Nuclear Technology – Project

You are to design a transport flask to move spent fuel from a PWR to a facility where it will be reprocessed. The fuel is UO2 with an initial enrichment of 3.5%. The operating history of fuel if given in a table below. It is to be cooled for 1000 days before going into your flask. The fuel assembly is displayed in Appendix 1.

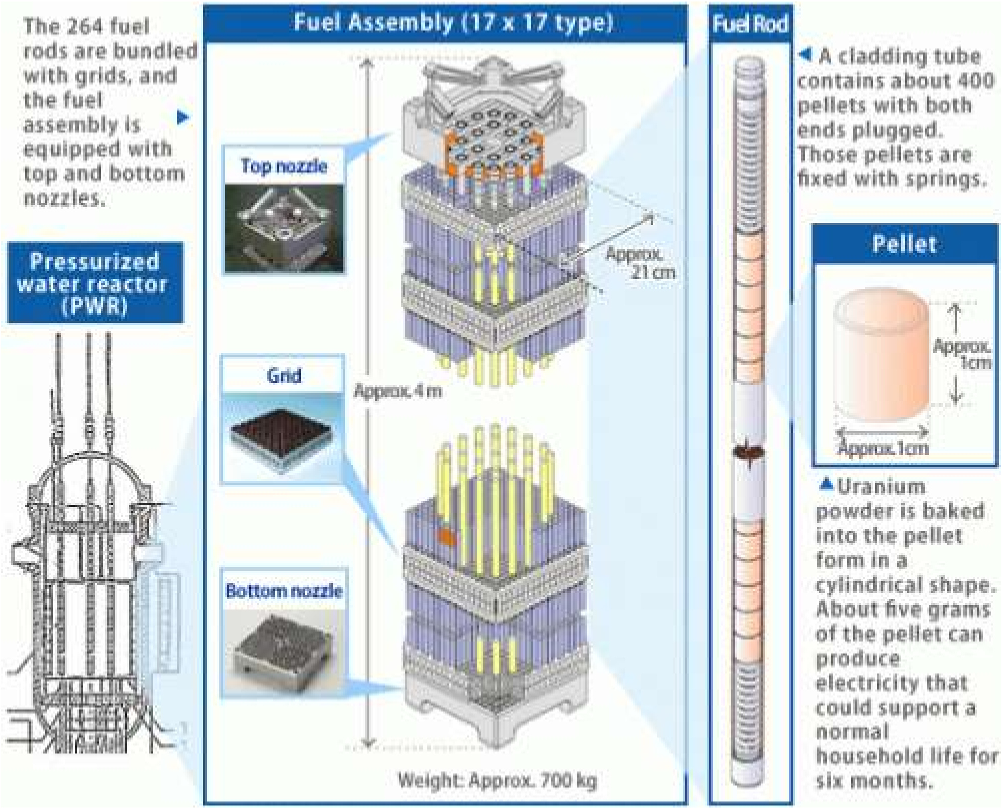
Sub-task 1 - Get the inventory data for the fuel.
The operating history is displayed in Appendix 2.
Tip: You can use SCALE Origen to do this. This should be the shorted task.

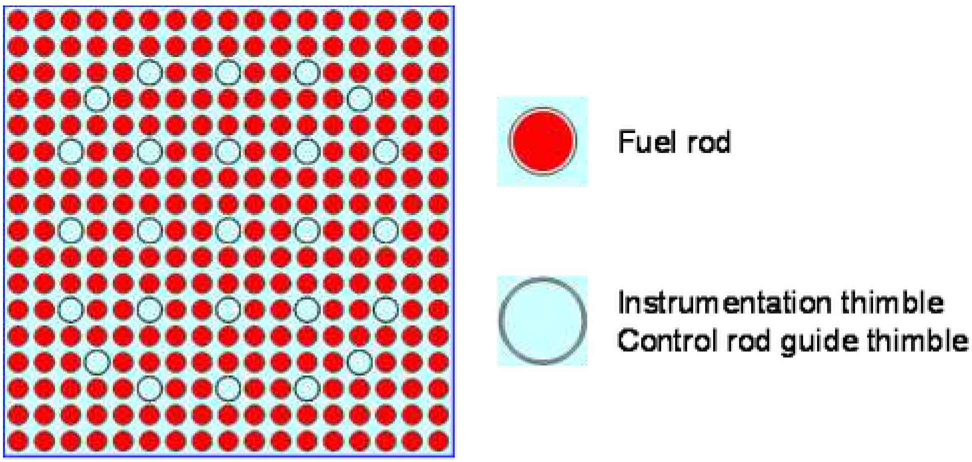
Sub-task 2 - Design your flask
Design your flask so that there won't be a criticality. The fuel inside the flask should be immersed in water to serve as a heat sink/heat transfer medium. For efficient shipping, your flask should accommodate multiple fuel assemblies - select an appropriate size and shape of flask to facilitate this. However, for criticality safety, your flask must have a k_eff of at most 0.90. Use a code to calculate k_eff in your flask when it is filled with its maximum load of fuel and make sure it is within the limit.
If the fuel shifts in your flask, or the water sloshes around to a different position, does your flask still meet the requirement?

