3 Results and conclusions

The RF ponderomotive force potential ψ_{rf}, RF reflection factor R_{rf} for He^+ and RF enhancement factor of ash removal efficiency η_{rf} vary with $E_\perp$ are shown in Fig. 1. The ash removal efficiency with RF enhancement $n_{pump}/n_0 = \eta\eta_{rf}$ for neutral helium atom energies 0.75 eV, 3 eV are shown in Fig. 2. For low energy neutral helium, when a RF field 150～200 V · cm^{-1} is applied the ash removal efficiency can be enhanced from $\eta = 0.5$ to $\eta\eta_{rf} = 0.9$.

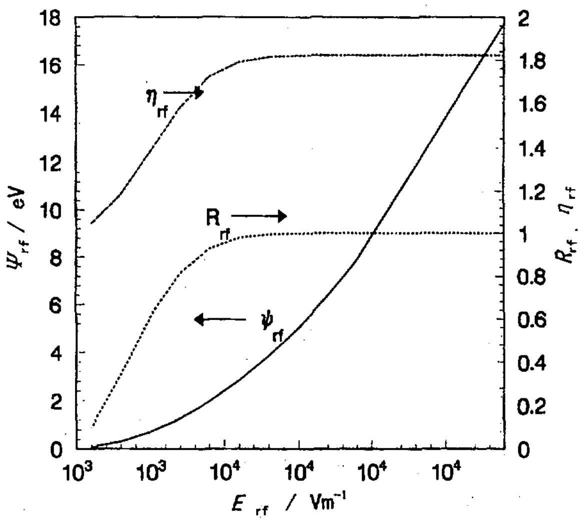

Fig. 1 E_{rf}/V · m^{-1}

$T_e = 30$ eV, $n_e = 1\times10^{13}$ cm^{-3}, $L = 20$ cm, $\eta = 0.5$, $B_{Div} = 1.6$ T, $\omega_{rf} = 1.1\ w_c(He^+)$, $w(He^0) = 0.75$ eV.

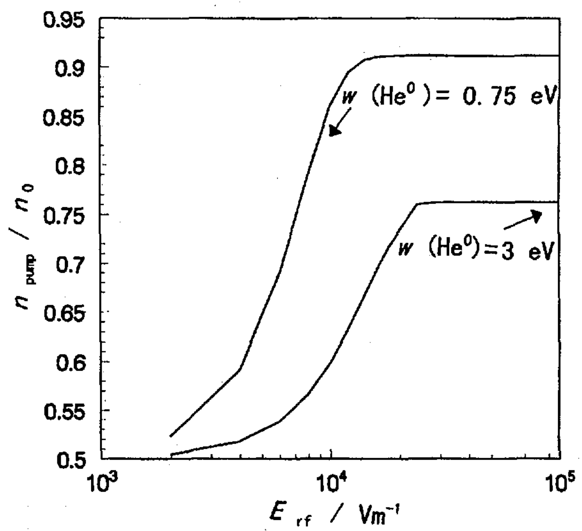

Fig. 2 RF enhanced ash removal efficiency versus applied external RF field

$T_e = 30$ eV, $n_e = 1\times10^{13}$ cm^{-3}, $\omega_{rf} = 1.1\ \omega_c(He^+)$, $B_{Div} = 1.6$ T, $L = 20$ cm, $\eta = 0.5$.

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2.2 Computer Simulation of FEB-E Tritium System

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Key words FEB Tritium system Tritium inventory

Based on Fusion Experimental Breeder (FEB) engineering outline design, a dynamic subsystem model is constructed for tritium fuel cycle system. A computer simulation code-SWITRIM has been developed to simulate the tritium fuel cycle system. The tritium inventories in 10 subsystems are calculated during one year operation period.

