasma exhaust system, and the tritium processing system is proportional to the tritium inventory in these subsystems.

The availability of an experimental reactor is low; at best, it is 25%. Therefore system downtime must be explicitly included in the model. We follow the model formulation of Ref. 10. The time axis is partitioned into intervals with a length of Δ. It is assumed that during a part of the interval, $r\Delta$, the system is up and during the rest of the interval, $(1-r)\Delta$, the system is down. Here the system availability is denoted by r. During the system downtime period, the tritium is not burned (or $\dot{N} = 0$), but all other subsystems are working in the normal condition.

We now have a set of differential equations given below. From the interval (I): $n\Delta \le t < n\Delta + r\Delta$,

$$dI_b/dt = \Lambda\dot{N} - (1/\tau_b - \lambda)\, I_b \tag{3}$$

$$dI_v/dt = \alpha\dot{N} - (1/\tau_v - \lambda)\, I_v \tag{4}$$

$$dI_p/dt = I_b/\tau_b + I_v/\tau_v - (1/\tau_p - \lambda)\, I_p \tag{5}$$

$$dI_s/dt = I_p/\tau_p - \lambda I_s - \dot{N}/f_B \tag{6}$$

For the interval (II): $n\Delta + r\Delta \le t < (n+1)\Delta$,

$$dI_b/dt = -(1/\tau_b - \lambda)\, I_b \tag{7}$$

$$dI_v/dt = -(1/\tau_v - \lambda)\, I_v \tag{8}$$

$$dI_p/dt = I_b/\tau_b + I_v/\tau_v - (1/\tau_p - \lambda)\, I_p \tag{9}$$

$$dI_s/dt = I_p/\tau_p - \lambda I_s \tag{10}$$

Here, n = 0, 1, 2, ... $I_b(t)$, $I_v(t)$, $I_p(t)$ and $I_s(t)$ are the tritium inventory in the blanket, the plasma exhaust system, the tritium processing system, and the storage unit, respectively. The initial condition used to solve Eqs. (3) to (6) for $0 \le t < r\Delta$ is $I_b(0)$, $I_v(0)$, $I_p(0)$ and $I_s(0)$ = a positive constant or 0. It is noted here that the critical TBR introduced earlier can be found by setting the time derivatives and $I_s(t)$ to zero in Eqs. (3) to (6) and solving those for Λ.

Eqs. (3) to (10) are solved analytically. First, Eqs. (3) to (6) are solved with the initial condition for the interval $[0, r\Delta]$. Next, Eqs. (7) to (10) are solved for the interval $[r\Delta, \Delta]$ by using the solutions of Eqs. (3) to (6) as the initial condition at $t = r\Delta$. Then Eqs. (3) to (67) are again solved for the interval $[\Delta, (1+r)\Delta]$ by using the solutions of Eqs. (7) to (10) as the initial condition at $t - \Delta$. These solutions are used to solve Eqs. (7) to (10) for the interval $[(1+r)\Delta, 2\Delta]$. This procedure is continued until solutions for the intervals $[n\Delta, (n+r)\Delta]$ and $[(n+r)\Delta, (n+1)\Delta]$ are found.

Since we ear analyzing ETR's, we assume the sub-breeding mode of operation. In this case the storage inventory $I_s(t)$ keeps decreasing with the maximum at t = 0. We look for L such that at the end of reactor life, T,

$$I_s(T) = I_{min} \tag{11}$$

Eq. (11) is analytically solved for L. The solutions are given as follows:

$$L = NUM/DEN \tag{12}$$

If T is the interval (I), NUM and DEN are given by

$$NUM = [1-K_n(\lambda)\exp(-\lambda T)]/\lambda$$

$$+ \alpha\,[1-K_n(\lambda_p)\exp(-\lambda_p T)]/\tau_v\lambda_p(\lambda_v - \lambda_p)$$

$$+ \frac{\alpha}{\lambda_v}\left(1 - \frac{1}{\tau_v(\lambda_v - \lambda_p)}\right)[\lambda\text{-}K_n(\lambda_v)\exp(-\lambda_v T)]$$

$$+ [I_{min} - I_s(0)\exp(-lT)]/\dot{N} \tag{13}$$

$$DEN = [1-K_n(\lambda)\exp(-\lambda T)]/\lambda$$

$$- [1-K_n(\lambda_p)\exp(-\lambda_p T)]/t_b\lambda_p(\lambda_b - \lambda_p)$$

$$-\frac{1}{l_b}\left[1 - \frac{1}{t_b(\lambda_b - \lambda_p)}\right][1-K_n(\lambda_b)\exp(-\lambda_b T)] \tag{14}$$

