Reactor Thermal-Hydraulics
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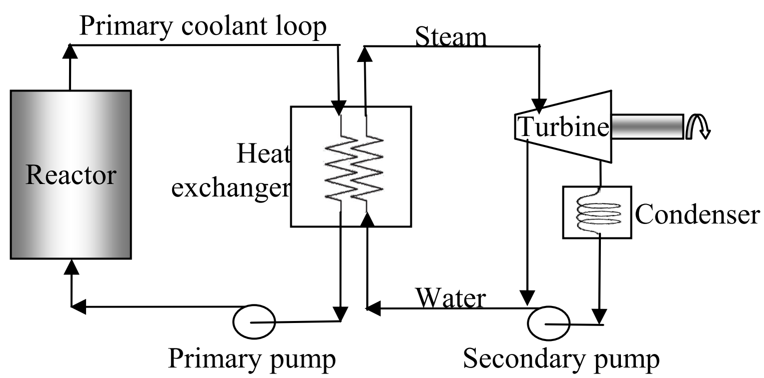
In a power reactor, the energy produced in fission reaction manifests itself as heat to be removed by a coolant and utilized in a thermodynamic energy conversion cycle to produce electricity. A simplified schematic of a typical nuclear power plant is shown in the diagram below.



Although this process is essentially the same as in any other steam plant configuration, the power density in a nuclear reactor core is typically four orders of magnitude higher than a fossil fueled plant and therefore it poses significant heat transfer challenges. Maximum power that can be obtained from a nuclear reactor is often limited by the characteristics of heat transport system rather than nuclear considerations. Various factors that influence the power level include the coolant type, core configuration to maximize heat transfer surface area, coolant flow rate, thermo-physical properties of coolant and core materials, and consideration of material compatibilities.

The most common coolant choices include water, liquid metals like molten sodium, and gases like helium. In water-cooled reactors, water picks up reactor heat and leaves the core at a temperature high enough to generate steam in a heat exchanger or directly in the core. In a pressurized water reactor, the system pressure (~14 MPa) is high enough to avoid any coolant boiling in the core. In a boiling water reactor, the system pressure (~4-7 MPa) corresponds to saturation at the reactor operating temperature causing the steam generation to directly take place in the reactor core. Although cheap and safe to handle, water is corrosive at high temperatures and poses significant safety challenges since it requires pressurized primary coolant systems. As a more attractive coolant with superb heat transfer characteristics and a much wider margin between melting and boiling points, the liquid sodium does not require a pressurized system, but a sodium-cooled fast spectrum reactor often includes an intermediate loop and requires special sodium handling technology since it reacts with water and air at elevated temperatures. Despite their low heat transfer capacity, with their non-reactive properties and low neutron absorption characteristics, the gas coolants are also considered in some reactor types.

In this lecture, the principles of nuclear reactor thermal hydraulics, from reactor core to steam generator, will be introduced and specific challenges that limit the reactor operations will be discussed for different coolant and reactor types. The parameters that limit the rate of heat removal such as the burnout heat flux for water cooled reactors or maximum cladding and/or fuel temperatures for gas and liquid-metal cooled reactors will be identified.