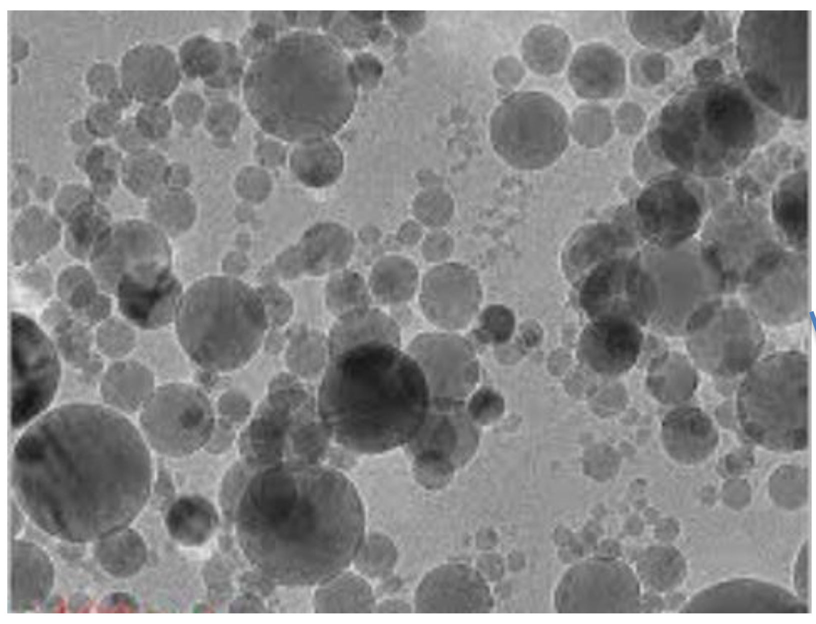
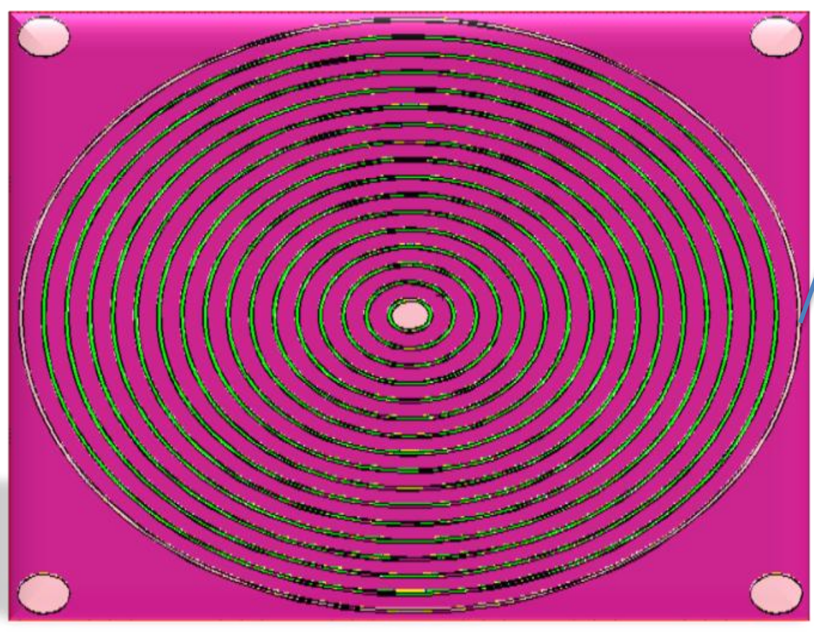
SMART Reactor Design Enhancements

