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Statistical calculation of hot channel factors

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ABSTRACT

It is a conventional practice in the design of nuclear reactors to introduce hot channel factors to allow for spatial variations of power generation and flow distribution. Consequently, it is not enough to be able to calculate the nominal temperature distributions of fuel element, cladding, coolant, and central fuel. Indeed, one must be able to calculate the probability that the imposed temperature or heat flux limits in the entire core are not exceeded. In this paper, statistical methods are used to calculate hot channel factors for a particular heterogeneous geometry, Material Testing Reactor (MTR). Tehran Research Reactor (TRR) is used as a case for the present parametric study. The obtained results from this method are compared with the other statistical methods. It is shown that among the statistical methods available, the semi-statistical method is the most reliable one.

1. Introduction

In the design of nuclear reactors, a number of uncertainties arise concerning variations in flow distribution, fuel element and coolant channel geometry, and nuclear flux spatial distribution. To facilitate the determination of the effects of such variations upon the thermal performance, hot channel factors are introduced. That is, a factor is introduced which relates the nominal channel characteristics to the most unfavorable maximum conditions that might occur in the core (Le Tourneau and Grimble, 1956).

The surface temperature is a function of two separate groups of variables. One group is composed of those variables that represent the physical characteristics of the fuel elements and the fuel channels; the other group is composed of those variables represents the parameters of the processes of heat generation and heat transfer excluding the physical dimensions which are part of the first group. Both of these groups of variables are essentially statistical variables. The statistical nature of the first group arises because of variations in the physical dimensions of the fuel element assembly due to manufacturing variations. The statistical nature of the second group arises from the uncertainty associated with the value of process parameter such as the heat transfer coefficient and the fission rate (Frederick, 1961).

Since the variables are statistical in nature, it is not possible to uniquely determine the surface temperature at a point in a reactor before it is built. What can be done is to compute the probability that the temperature, at a fixed point, will be greater than a given value or lie between given limits. This paper is concerned with the techniques of computing such probabilities. Rude and Nelson (1960) have applied some statistical considerations to the hot-channel factor approach to the surface temperature problem, while Tingey (1961) proposes a statistical error analysis; however, in both papers the statistical variables are assumed to have Gaussian (normal) distribution function. The approach presented in this paper takes into consideration the effect of other variables that affect the nominal temperature distributions. In fact one calculates the overall factor due to its nature by the semi-statistical method, Todreas and Kazimi (1990).

In the current frame work a mathematical model for evaluating hot channel factors by statistical method is presented. In this model design values of Tehran Research Reactor steady state are used for the calculation by the statistical method. The results achieved from this study by statistical method are compared with the other statistical methods. Then, as a case of study, Tehran Research Reactor is considered for the safety analysis during upgrading.

2. Methods of evaluation

Engineering hot channel factors may be broken down into three distinct components corresponding to

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(i) Uncertainties that influence the heat flux, F_q
(ii) Uncertainties in the temperature rise or enthalpy in the channel, F_b
(iii) Uncertainties in the heat transfer coefficient, F_h.

These factors should be introduced into the analysis as

$$q''_{hc} = F_q \times q''_{nc} \tag{1}$$

$$\Delta T_b = F_b \times \frac{Q}{(c_p \times \dot{m})} \tag{2}$$

$$\Delta T_{cs} = F_h \times \frac{q''}{h} \tag{3}$$

where the notation h_c refers to the hot channel value and nc refers to the nominal channel value for the heat flux(q''), and $\dot{m}$is the mass flow rate. The remaining notation is standard. F_bCan be defined as the ratio $\Delta T_{hc}/\Delta T_{nc}$for the bulk ($b$) coolant temperature, and $F_h$can be defined as a similar ratio in the clad surface (cs) temperature. These components can be broken down further into sub-factors and combined either multiplicatively