If T is the interval (II, NUM and DEN are given by

$$NUM = [1-K_n(\lambda)\exp(-\lambda\Delta_n)]\exp[-(T-\Delta_n)]/\lambda$$

$$+\frac{\alpha}{\lambda_v}\left[1+\frac{1}{\tau_v(\lambda_v-\lambda_p)}\right][1-K_n(\lambda_v\exp(-\lambda_v\Delta_n)]\exp[-\lambda_v(T-\Delta_n)]$$

$$+\frac{\exp[-\lambda_p(T-\Delta_n)]}{\tau_v(\lambda_v-\lambda_p)}\left[\frac{\lambda_v}{\lambda_p}[1 - K_n(\lambda_p)\exp(-\lambda_p\Delta_n)]\right.$$

$$\left.-2[1 - K_n(\lambda_v)\exp(-l_v\Delta_n)]\right]$$

$$+ [I_{min} - I_s(0)\exp(-\lambda T)]/\dot{N} \tag{15}$$

$$DEN = [1-K_n(\lambda)\exp(-\lambda\Delta_n)]\exp[-\lambda(T-\Delta_n)]/\lambda$$

$$-\frac{1}{\lambda_b}\left\{\left[1+\frac{1}{\tau_b(\lambda_b-\lambda_p)}\right][1-K_n(\lambda_b)\exp(-\lambda_b\Delta_n)]\exp[-\lambda_b(T-\Delta_n)]\right.$$

$$+\frac{\exp[-\lambda_p(T-\Delta_n)]}{\tau_b(\lambda_b-\lambda_p)}\left[\frac{\lambda_b}{\lambda_p}[1 - K_n(\lambda_p)\exp(-\lambda_p\Delta_n)]\right.$$

$$\left.-2[1 - K_n(\lambda_v)\exp(-\lambda_b\Delta_n)]\right] \tag{16}$$

In Eqs. (13) to (16), parameters are defined as follows:

$\Delta_n = (n+r)\Delta$, $\lambda_b = \lambda + 1/\tau_b$, $\lambda_v = \lambda + 1/t_v$, and $l_p = \lambda + 1/t_p$.

The function K_x is

$$K_x = G(x) + [1-G(x)]\exp(\exp(xnD) \tag{17}$$

where $G(x) = [\exp(xr\Delta)-1]/[\exp(x\Delta)-1]$.

A computer program has been developed to compute the required TBR by implementing Eq. (12) together with Eqs. (13) - (16). For a given τ_b, τ_p, τ_v, r, $I_s(0)$, I_{min}, Δ, and T, the program looks for a time interval in which T resides. Depending on whether T is in the interval (I) or (II), appropriate equations for Λ are chosen.

As mentioned before, we assume that tritium is not consumed during downtime. This suggests that simply reducing the fusion power according to the availability and ignoring downtime (reduced power approximation) might be a good approximation for certain cases. To examine this, we first define relative error ε of the required TBR by

$$\varepsilon = (\Lambda^* - \Lambda)/\Lambda \tag{18}$$

where Λ^* = the required TBR obtained by the reduced power approximation. Fig. 4 shows the results for fusion power P_f = 1000 MW, τ_b = 10 days, τ_v = 1 day, τ_p = 0.5 day, f_B = 5%, $I_s(0)$ = 10 kg, and I_{min} = 1 kg for 50 and 100% availability.

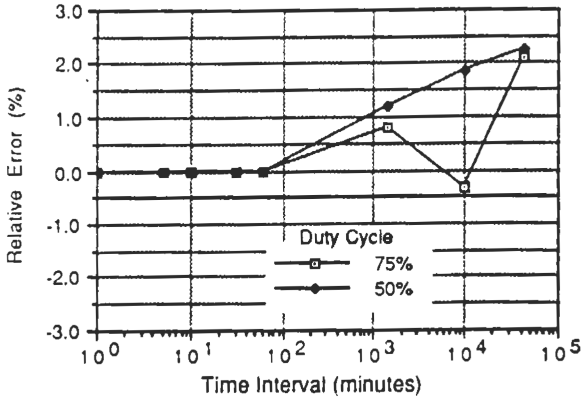

Fig. 4 Relative error of required TBR

It can be said from the figure that the error of the reduced power approximation is large for a time interval larger than one day; but, operations with a time interval shorter than one hour can be analyzed with good accuracy by the reduced power approximation. Therefore, the required TBR of a reactor operated in a pulse mode in which a plasma is fired every 10 minutes with a 75% duty cycle can be calculated by simply reducing the fusion power by 25%. On the other hand, a system which is operational for only one week in every month must be analyzed by using the exact formulas we have just derived.