1 Subsystems

FEB-E tritium cycle system is devided into 10 subsystems, the simulation is treated as time-dependent problem and 100% availability is assumed. The physics bases of SWITRIM code are as follows: (1) Tritium storage and fuelling subsystem has initial tritium storage $Y_0(0)=0.9$ kg and tritium container has permeation barrier to reduce non-decay loss fraction to 0. 0001 d^{-1} and radioactive decay $\lambda=1.54\times10^{-4}$ d^{-1} is considered. Pellet formation, acceleration and launching take total 20 minuts, fuelling rate is $N=1.073$ kg · d^{-1} and plasma fractional burnup is $\beta=0.0208$. (2) Outboard blanket tritium breeding LLi is repeatedly moved out to recover tritium every 10 days with tritium mass fraction about 10×10^{-6} atoms[1]. (3) Inboard blanket breeding LLi is moved out to recover tritium every 24 h with tritium concentration about 10×10^{-6} atoms. Total tritium breeding ratio is $\Lambda=1.10$; $\Lambda_1=0.45$ is contributed form outboard and $\Lambda_2=0.65$ from inboard. Tritium diffuses to the helium coolant from LLi with the fractions $\varepsilon_1=\varepsilon_2=0.0001$ d^{-1}. (4) First wall, limiter and divertor are cooled by helium and tritium is recovered from He coolant every 100 days, if blanket temperature runs to 680 ℃, the tritium permeation to the structural materials of first wall, limiter and divertor is characterized by a fraction of $\sigma=0.01\%$ per day, considering pressure driven permeation PDP enhancement, but no neutron damage trapping effects. The tritium in structural materials is regarded as unrecoverable but tritium loss to the coolant from the materials is taken into account by $\varepsilon_3=0.0001$ d^{-1}. (5) Plasma exhausted gases are unburnt fuel particles, helium ash, tritiated water and other impurities. Tritium mean residence time in this subsystem takes 0. 5 ～1 h, non-decay loss fraction $\varepsilon_4=0.0001$ d^{-1}. (6) Fuel clean up unit (FCU) is a palladium membrane reactor which consists of permeator and catalytic reactor to shift water and methane into gases; the processing time takes 1～2 h. (7) Isotope separation system (ISS) is a combined cryogenic fractional distillation system with modified cold trap, precipitation and decomposition of necessary steps to recover tritium from LLI; total residence time takes 3. 5～7 h. (8) Tritium waste treatment (TWT) subsystem is to treat low level solid tritium waste, the residence time takes 10 h. (9) In the subsystem, beryllium neutron multiplier, the tritium inventory is produced by reactions $^9Be(n,T)\,^7Li$ and $^9Be+n\rightarrow{}^4He+{}^6He$, $^6He\rightarrow{}^6Li+\beta^-$, $^6Li+n\rightarrow{}^4He+T$. For the time being, we don't consider recovering tritium from beryllium; non-decay loss fraction is 0. 0001 % per day. (10) Helium coolant, the tritium is recovered from helium coolant every 100 days.

2 Equations

Governing equations are given as follows:

For tritium storage and fuelling subsystem:

$dY_0 = \tau_6 Y_6 - N - \varepsilon_0 Y_0 - (\lambda + \varepsilon_0)TN$; $Y_0(0) = 0.90000$.

For outboard blanket (LLi):

$dY_1/dt = \beta N\Lambda_1(1 - b - \gamma) - \lambda Y_1 - \varepsilon_1 Y_1$. If t equals to interger times of ten, the initial values are set as follows: $t_1=0.00000, Y_1(t_1)=0.00000; t_2=10.00000, Y_1(t_2)=f_T Y_1(t_2-0.00001); t_3=20.00000, Y_1(t_3)=f_T Y_1(t_3-0.00001); t_4=30.00000, Y_1(t_4)=f_T Y_1(t_4-0.00001)$; ……; in doing so up to $t=365.0000$.

