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# BRIEF COMMUNICATION

# THE CALCULATION OF DRYOUT IN A ROD BUNDLE—A COMPARISON OF EXPERIMENTAL AND CALCULATED RESULTS

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## 1. INTRODUCTION

Recently a method of calculating the dryout power for boiling two-phase flow in a nuclear reactor rod bundle was described by Whalley (1977); however only a limited series of comparisons with experimental data was given. Bailey & Lee (1977) have now published a summary of a large amount of experimental data on dryout in 37-rod bundles of the type used in the Steam Generating Heavy Water Reactor. A cross section of this bundle geometry is shown in figure 1. The rod bundles tested were 3.66 m long and were cooled by boiling light water. The diameter of the rods was 16 mm and the internal diameter of the pressure tube was 130.5 mm.

The calculations described here were performed using the method of Whalley (1977), where an annular flow model is used to calculate the liquid flowrate as a thin film on each of the heated rods. When one of these liquid film flowrates becomes equal to zero it is assumed that dryout occurs, and the heat-transfer coefficient may then drop to an unacceptably low value. The subchannel arrangement used in the calculations is shown in figure 1. All the calculations were performed with the liquid mass-transfer coefficients calculated from the surface tension using the graphical correlation given by Whalley (1977). The boundary conditions were also exactly as described previously. In particular the calculation was started at a quality of 1%, at which point it was assumed that 99% of the water was entrained into the steam as small drops. No alterations to the previously described method were made, except that a generalisation to allow for the effect of a non-uniform heat flux in the axial direction was made.

The experimental and calculated powers which could be applied to the bundle before dryout occurs, the dryout power, are now compared. The results are divided into sections describing

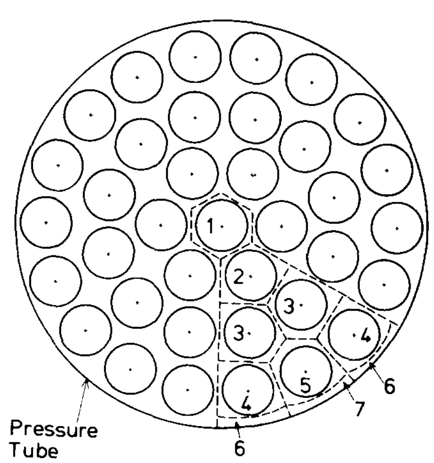


Figure 1. Thirty-seven-rod bundle, showing division into subchannels.

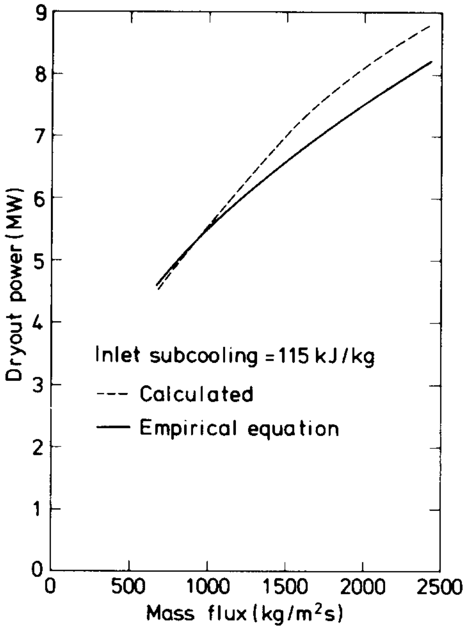


Fig. 2.

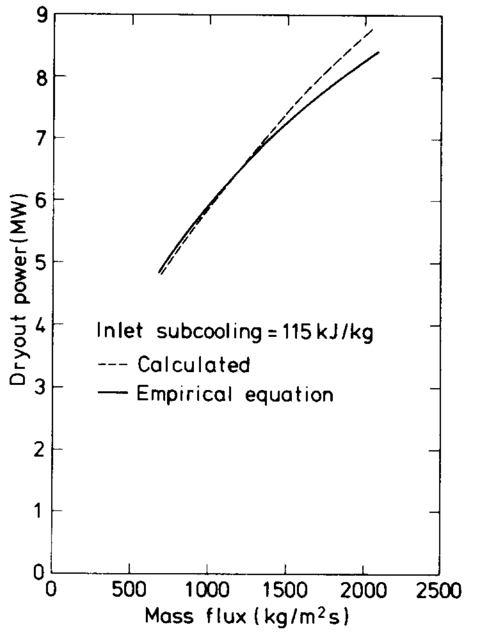


Fig. 3.

Figure 2. Experimental and calculated dryout power for a differentially enriched bundle (pressure = 68.3 bar).

Figure 3. Experimental and calculated dryout power for a differentially enriched bundle (pressure = 48.6 bar).

the effects on the dryout power of altering the system pressure and the mass flux of the water, the radial heat flux distribution, the axial heat flux distribution and the concentricity of the bundle in the surrounding pressure tube.