IV. ANALYSIS OF THE NEXT FUSION ENGINEERING DEVICE

The initial requirement of tritium can be roughly estimated by looking into steady-state inventories. It is easy to understand that the amount of tritium supplied from external sources, S, is given by:

$$S = \dot{N}T - \Lambda\dot{N}T + \sum_i I_i(\infty) \qquad (19)$$

where $\dot{N}$ = tritium burning rate, L = TBR, T is the length of reactor life, $I_i(\infty)$ is the steady state tritium inventory of subsystem i.

For the model described in Section III, $I_i(\infty)$'s and $\dot{N}$ are calculated for P_{fusion} = 608.6 MW, f_B = 5%, τ_b = 10 days, τ_v = 2 hours and τ_p = 1 day. In Fig. 5, S is plotted as a function of Λ for T = 1 and 2.5 years. Here, T is in the unit of the full power year of operation. If Λ = 1, S = 2.9 k which is the summation of steady state inventories in the blanket, the plasma exhaust system, and the tritium processing system. If only 0.5 of TBR is achievable, 44 kg of tritium must be supplied for 2.5 FPY of operation. If no tritium breeding takes place, then more than 80 kg of tritium must be purchased.

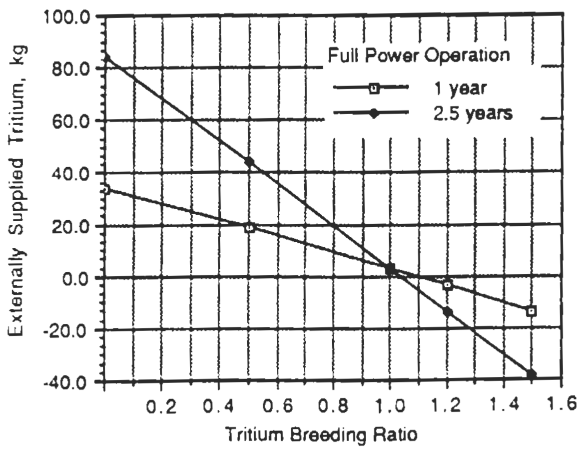

Fig. 5 Tritium requirement as a function of TBR

In the rest of this section we examine the variation of the required TBR due to variation of parameters included in the model by using the computer program described in Section III. When values are not specifically mentioned, the following default parameters are used: P_{fusion} = 608.6 MW, neutron wall load = 1.148 MW/m^2, f_B = 5%, τ_b = 10 days, τ_v = 2 hours, τ_p = 1 day, D = 30 days, r = 30%, T = 6 years, $I_S(0)$ = 5 kg, I_{min} = 0 kg. These are typical for the proposed ITER design.

Fig. 6 shows the required TBR as a function of fusion power for various system availabilities. For very large fusion power machines, a TBR of unity (strictly speaking, slightly greater than unity) is required and it is independent of the availability. For very low power machines, the required TBR is strongly dependent of the availability and generally it is much smaller than unity. At 600 MW, the required TBR is 0.82, 0.97, and 0.98 for 5%, 15%, and 25% availability. Thus, if the availability is very low (~5%), then the TBR can be reduced by more than 10% from that of higher availability machines.

One of the major goals of an ETR is the testing of systems under a radiation environment close to that of commercial reactors. Since the fusion power and length of reactor life is limited, relatively high system availability must be achieved. Fig. 7 shows the achievable neutron fluence, F, as a function of the availability, A, for various lengths of reactor life, T. The calculations were performed by assuming 1.148 MW/m^2 of neutron wall load, Γ, and by using a relation: F=GTA. Ref. 4 states that an ETR needs at least 4 MW • yr/m^2. From the figure, one can see that the machine must achieve 30% availability over a 12 year period to reach this goal. Even if the neutron wall load can be increased by 50%, 20% availability is still needed.