$$F_b = f_{b1} \times f_{b2} \times f_{b3} \times \ldots \tag{4}$$

Or statistically

$$F_b = 1 + \sqrt{\sum_i (1 - f_{bi})^2} \tag{5}$$

Many of the sub-factors may be determined from the tolerances in the specifications for the fuel elements, pumps, and other related components. Other sub-factor may be determined from limitations in the ability to measure certain parameters accurately, such as, flow rates and temperatures. Other sub-factors may still require some engineering judgment in the assessment of the quality of the data available. Some thermal-hydraulic analysis may be useful in determining the range of influence of certain variations. The fuel plate tolerances with upper and lower thicknesses specified for the entire fuel plate can conservatively be assumed to be the result of variation in the fuel meat thickness. A thicker fuel meat region results in an increase in the local heat flux. Here one could also assume that the meat is thicker over the entire length of the plate and that the bulk temperature is also affected by this variation in thickness. This overall variation is addressed under density uncertainties. If the nominal meat thickness is t_m and the tolerance on the plate is $\pm\Delta t_p$, the heat flux sub-factor may be expressed as

Table 1
Components of hot-channel factors for the TRR.

Physical uncertainty	F_q	F_b	F_h
Nuclear			
^{235}U loading	1.02	1.02	1
^{235}U homogeneity	1.08	1.08	1
Engineering:			
Fuel meat thickness (m)	1.05	1	1
Coolant channel area (m^2)	1	1.075	1.075
Power measurement (MW)	1.05	1.05	1.05
Calculated power density (W/m^3)	1.10	1.10	1
Coolant flow rate (Kg/s)	1	1.11	1.08
Heat transfer coefficient (W/m^2 °C)	1	1	1.33
Multiplicative combination	1.33	1.51	1.62
Statistical combination	1.14	1.19	1.35

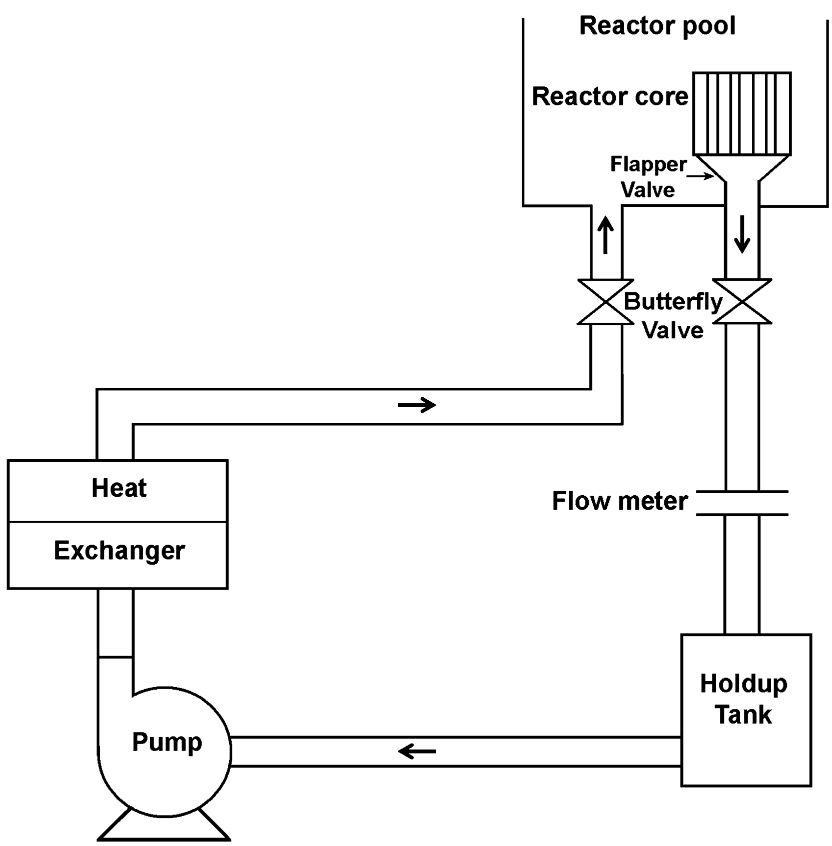

Fig. 1. TRR reactor containment and peripherals with emphasis on primary cooling circuit.