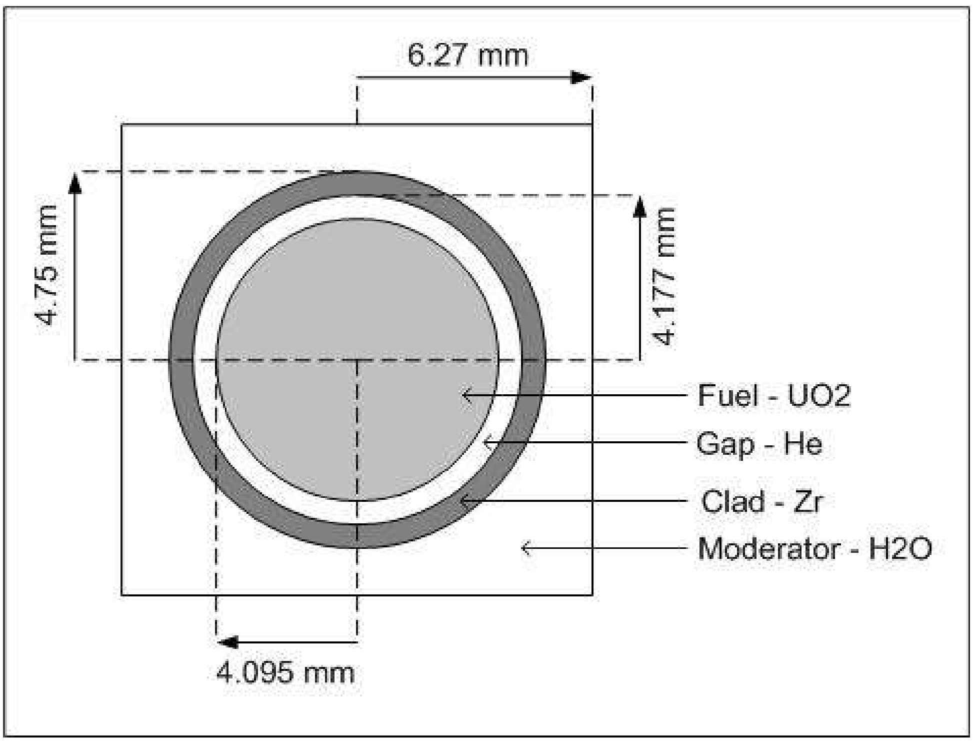
Sub-task 3 - Design shielding for your flask.
Assume that your government has regulated that the radiation level shall on the external surface shall not exceed 1 mSv/h. Find the dose rate on the surface of your flask, and design shielding of an appropriate material and thickness to make sure you will meet this requirement. Common practice is to use a code (such as MCNP or SCALE Monaco/MAVRIC) to estimate the dose rates.

Tip: Unless you have previous knowledge in MCNP, it will not be feasible to use it for this exercise. For the limited time frame of this project, you can therefore choose to I) make a crude approximation of your geometry and calculate the dose “by-hand” (using the linear attenuation formula) or ii) use simplified geometry in GEANT4 with a volume source of the General Particle Gun.
Bonus: If the fuel shifts in the flask, or the water drains out, or anything like that, will your flask still meet the requirement?

Appendix – A Westinghouse 17x17







Geometry	Square 17×17 matrix
Fuel assembly dimension	Square 214 x 214 mm
Composition per assembly	Total: 289 Fuel: 264 Control rod guide thimble: 24 Instrumentation thimble: 1
Fuel material	UO_2 (U235,U238,Oxygen)
Cladding material	Zircaloy-4 98.23 wt% zirconium 1.45% tin 0.21% iron 0.1% chromium 0.01% hafnium Density: 6.55 g/cc Melting point: 1850°C
Gap filler	Helium gas
Fuel average density	95 – 96% Theoretical Density* UO_2-TD = 10.96 g/cc
Moderator (coolant)	light water (H_2O) average density 0.7295 g/cc
H/HM ratio (hydrogen to heavy metal ratio)	1.7 – 3.4 (depends on enrichment level)
Enrichment	2.5 – 5 Wt % U235
Fuel pellet diameter	8.19 mm
Pellet-clad gap	0.082 mm
Clad thickness	0.572 mm
Outer diameter of fuel rods	9.5 mm
Pitch (center-to-center)	12.54 mm
P/D	1.32

* The theoretical density (TD, 100% dense, or no porosity) . In practice, there is always some porosity in a polycrystalline pellet.

Sources:
https://syeilendrapramuditya.wordpress.com/2009/04/14/standard-pwr-nuclear-fuel-assembly-17x17-technical-specification/

The Westinghouse Pressurized Water Reactor Nuclear Power Plant. Westinghouse Electric Corporation (1984)

Zirconium Alloys. Technical Data Sheet. VERSION 1 (2/3/2015) ATI
https://www.atimetals.com/Products/Documents/datasheets/zirconium/alloy/Zr_nuke_waste_disposal_v1.pdf

Appendix 2 – Operating History

Operating history

Cycle	Power (MW/MtU)	days
1	37	150
	42	25
	45	75
	35	50
	37	50
Refueling		49
2	35	100
	0	30
	34	85
	38	85
	33	105
refueling		70
	16	20
	15	435
Discharge		