Loss-of-coolant accident in the fluidized bed nuclear power reactor

Kühlmittelverluststörfall in einem Wirbelbett-Kernreaktor

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For the purpose of developing an independent national nuclear technology and an effective manner of transferring such a technology, as well as developing a simple and safe nuclear power reactor, a reactor system based on fluidized bed concept is under study [1–3]. Here a preliminary analysis of the loss-of-coolant accident (LOCA) for this reactor is performed.

The reactor is modular in concept and consists of many vertical cylindrical calandria tubes. The zircaloy cladded one centimeter diameter spherical fuel pellets are made of uranium-thorium dioxide floating in an organic coolant contained in the tubes. The upper part of the tubes which constitute the reactor core have larger diameters than the lower part and contain the fuel in the fluidized state when the reactor is under operation. The upper and lower parts of the calandria tubes have diameter of 25 and 20 cm respectively. The reactivity change and thus reactor control is obtained by changing the coolant velocity and consequently varying the fuel-to-moderator ratio. The velocity of coolant can be maintained over a wide range. The lower limit is that necessary to transport the fuel pellets from the lower part to the core part of the reactor. The upper limit is that fluidize and expand the bed to the extent that would just transport or carry the solids out of the core.

The lower part of the tubes contain the fuel pellets under subcritical collapsed condition resulting from reactor shut down and the accident conditions such as LOCA. The lower part of the reactor is enclosed by a cylindrical stainless steel calandria which becomes flooded with water from accumulators in the case a loss-of-coolant accident occurs.

The heat transfer calculations are made for the case of loss-of-coolant accident and was found that under most pessimistic conditions, the decay heat is transferred to the water surrounding the lower part of the calandria tubes by natural convection without resulting an excess temperature rise anywhere in the reactor.

The time-dependent temperature distribution is obtained by solving the general heat conduction equation analytically [4].

$$\frac{d^2T}{dr^2} + \frac{1}{r}\frac{dT}{dr} + \frac{Q}{k} = \frac{1}{\alpha}\frac{\delta T}{\delta\theta} \qquad (1)$$

Where decay heat generation term Q is calculated from

$$Q = (3 - 0.003\theta)10^{-2}Q_0 \qquad 0 < \theta < 200 \text{ sec.}$$

$$Q = 0.095Q_0\theta^{-0.26} \qquad \theta > 200 \text{ sec.} \qquad (2)$$

assuming that the reactor has been in operation for a very long time before the accident. Q_0 is the volumetric heat generation rate immediately before the reactor shut down. A value of 60 W/cm³ is used for this analysis.

The boundary conditions used are

$$T(0,\theta) < \infty$$

$$\text{and} \qquad k\left.\frac{dT}{dr}\right|_{r=R} = h(T-T_f) \qquad (3)$$

where $T(0, \Theta)$ is the temperature at the center of the calandria tube of diameter R, at time Θ and T_f is the bulk temperature of water surrounding it. Other symbols are of usual convention.

After normalizing Eq. (1) and applying the separation of variables technique to the homogeneous part of the differential equation and using the orthogonality relation for Bessel function, the temperature distribution is found to be

$$T(r,\theta) = T_f + \frac{2QR^2}{k}\sum_{n=1}^{\infty} J_0\left(\frac{\lambda_n}{R}r\right)\frac{J_1(\lambda_n)\left[1-\exp\left(\frac{-\lambda_n\alpha\theta}{R^2}\right)\right]}{\lambda_n^3\left[J_0^2(\lambda_n)+J_1^2(\lambda_n)\right]} \qquad (4)$$

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