## 2. EFFECT OF PRESSURE AND MASS FLUX

Figures 2, 3 and 4 show the effect of mass flux on the dryout power at three different pressures when the bundle is heated to simulate a differentially enriched fuel bundle. This is a

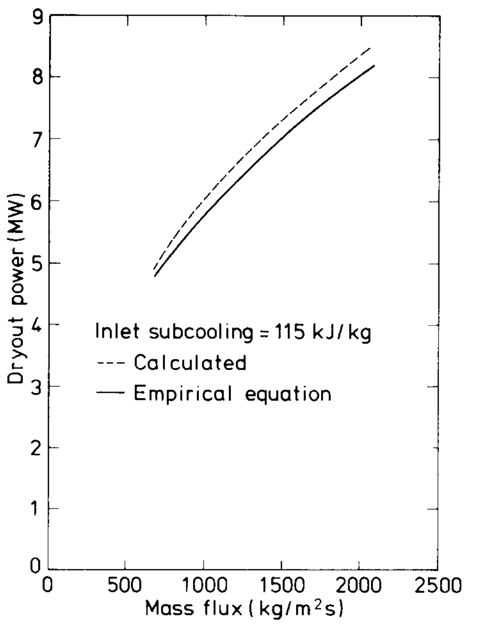


Figure 4. Experimental and calculated dryout power for a differentially enriched bundle (pressure = 28.3 bar).

bundle where there are rods containing two types of fuel with different enrichments of uranium-235. In the experiments and in the calculations it was assumed that the heat fluxes on the centre rod, the inner ring of 6 rods, the middle ring of 12 rods and the outer ring of 18 rods are in the ratio 0:0.8:1.0:1.0 in the reactor. The heat flux on each rod was constant in the axial direction. The experimental results are represented in figures 2, 3 and 4 by an empirical equation given by Bailey & Lee (1977) which fitted the data points with a root mean square error of 1.8%.

Dryout was calculated to occur first on the middle ring of 12 rods, and this was also found experimentally. The agreement between the experimental and calculated values of the dryout power is generally quite good: the root mean square error of the calculated values was approximately 7.5%.

The qualities at which dryout occurs for the results shown in figures 2, 3 and 4 was generally between 30% and 70%.

## 3. EFFECT OF RADIAL HEAT FLUX PROFILE

Bailey & Lee report on the differences between rods heated to simulate differentially enriched fuel (described in section 2) and single enrichment fuel. With single enrichment fuel there is only one type of fuel, and consequently the radial heat flux distribution is less uniform. It was assumed for single enrichment that the heat fluxes on the centre rod, the inner ring of 6 rods, the middle ring of 12 rods and the outer ring of 18 rods are in the ratio 0:0.57:0.66:1.0 in the reactor. Again the heat flux on each rod was constant in the axial direction.

Experimental and calculated results are shown in figure 5. For the single enrichment bundle,

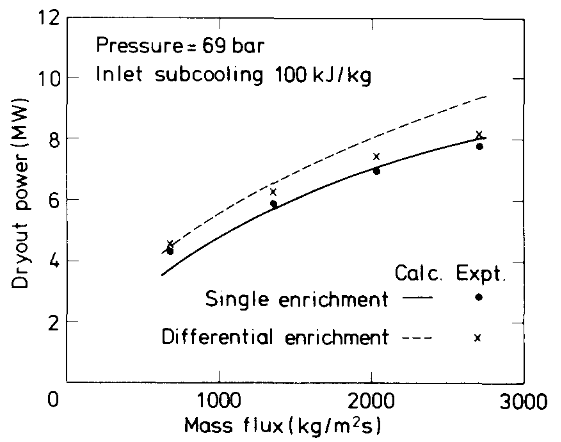


Figure 5. Effect of radial heat flux profile on dryout power.

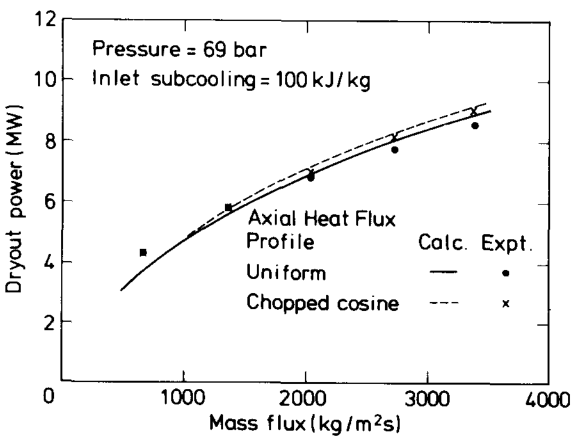


Figure 6. Effect of axial heat flux profile on dryout power.

dryout was calculated to occur first on the outer ring of 18 rods, and this was also found experimentally. The calculated results indicate that the differentially enriched bundles give higher dryout powers than do the single enrichment bundles, but the calculations overestimate the difference which was found experimentally.