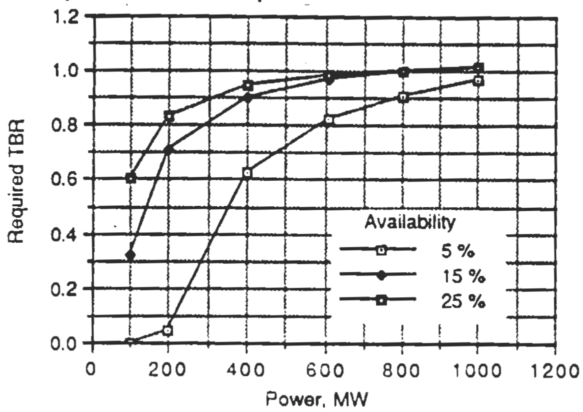

Fig. 6 Required TBR vs. fusion power

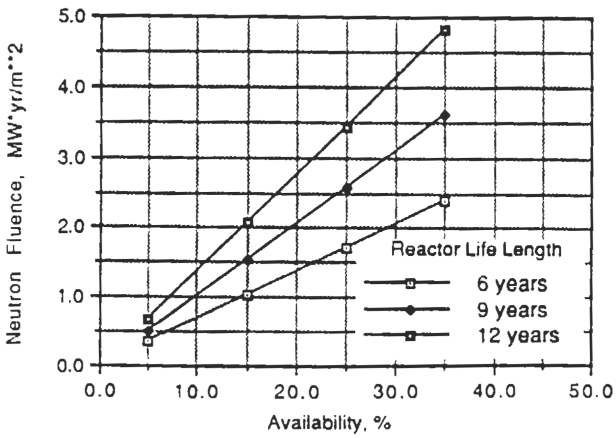

Fig. 7 Neutron fluence vs. availability

The required TBR is calculated by varying both the length of reactor life and the availability. The results are shown in Fig. 8 in which the neutron fluence is adopted for the horizontal axis. From the figure one can conclude that for a relatively high availability the neutron fluence can be varied by varying the reactor life length with a slight change in the required TBR. On the other hand, for low availability machines a rapid increase in the required TBR only results in a small increase in the achievable neutron fluence. It is noted that 3MW/•yr/m^2 of neutron fluence is obtained by a machine which can achieve a TBR of unity, 25% availability over an 11 year period.

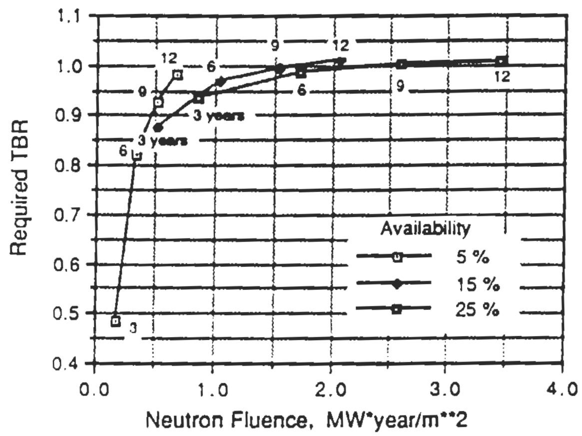

Fig. 8 Required TBR vs. neutron fluence

We introduced a time interval Δ in the model. The reader is reminded here that the model assumes tritium burning only in the time period between nΔ and nΔ + rΔ (n is an integer or zero); the burning is stopped (or the system is down) in the time period between nΔ + rΔ and (n+1)Δ. In other words, the system fails once every Δ period. The value of Δ can vary although the availability is the same. The dependence of the required TBR on Δ is investigated by varying Δ from one day to 60 days. The results are presented in Fig. 9 for various availabilities. An interesting observation once can make from the figure is that as Δ increases the required TBR also increases. The increase of TBR is more rapid for short Δs. This can be explained from the fact that the saturation (steady-state) inventory in subsystems gets smaller as Δ gets shorter. A lower saturation inventory results in a smaller TBR as one sees from Eq. 19. It is concluded that for a fixed availability, scheduled maintenance frequently performed is better than unscheduled maintenance less frequently performed in terms of the requirement of TBR.