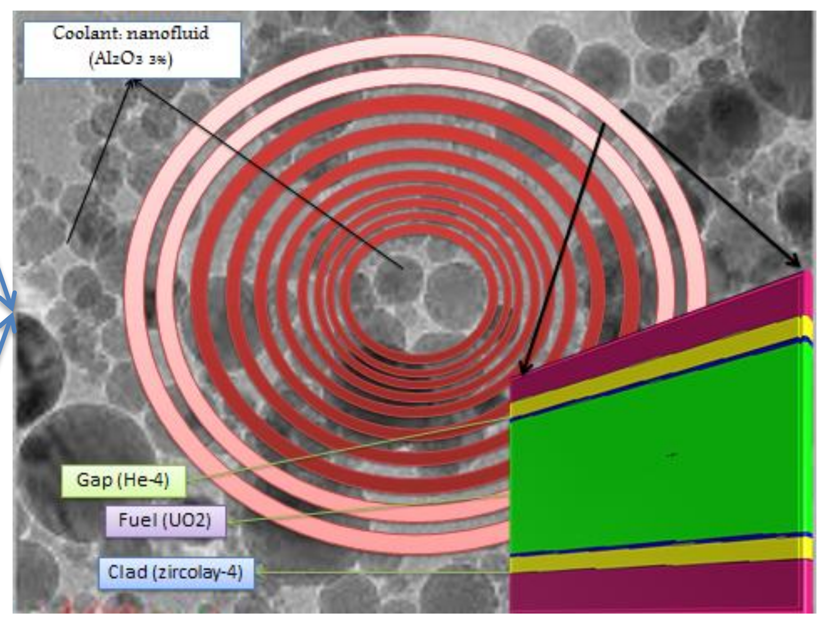
Eng. Obaidat / Eng. Bani Ahmad
JAEC

Abstract & Objectives

Small Modular Reactors (SMRs) technology is currently under development. These reactors are considered a safe, reliable, and sustainable source of energy for developing countries with small electric grids. Many challenges face the introduction of smart reactors as a competitive option in the market, of which is the price of the electricity generated and the short fuel cycle span. The purpose of this project is to introduce a new design enhancement for the reactor through using hollow fuel cylinder and nanofluid coolants.