For inboard blanket(LLi):

$dY_2/dt = \beta N\Lambda_2(1 - b - \gamma) - \lambda Y_2 - \varepsilon_2 Y_2$. If t is an integer, the initial values are set as follows: $t_1=0.00000$, $Y_2(t_1)=0.00000$; $t_2=1.00000$, $Y_2(t_2)=f_T Y_2(t_2-0.00001)$; $t_3=2.00000$, $Y_2(t_3)=f_T Y_2(t_3-0.00001)$; $t_4=3.00000$, $Y_2(t_4)=f_T Y_2(t_4-0.00001)$; …; doing so up to $t=365.0000$.

For first wall, limiter and divertor:

$dY_3/dt = \sigma(1 - \beta)N - \lambda Y_3 - \varepsilon_3 Y_3$; $Y_3(0) = 0.00000$.

For plasma exhaust:

$dY_4/dt = (1 - \beta)(1 - \sigma)N - \lambda_4 Y_4 - \varepsilon_4 Y_4 - \lambda Y_4$; $Y_4(0) = 0.00000$.

For FCU(PMR):

$dY_5/dt = \tau_4 Y_4 - \lambda_5 Y_5 - \varepsilon_5 Y_5 - \lambda Y_5$; $Y_5(0) = 0.00000$.

For ISS:

$dY_6/dt = \tau_5 Y_5 - \lambda_6 Y_6 + \tau_{10} Y_{10} + \tau_7(1 - g)Y_7 - \varepsilon_6 Y_6 - \lambda Y_6$. If t is an interger or interger times of ten, then the initial values are set as: $t_1=0.00000$, $Y_6(t_1)=0.00000$; $t_2 = 1.00000$, $Y_6(t_2) = (1-f_T)Y_2(t_2-0.00001)+Y_6(t_2-0.00001)$; $t_2=2.00000$, $Y_6(t_3)=(1-f_T)Y_2(t_3-0.00001)+Y_6(t_3-0.00001)$; …; $t_{11}=10.00000$, $Y_6(t_{11})=(1-f_T)Y_2(t_{11}-0.00001)+Y_6(t_{11}-0.00001)+(1-f_T)Y_1(t_{11}-0.00001)$; $t_{12}=11.00000$, $Y_6(t_{12})=(1-f_T)Y_2(t_{12}-0.00001)+Y_6(t_{12}-0.00001)$; $t_{13}=12.00000$, $Y_6(t_{13})=(1-f_T)Y_2(t_{13}-0.00001)+Y_6(t_{13}-0.00001)$; …; $t_{21}=20.00000$, $Y_6(t_{21})=(1-f_T)Y_2(t_{21}-0.00001)+Y_6(t_{21}-0.00001)+(1-f_T)Y_1(t_{21}-0.00001)$; $t_{22}=21.00000$, $Y_6(t_{22})=(1-f_T)Y_2(t_{22}-0.00001)+Y_6(t_{22}-0.00001)$; …; in doing so up to $t=365.00$.

For TWT:

$dY_7/dt = \sum_{i=4}^{6}\varepsilon_i Y_i - \lambda_7 Y_7 + \varepsilon_0 Y_0 + \varepsilon_0 TN\text{-}\lambda Y_7$; $Y_7(0) = 0.00000$.

For beryllium neutron multiplier:

$dY_9/dt = Nb\beta\Lambda + N\Lambda\beta\gamma - \lambda_9 Y_9$; $Y_9(0) = 0.00000$.

For helium coolant:

$dY_{10}/dt = \varepsilon_1 Y_1 + \varepsilon_2 Y_2 + \varepsilon_3 Y_3 + \varepsilon_9 Y_9 - \lambda_{10} Y_{10}$; $Y_{10}(0) = 0.00000$.

For total inventory:

$dY_{11}/dt = N\Lambda\beta + (1 - \beta)N - (\lambda + \varepsilon_0)TN - g\tau_7 Y_7 - N - \lambda\left[\sum_{i=1}^{7}Y_i + Y_9 + Y_{10}\right]$; $Y_{11}(0) = Y_0(0)$.

