## PROBLEMS

**9-1.** A research reactor core is cubical, 20 ft on the side. The fuel elements are made of 1-in.-diameter solid natural-uranium metal rods. They are placed horizontally in the center of 3-in.-diameter graphite holes. Air is used as the coolant. It is forced at atmospheric pressure and an initial velocity of 15 fps. For the centermost fuel element, air enters at 80°F and leaves at 190°F. Calculate (*a*) the heat-transfer coefficient, and (*b*) the maximum neutron flux in the core, neglecting cladding and extrapolation lengths.

**9-2.** Compare the heat-transfer coefficients and the pumping power (hp) per 1,000-ft length of 1-in.-ID smooth-drawn tubing of the following coolants: (*a*) air at 10 atm, 100 fps, and 400°F; (*b*) $CO_2$ at the same conditions; (*c*) He at the same conditions; (*d*) water at 20 fps and 400°F; and (*e*) sodium at the same conditions. (Sodium for comparison-use Eq. 10-2.)

**9-3.** A nitrogen-cooled reactor uses $UO_2$ fuel. The fuel elements are 0.5 in. in diameter and are encased in a graphite can 0.1 in. thick. At a particular cross section the coolant pressure and bulk temperature are 6 atm and 1000°F. The stream velocity is 375 fps. At the same section the volumetric thermal source strength is $2 \times 10^6$ Btu/hr ft³ and the maximum fuel temperature is 5000°F. Determine (*a*) the heat-transfer coefficient and (*b*) the necessary equivalent diameter of the coolant channel. Neglect contact resistance between the fuel and the graphite. Use $k_{\text{graphite}} = 35$ Btu/hr ft °F (aged).

**9-4.** In Prob. 6-1, if the iron shield is cooled with pressurized light water having a bulk temperature of 400°F and if the temperature within the shield is not to exceed 425°F, find the minimum water velocity necessary on the side facing the $\gamma$ radiation. The coolant channel is narrow, 2 in. wide, but has large dimensions otherwise.

**9-5.** Helium coolant enters and leaves a reactor core at 400 and 1049°F, respectively. The mass rate of flow of helium is 100,000 $lb_m$/hr. The reactor core contains 400 fuel elements made of 3 percent enriched $UO_2$ in the form of vertical plates 4 in. wide and 0.135 in. thick (including 0.005-in.-thick cladding on each side). A solid moderator is used in the form of vertical plates interposed between the fuel plates so as to form coolant channels $\frac{1}{4}$ in. wide. The core is cylindrical, 8 ft in diameter and 8 ft high. Calculate the maximum neutron flux in the core. Use density of $UO_2 = 10.5\ g_m/cm^3$. Neglect extrapolation lengths.

**9-6.** Light liquid water is used as a reactor coolant. In a particular channel, the average bulk temperature is 300°F. Determine the percent change in $W'/q$ if it were to be used in the same channel, with the same mass-flow rate, the same mean temperature between ladding and coolant, but at average bulk temperatures of 200 and 400°F. Assume saturated conditions in all cases.

**9-7.** A pressurized-water reactor uses $UO_2$ cylindrical fuel pellets, 0.5 in. diam surrounded by a helium gap 0.003 in. wide and by Zirconium cladding 0.03 in. thick. The fuel rods are arranged in square lattice, 0.7 in. between centers. At a particular section, the bulk water temperature and velocity are 520°F and 15 fps respectively. $q''' = 5 \times 10^7$ Btu/hr ft². Find (*a*) the convective heat transfer coefficient, and (*b*) the minimum system pressure so that no boiling occurs in the film.

**9-8.** A fuel rod is composed of 0.45 in. diameter fuel ($k_f = 25.4$) with 0.025-in. thick cladding ($k_c = 45$). For metallurgical reasons the maximum temperatures in the fuel and cladding must not exceed 750°F and 600°F respectively. The rod is water-cooled. At a particular cross section the water temperature is 500°F. Find (*a*) the heat-transfer convective coefficient, and (*b*) the minimum water pressure to avoid boiling at that cross section.

**9-9.** A reactor core operating at 2000 psia contains parallel fuel rods having 0.55 in. fuel material diameter and 0.60 in. overall diameter. The rods are arranged in a square lattice with a spacing of 0.66 in. between centers. Water coolant flows parallel to the tubes. At a particular position in the core, the volumetric thermal source strength is $4 \times 10^7$ Btu/hr ft$^3$ and the coolant temperature is 540°F. Find the minimum water velocity at that position if the temperature difference across the film is not to exceed 50°F.