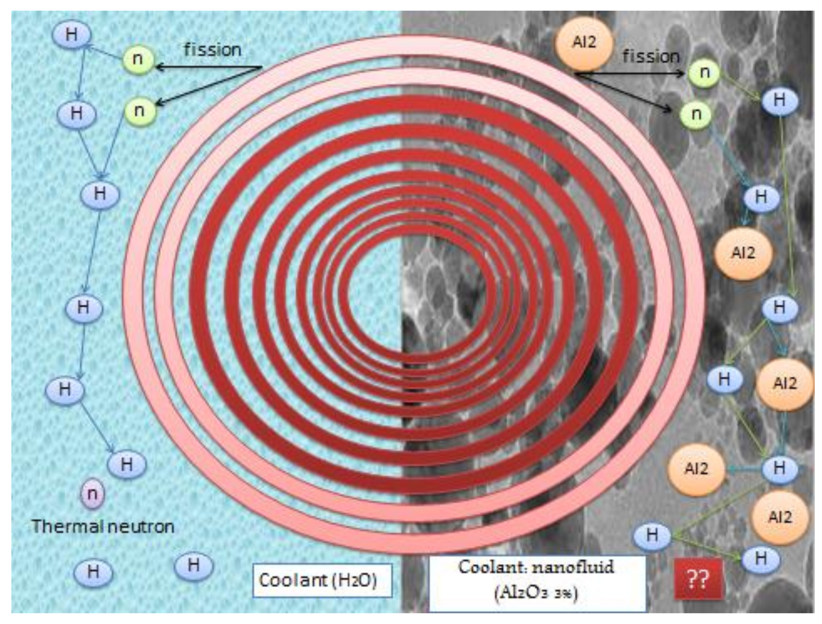


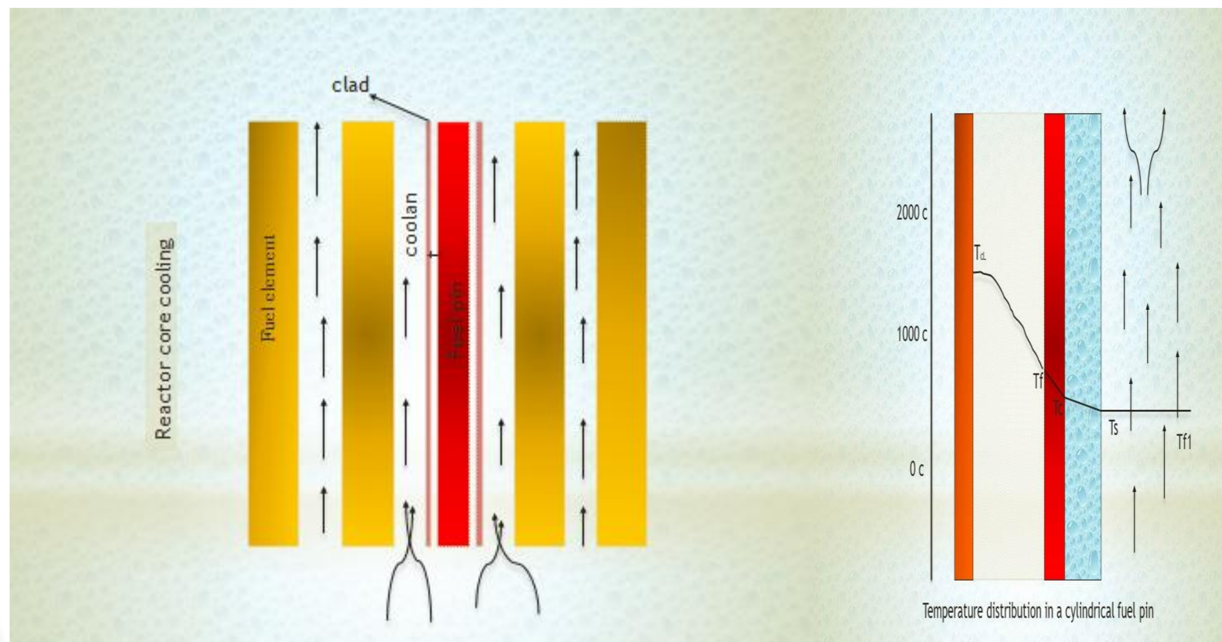
Materials & Methods

The approach to this design enhancement will constitute two parts; the neutronics design, and the thermal hydraulics design. The neutronics aspect of the design will be developed through the usage of the MCNPX software package, this will revolve around increasing burnup and increasing the heat transfer surface through the usage of hollow nuclear fuel cylinders and obtaining a quantitative estimate of the effect of nanofluids on the nuclear reactivity control. This will contribute to obtaining the same power level by using less amount of fuel, which provides a significant economic advantage.

The second part, the thermal hydraulics design, which studies the effect of adding nanoparticles to the coolant, and how would this affect the thermal conductivity and hence, the amount of heat extracted from the fuel rods.

Case study: the scattering cross-section of the moderator effects the efficiency of the thermal neutron flux, where the main objective of the moderators is slowing down the fast neutrons that are generated from the core, for this its preferred to use low atomic weight isotopes such us hydrogen, deuterium and graphite due to there high scattering cross-section.. The usage of nano particles in the moderator will affect the slowing down process in two different ways, the scattering cross-section of the nano particles is lower than (H,D),which in this case the neutron need more the 8 mean free paths to thermalized, on the other hand, the ratio of the delayed neutrons will increase due to the high capture cross-section, which will provide a significant safety advantage.



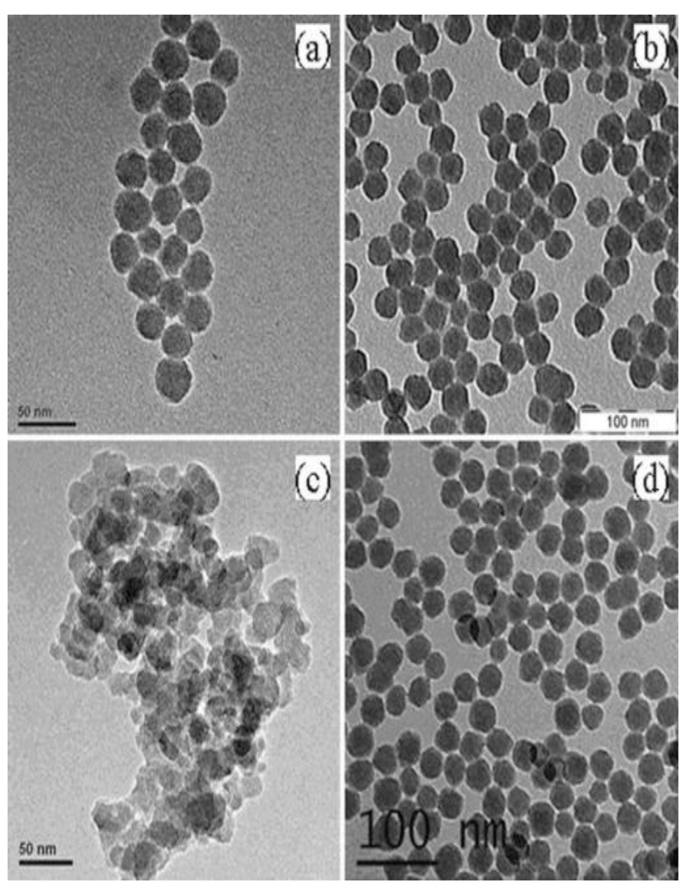


IMAN1

Results

The addition of nano-sized particles to a liquid has been found to increase the thermal conductivity and critical heat flux. Increasing the critical heat flux, which is, the thermal limit of a phenomenon where a phase change occurs during heating (such as bubbles forming on a metal surface used to heat water), which suddenly decreases the efficiency of heat transfer, thus causing localized overheating of the heating surface, would empower the heat transfer process and more heat will become extractable from the Nuclear Fuel rod. The table below show the increase in the critical heat flux measured by using nanofluids.

