FUSION TECHNOLOGY question #3 on ICF pellets

As usual – show all work to justify the answer

4) We will explore the pellet injection process for Laser fusion.

a) Calculate the minimum injection velocity for fuel capsules needed to produce an electrical power output, $P_{electric}$, of 1 GW with a fusion energy yield of W_{pellet}=150 MJ per pellet in an ICF power plant. The spherical wall of the reactor has a radius of R=5 metres. The thermal efficiency of heat to electrical conversion, η_{conv}, is 33%.

b). Calculate the average inner wall surface temperature due to the alpha power incident on it for a range in wall thicknesses: First assume that all the alpha power is absorbed by the inner surface of the chamber wall; Radiation and debris from the pellet during the fusion explosion do not heat the surface. Neutrons are absorbed past the wall in a blanket, IR losses from the surface due to its heating are negligible. Treat the wall for a range of tungsten and stainless steel (304 type) wall thicknesses of t= (5, 10, 20, 40) mm and the thermal conductivity, κ (W/m/K) = 21.4 for stainless, 173 for tungsten. The temperature of the wall's outer surface is fixed at the coolant temperature of 150°C (pressurized water). Ignore the pulsed nature of the operation and instead use the average wall power density. This is best done as a table of the following form –

Wall thickness t (mm)	T_{surf}(°C) for 304 stainless steel	T_{surf}(°C) for tungsten
5		
10		
20		
40		

Stainless steel looses ~ ½ its room temperature structural strength (yield, tensile strength) at temperatures ~ 500-700°C. Which material would be preferred from the structural and temperature viewpoint? Which material would be best in terms of activation?

c) Determine the IR heat flux emitted from the hot chamber wall surfaces (W/m^2), Q_{IR}[W/m^2], for surface temperatures of 1050°C for stainless steel and 260°C for tungsten. The emissivity of the chamber surface, $\varepsilon_{chamber}$, is 0.2 for tungsten and 0.6 for stainless steel. Is Q_{IR} less than Q_{wall} of part b as assumed earlier?

d) Determine the pellet DT ice layer temperature rise due to Q_{IR} as the pellet travels through the chamber to the center. Assume that the ice shell is heated uniformly by the IR heat load originating from the chamber walls (part c) and $\varepsilon_{DT\ ice}$=1 ; The shell initial temperature is 17K and the melting point is 18.5K; the heat capacity of the DT ice is 8.8 J/g-K, and the density of frozen DT is 2.2x10^5 g/m^3. The two limiting surfaces of the ice shell are at r_{shell}=0.8 and 1.0 mm.

e) For the single case of the stainless steel wall at 1050°C of question c above and calculate what pressure of xenon gas would lead to a similar heat load to the pellet as for IR heating. Assume the gas temperature is the same as the wall temperature given that they are in equilibrium and that all the energy of the Xe atoms (@wall temperature) incident on the pellet is transferred to the ice.

What other processes could heat the pellet?