3 Input parameters(reference case)

$\tau_1=0.100, \tau_2=1.000, \tau_3=0.010, \tau_4=48.000, \tau_5=24.000, \tau_6=6.860, \tau_7=2.400, \tau_{10}=0.010, \beta=0.0208, N=1.073, \Lambda_1=0.450, \Lambda_2=0.650, \Lambda=\Lambda_1+\Lambda_2=1.100, b=0.00949, \gamma=0.01157, \sigma=0.0001, g=1\times$

10^{-7}, $\lambda = 0.000154$, $\lambda_1 = 0.100$, $\lambda_2 = 1.000$, $\lambda_3 = 0.010$, $\lambda_4 = 48.000$, $\lambda_5 = 24.000$, $\lambda_6 = 6.86$, $\lambda_7 = 2.400$, $\lambda_9 = 0.000254$, $\lambda_{10} = 0.010$, $T = 0.0139$, $\varepsilon_1 = 0.0002$, $\varepsilon_2 = 0.0001$, $\varepsilon_3 = 0.0001$, $\varepsilon_4 = 0.0005$, $\varepsilon_5 = 0.0003$, $\varepsilon_6 = 0.002$, $\varepsilon_0 = 0.0001$, $\varepsilon_9 = 0.000254$, $f_T = 0.1$.

4 Results and discussion

As a reference case, the minimum unrecoverable tritium concentration in LLi $f_T = 0.1$, total plasma exhaust processing time takes 5 h, the tritium inventories in 10 subsystems and total inventory of FEB are calculated and shown in Fig. 1. $Y_6 \approx 0.26$ kg in ISS subsystem is dominant because of low plasma burn up fraction. The necessary minimum initial tritium inventory is 318 g. The tritium storage and total tritium inventory are 1.18 kg and 1.69 kg, respectively, after one full-power-year (FPY) operation. The tritium inventory in helium coolant is 5×10^{-3} kg · a^{-1}. and tritium holdup in structural materials of first wall, limiter and divertor is 0.037 ~ 0.059 kg · a^{-1}. The tritium retention in beryllium multiplier is 0.18 kg · a^{-1}. The balanced tritium inventories in following six subsystems are obtained: ISS 0.157 ~ 0.256 kg; plasma exhaust 0.022 kg; FCU 0.0437 kg; LLi (inboard) 0.00158 ~ 0.0158 kg; LLi (outboard) 0.0109 ~ 0.105 kg; TWT 0.00017 ~ 0.0002 kg.

Our conclusions are that higher fractional burn up β in plasma is important and the required minimum initial tritium inventory $Y_0(0)$ strongly depends on the plasma exhaust processing time.

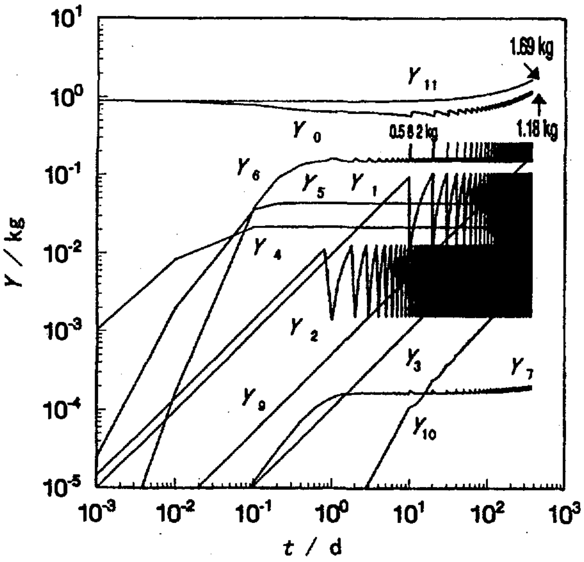

Fig. 1 As a reference case, the tritium inventories in 10 subsystems and total inventory of FEB versus time

$f_T = 0.1$; FEP time = 5 h; $\sigma = 0.0001$; $\varepsilon_1 = 0.0002$; $\varepsilon = 0.0001$; $Y_0(0) = 0.9$.

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