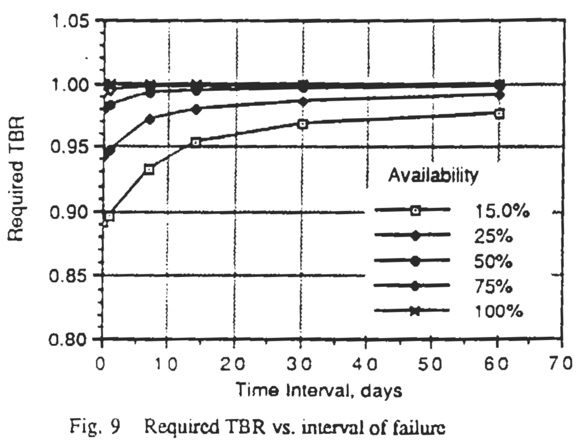

Fig. 9 Required TBR vs. interval of failure

The results given in Fig. 5 suggest that the required TBR can be reduced by supplying more tritium from external sources. Fig. 10 shows the required TBR as a function of the initial inventory in the storage unit $I_s(0)$ for various lengths of reactor life. Once can see that the required TBR decreases almost linearly as $I_s(0)$ increases. The slope of curves is larger for a shorter reactor life. The required TBR is reduced to 0.68 by supplying 25 kg of initial inventory compared to 0.98 for 5 kg of initial inventory. It is noted that all the tritium is not necessary to be supplied at the beginning of reactor life. The initial inventory should add up to the saturation inventories of the subsystems. The rest can be supplied periodically over the life of the reactor, although the summation should be equal to the amount of $I_s(0)$ we defined earlier.

So far, the required TBR is computed for $I_{min} = 0$; that is, the tritium inventory in the storage unit at the end of reactor life is zero. Some amount of tritium must be kept in the storage unit so that a reactor is still operational when the tritium processing system fails and no tritium flows back to the storage unit. As seen from Eq. (12), together with Eqs. (13)-(16), the required TBR is proportional to I_{min}. The dependence of TBR on I_{min} is shown in Fig. 11 for 5 kg and 10 kg of initial inventory. If 3 kg of tritium, which is required to cover the saturation inventory of subsystems, is considered as the minimum storage inventory, the required TBR is 0.98 fore 10 kg of the initial inventory. This is 8% larger than the TBR (0.91) for $I_{min} = 0$. When the initial inventory is 5 kg, the sub-breeding mode of operation cannot assure the minimum inventory more than 2 kg.

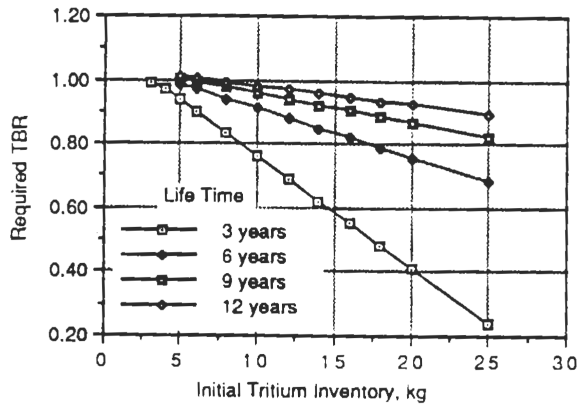

Fig. 10 Effect of initial tritium inventory on TBR

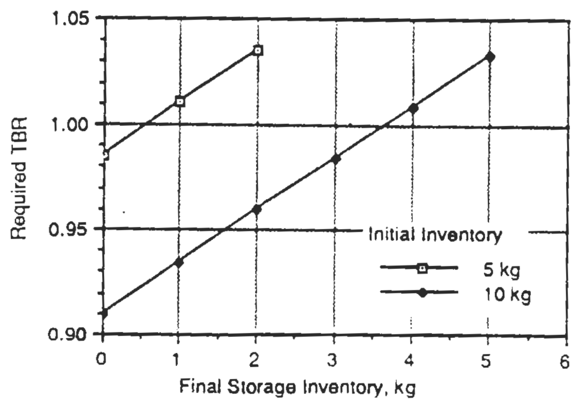

Fig. 11 Required TBR vs. final storage inventory

In Refs. 5 and 10, the sensitivity of the required TBR to the variation of model parameters was investigated. A similar analysis to the present model is performed by assuming $I_t(0)$ = 20 kg. The variations of the required TBR relative to that of the reference case are given in Fig. 12. Here we have varied f_B, τ_p, τ_v, and τ_b between 1/5 and 5 times the reference values. The required TBR is very sensitive to the variation of f_B and τ_p; while it is less sensitive to the variation of τ_v and τ_b. The observed high sensitivity can be attributed to the large amount of tritium flowing through the plasma chamber and the tritium processing system. The sensitivity of TBR to τ_v is small because the magnitude of τ_v is short (2 hours). The burn-up fraction f_B may not be