**9-10.** Helium at 300°F and 10 atm pressure flows in a 1 in.-diameter tube at 350 fps. The tube walls are at 280°F. Find the error in heat flux, Btu/hr ft$^2$, if aerodynamic heating is not taken into account.

conditions. They also showed a large velocity effect. The presence of noncondensable gases affects dropwise condensation in a manner similar to that for filmwise condensation.

Because of the difficulty of maintaining reliable dropwise condensation in practice, filmwise heat-transfer coefficients are recommended for design purposes.

## PROBLEMS

**11-1.** If the surface tension between the liquid and vapor for water at 212°F is 4.03 $lb_f/ft$, calculate the amount of liquid superheat necessary to generate a $4.68 \times 10^{-3}$ in. diameter bubble at atmospheric pressure (average).

**11-2.** In an experiment on pool boiling of water, the heat flux and water temperature and pressure were simultaneously increased so that saturation boiling occured at all times. Burnout occured when the pressure reached 300 psia. Assuming for simplicity that burnout heat transfer occured solely by radiation, and that the radiation heat transfer coefficient is 20 Btu/hr ft² °F, estimate the temperature of the heating surface at burnout.

**11-3.** What should the maximum allowable volumetric thermal source strength be for a flat-plate fuel element operating in saturated pool boiling water on the lunar surface where the gravitational forces are one sixth those on earth? The system pressure is 100 psia. The element measures $4 \times 0.25$ in. Ignore cladding and use a 2:1 safety factor.

**11-4.** Water flows at 2,000 psia and 500°F through a hollow cylindrical fuel element having inner and outer diameters of 1 and 1.28 in. respectively, including 0.030 in. cladding on both sides. The outer surface is surrounded by graphite and may be considered insulated. For a water velocity of 30 fps, estimate the volumetric thermal source strength that would cause burnout.

**11-5.** A 5-ft high boiling-water reactor channel operates at 600 psia. Water enters the channel at 470°F and 4 fps. $2 \times 10^6$ Btu/hr are generated sinusoidally in the channel. The channel may be assumed circular, 2-in. in diameter, with fuel cross-sectional area of 0.0218 ft². Neglect the extrapolation lengths. Assuming that burnout will probably occur at the center plane, determine whether the channel is safe.

**11-6.** A boiling-water reactor channel operating at 1,000 psia is 7.68 ft high and contains 0.80 in. diameter fuel rods (including 0.025 in. cladding). Water enters the channel saturated at 15 fps. The flow area per fuel element is 0.0018 ft². It is assumed for simplicity that energy is generated sinusoidally in the channel with a maximum volumetric thermal source strength of $2 \times 10^7$ Btu/hr ft³, and that the extrapolation lengths may be ignored. Calculate the critical heat fluxes at the entrance, center, and exit of the channel. Sketch the variation of critical heat flux and actual heat flux versus height up the channel and calculate the minimum safety factor (ratio of critical-to-actual fluxes) in the channel.

**11-7.** Liquid sodium flows at 20 fps and 700°C inside a 4-ft long hollow cylindrical fuel element having diameters 1 and 0.5 in. respectively. The outside surface of the element may be considered insulated. Using a safety factor of 2, what should be the highest value of volumetric thermal source strength to avoid burnout?

**11-8.** A pressurized-water reactor channel operating at 2000 psia contains fuel with a total surface area of 2.7 ft² and has a flow area of 0.01 ft². $4 \times 10^4$ $lb_m/hr$ of water enter the channel at 580°F. When $2.33 \times 10^6$ Btu/hr were generated in the channel, the heat flux at midplane was just sufficient to cause burnout. Find the ratio of maximum-to-average heat flux at these conditions.

**11-9.** Saturated steam at 1000 psia enters the top of a 1 in. diameter, 12 ft long vertical tube at 10 fps. The tube walls are held at 530°F. Estimate the heat transfer, Btu/hr, and the mass flow rates of steam and water at the tube exit, $lb_m/hr$.

**11-10.** A turbine condenser operating at 1 psia contains 400 2.4 in. diameter, 20 ft long horizontal tubes arranged in 40 rows, 10 tubes deep. Cooling water flows inside the tubes in a one-pass arrangement with a heat transfer coefficient of 312 Btu/hr ft² °F. The conductive resistance in the tube walls may be ignored. If the tube walls are at 98°F, calculate (a) the amount of steam condensed, $lb_m/hr$, and (b) the average cooling water temperature.