Nanofluid(s)	Heater type	Max CHF enhancement
Al_2O_3 in water, 0.001-0.025 g/L	Cu plate	200%
SiO_2 (15-50 nm) in water, 0.5 v%	NiCr wire	60%
Al_2O_3 (38 nm) in water, 0.037 g/L	Ti layer on glass substrate	67%
TiO_2 (27-85 nm) in water, 0.01-3 v%	Cu plate	50%
Al_2O_3 (70-260 nm) and ZnO in water Al_2O_3 in ethylene glycol	Cu plate	200%
Al_2O_3 (10-100 nm) in water, 0.5-4 v%	Stainless steel plate	50%
TiO_2 (85 nm) in water, 10^{-5}-10^{-1} v%	NiCr wire	200%
SiO_2, CeO_2, Al_2O_3 (10-20 nm) in water, 0.5 v%	NiCr wire	170%
Au (4 nm) in water	Cu plate	175%
SiO_2 (20-40 nm), ZrO_2 (110-250 nm), Al_2O_3 (110-210 nm) in water, 0.001-0.1 v%	Stainless steel wire	80%



The findings can be summarized as follows:

- Significant CHF enhancement (up to 200%) occurs with various nanoparticle materials, including silicon, aluminum and titanium oxides.
- The CHF enhancement occurs at relatively low nanoparticle concentrations, typically less than 1% by volume.
- During nucleate boiling some nanoparticles precipitate on the surface and form a layer whose morphology depends on the nanoparticle materials.
- Most studies report no change or some deterioration of heat transfer in the nucleate boiling regime (prior to CHF).

Conclusion

-Our Project will be divided into five phases:

PHASE I: Reactor Modeling
PHASE II: Neutronics Calculation & Analysis.
PHASE III: Thermal Hydraulics Calculation & Analysis.
PHASE IV: Burnup Calculations.
PHASE V: Overall Reactor Enhancements.

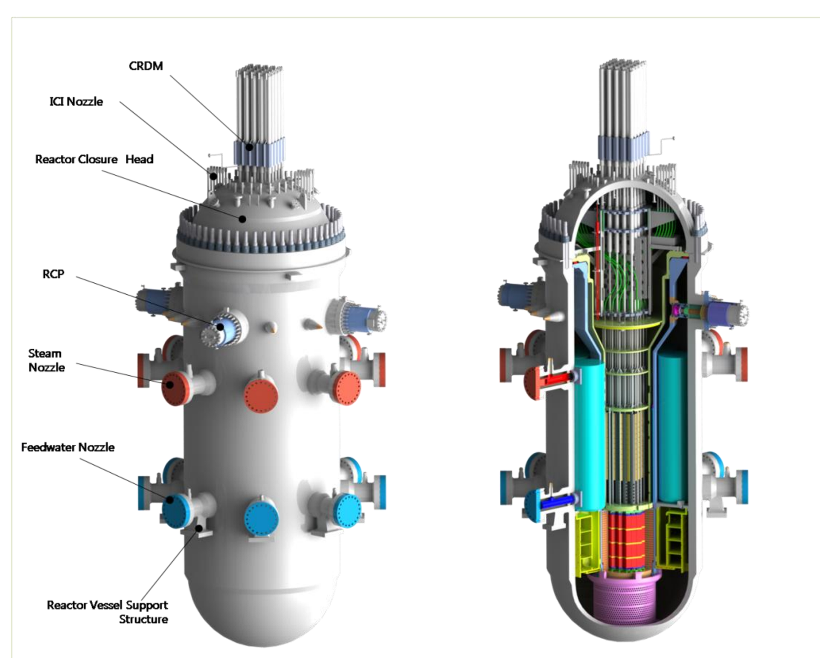
-Our vision of the enhanced design is using:

Circular Fuel Design.
Nanofluid Coolant & Moderator

-Our Expected Outcomes:

Increased Burnup.
Increased Heat Transfer through increasing fuel surface area and use of nanofluids (Case Study)
Increased capture cross section in coolant (Case Study).

The use of a supercomputer like IMAN1 will provide the computational power required to provide a very accurate and detailed analysis of the model at hand. Also, the short computational time offered will provide a large room for the development and enhancement of the model.



References

Technology Transfer Services (TTS), Steam Thermodynamics Article, 2009