## 4. EFFECT OF AXIAL HEAT FLUX PROFILE

Bailey & Lee report a series of experiments on a simulated single enrichment fuel bundle, where the effect of the heat flux variations in the axial direction was studied. In particular the difference between a uniform axial heat flux and a chopped cosine distribution was determined. A chopped cosine distribution is one in which the heat flux varies like a cosine wave, being a maximum half way along the bundle in the axial direction and a minimum at the ends. The heat flux is not allowed to go to zero, but the cosine wave is chopped at each end so that, in this case, the ratio of the maximum heat flux to the mean (the form factor) for each rod was equal to 1.38.

The experimental and calculated dryout powers are shown as a function of mass flux in figure 6. There was little difference in the overall dryout power for the two axial heat flux profiles. However it is found, both from the calculations and the experiments, that for the chopped cosine case the dryout position moves upstream as the mass flux is increased, whereas for the uniform heat flux case, dryout always occurs first at the end of the bundle.

## 5. BUNDLE ECCENTRICITY

Experimentally it was found that the dryout power for differentially enriched bundles was not sensitive to eccentric mounting in the pressure tube which surrounds the bundle. However for single enrichment bundles, eccentric mounting reduced the dryout power. The difference in behaviour was ascribed by Bailey & Lee to the possibility that, when dryout occurs on the middle ring of 12 rods (as in the differentially enriched case), the rods which dryout first do not feel the effect of the eccentricity because they are not adjacent to the pressure tube. However when dryout first occurs on the outer ring of 18 rods (as in the single enrichment case) the rods which dryout first are greatly affected by the eccentricity.

The effects of eccentricity could not be checked by calculation in the 37-rod bundle, as the high degree of symmetry is lost and there are now a large number of subchannel types. To calculate the possible effects of eccentricity, a 7-rod bundle (as in figure 7) was examined. The 7-rod bundle had the same rod diameter (16 mm) and the same overall mean hydraulic diameter

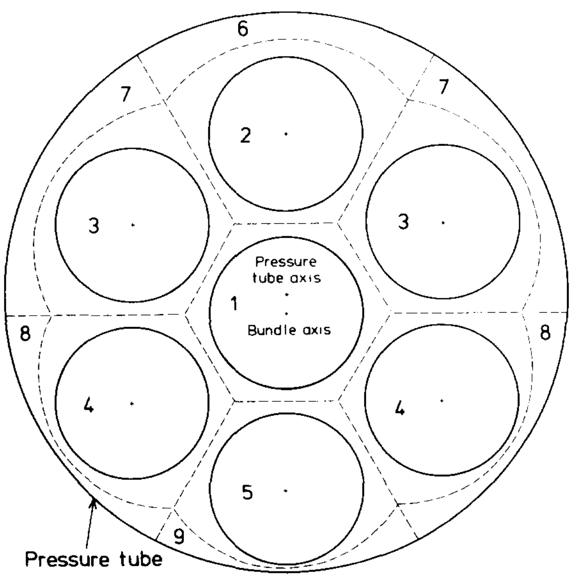


Figure 7. Eccentric 7-rod bundle, showing division into subchannels.

(10.5 mm) as the 37-rod bundle. All 7 rods were assumed to be heated; the heat flux on the centre rod was not necessarily the same as that on the 6 outer rods. In the calculations it was found that if dryout occurred on the centre rod with no eccentricity, then the introduction of eccentricity causes little or no variation in the dryout power, unless the eccentricity is large enough to move the dryout away from the centre rod. If dryout occurs on the outer rods with no eccentricity, then the introduction of eccentricity causes decreases in the dryout power of up to 25%, and dryout occurs in subchannel 5 (see figure 7). Subchannel 5 contains the rod which is nearest the pressure tube. Experimentally it is also found that dryout occurs where the heated rods are closest to the pressure tube.

## 6. CONCLUSIONS

The calculation method generally provides good results for dryout position and dryout power, and successfully takes account of variations of mass flux, pressure, axial heat flux distribution and, as far as can be ascertained, bundle eccentricity in the pressure tube. The effect on the dryout power of the variations of heat flux in the radial direction is less successfully calculated; this may be because the description of the cross flow mixing in the calculational model is quite crude. The calculation overestimates the effect of the radial heat flux profile, and this could be corrected by increasing the cross flow mixing. Such changes in the model were not made during this work, as these calculations were primarily intended as domonstrations of the results obtained without any tuning of the parameters of the model.

## REFERENCES

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