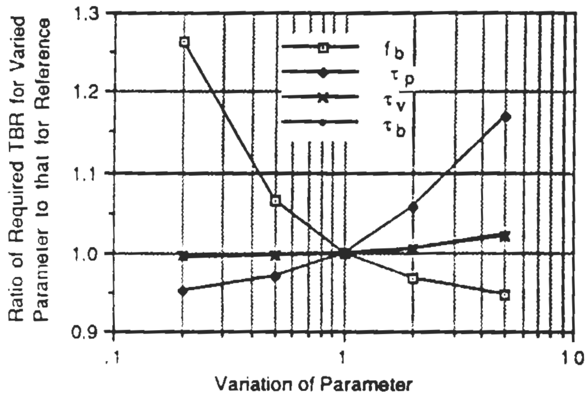

Fig. 12 Sensitivity of required TBR to varation of model parameters

much larger than 5%, which we used here; but it is very likely that we can achieve only 1%. Then the TBR must be increased by 25%. Thus the burn-up fraction should be thoroughly examined by simulation. Some data on the residence time in the tritium processing system can be obtained from an ongoing project at the TSTA facility.[11] Even though the residence time in a blanket is not important for the present regime of parameters, it is useful to have data, which can be obtained from detailed modeling of tritium transport in the blanket. The data on the residence time in the plasma exhaust system is difficult to obtain; no effort is currently being made in this area. Again, a simulation will prove to be a powerful tool.

V. SUMMARY

An ETR can be operated in the sub-breeding mode, in which all the tritium supplied from external sources is exhausted by the end of the reactor life with a small amount of tritium left for a case of failure of the tritium processing system. By assuming such a mode of operation with no tritium left at the end of reactor life, we have found that a 600 MW reactor requires a TBR of unity to achieve 3 MW*year/m^2 neutron fluence within 10 year operation with 25% system availability when 5 kg of tritium is supplied from external sources. There will be more than 25 kg of tritium available from non-fusion facilities by the time the reactor will go into operation; thus, if necessary, such a large amount of tritium can be purchased with expense of fuel cost. Consequently, the required TBR can be greatly reduced from unity. For instance, a TBR of 0.9 is required for the same operational condition if 20 kg of tritium is supplied. The estimation of the required TBR is extremely sensitive to a variation of the tritium burn-up fraction in plasma and the tritium residence time in the tritium processing system. Even though the uncertainty stemming from the uncertainty of these parameters can be compensated by increasing the external tritium supply, enhancing the prediction capability of these will be very useful for the successful development of the next fusion machine and commercial reactors.

ACKNOWLEDGEMENTS

We would like to thank Dr. P. Gierszewski for his helpful comments. This work was supported by U.S.DOE Grant No. DE-FG03-88ER52150.

REFERENCES

[1] M. M. WALDROP, "DOE Pushes Case for New Defence Reactors," Science 241 (29 July 1988) 526-528.

[2] Y. WATANABE, "Estimating Military Production of Tritium in U.S.," unpublished report, (September 1988).

[3] T. S. DROLET, K. Y. WONG, and P. J. C. DINNER, "Canadian Experience with Tritium- The Basis of a New Fusion Project," Nucl. Tech./Fus., 5 (1984)17029.

[4] M. A. ABDOU et al., "A Study of the Issues and Experiments for Fusion Nuclear Technology," Fus. Techn. 8 (1985)2595-2645.

[5] M. A. ABDOU, E. L. VOLD, C. Y. GUNG, M. Z. YOUSSEF, and K. SHIN, "Deuterium-Tritium Fuel Self-Sufficiency in Fusion Reactors," Fus. Techn., 9 (1986)250-285.

[6] W. F. VOGELSANG, "Breeding Ratio, Inventory, and Doubling Time in a D-T Fusion Reactor," Nucl. Tech., 15 1972)470-474.

[7] M. SEHNERT and W. E. KASTENBERG, "On the Determination of Tritium Inventories in CTR Power Plants," Trans. A.N.S., 22 (1975)25-26.

[8] M. SEHNERT, "Tritium Inventory Consideration in Controlled Thermonuclear Reactors," M.S. Thesis, University of California, Los Angeles (1975).

[9] D. CARRE, E. PROUST, and A. ROCABOY, "Analysis of the Tritium Requirements for Power Reactor," Nucl. Tech./Fus., 4 (1983)93-98.

[10] J. JUNG, "An Assessment of Tritium Breeding Requirements Based on the Tritium Fuel Cycle," Fus. Tech., 9 (1986)308-319.

[11] J. L. ANDERSON and J. R. BARLIT, "Tritium Technology Studies at the Tritium Systems Test Assembly," Fus. Tech. 10 (1986) 1329-1333.