1)

The mean no. of fission neutrons per thermal neutron ; η from the reproduction factor formula k_∞

$$\eta = \nu \frac{\sigma_f}{\sigma_a + \sigma_f}$$

ν = Mean # of neutrons per fission

σ_f = cross section for fission

σ_a = cross section for absorbtion

for ^{239}Pu $\sigma_f = 842$ b $\sigma_a = 276$ b $\nu = 2.96$ (1)

$$\therefore \eta = 2.96 \times \frac{842}{842 + 276} \quad (2)$$

$$= \underline{\underline{2.23}} \quad (2)$$

2)

The pp cycle is $4(^1H) \rightarrow {}^4He + 2e^+ + 2\nu_e + 2\gamma$

Total electromagnetic energy is from photons only

$= 6.55$ MeV per input p^+ ($= 26.2$ MeV per pp cycle)

flux of radiation is $9.4 \ J \ cm^{-2} \ s^{-1}$

$$= \frac{9.4}{1.6 \times 10^{-19}} \times \frac{1}{10^6} = 5.87 \times 10^{13} \ MeV \ cm^{-2} \ s^{-1} \quad (2)$$

$$\# \text{ of reaction} = \frac{5.87 \times 10^{13}}{26.2} = 2 \times 10^{12} \ cm^{-2} \ s^{-1} \quad (1)$$

each reaction produces 2 ν_es

$$\therefore \nu_e \text{ flux} \approx \underline{\underline{4 \times 10^{12} \ cm^{-2} \ s^{-1}}} \quad (2)$$

[note: 2 marks per stage of calculation for total of 6 marks]

3) Fusion reactors use the DT reaction because

i) the cross section for DT is 1-2 orders of magnitude larger than DD reaction [2]

ii) The DT reaction has a larger Q than the DD reaction [2]

The energy density output per second = $n_1 n_2 <\sigma v> Q$ [2]

$= n^2 <\sigma v> Q$

$= 10^{40} \cdot 10^{-22} \cdot 17.6$

$= 17.6 \times 10^{18}$ MeV m^{-3} s^{-1} [2]

(i.e. in 1s the energy density output is 17.6×10^{18} MeV m^{-3})

Unit volume of plasma contains e, D and T particles at same temperature. There are n electrons per cubic meter and also n D+T nuclei per cubic meter. Thus 2n particles in total each with 3/2kT of thermal kinetic energy.

So energy density $= 3/2kT \cdot 2n$

$= 3kT\, n$ [2]

output fusion energy density in time t = $t \cdot n^2 <\sigma v> Q$ MeV m^{-3} s

fusion energy density available for heating $= 0.80 \cdot t \cdot 17.6 \times 10^{18}$ MeV m^{-3} s

Thus confinement time for self-sustaining fusion reaction

$= 3kT/(0.8 \cdot n <\sigma v> Q)$ [2]

$= 3 \times 0.01 / (0.8 \times 10^{20} \times 10^{-22} \times 17.6)$

$= 0.2$ s [2]

[note: will also accept an answer of which is different by a factor of 4, i.e. t=0.8s since there was an ambiguity in the definition of the number density n in first and second parts of the question]