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Experimental Determination of Local Steam Bubble Velocities
in BWR Fuelelements

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Summary

Results are presented for the experimental determination of local steam bubble velocities and of the local steam void content in the core of B Boiling Water Reactor Lingen. The local steam bubble velocity was determined by 3 SPN-detectors, moveable over the core-height, by applying correlation analysis. Furthermore a method is described by which the intensity of the fluctuating signal (RMS-values) is used to derive the local steam void content as function of core-height. The experimental results are compared to theoretical calculations and show very good agreement.

Experimental Analysis

The experiments were performed in a near central fuel element position of the Lingen BWR. Three neutron detectors of the SPN-type /1/ were located in different axial locations. In addition a U^{235} Ionisation chamber could be used to determine the axial power profile.

During operation at full power the signals from the various detector positions (which could be varied during operation) were stored on an analogue magnetic tape; the information was transformed into digital form for processing in a digital computer.

To determine the average steam bubble velocity, a cross-correlation analysis of the signals from detectors in neighbouring cooling channels at neighbouring axial positions was performed. This is shown schematically in Fig. 1.

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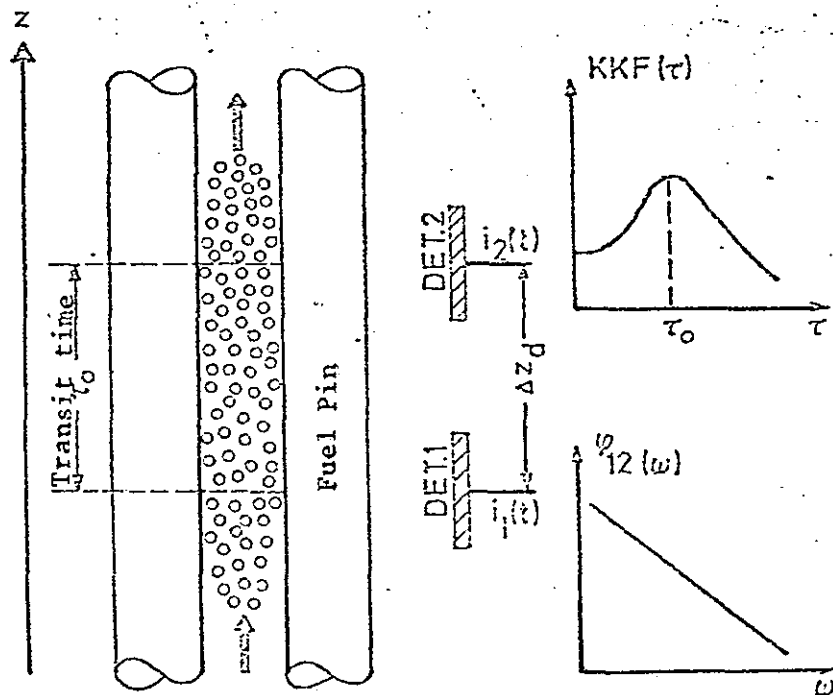


Fig. 1: Correlation Analysis of Detector Signals

The maximum of the cross-correlation function KKF yields the average transit time τ_0 of a steam bubble from detector 1 to detector 2. τ_0 can also be determined from the phase shift ϕ_{12} of both the correlated detector signals. The slope of the curve ϕ_{12} in dependence from frequency results in the average transit time τ_0 .

In Fig. 2 the radial distribution of neutron flux in fuel pin and coolant channel is shown qualitatively together with a local void region. The gradient of neutron flux is important for the reactivity feed back of the void content. The flux variations due to the bubble growth and transport is given by the normalized RMS-value of the detector signals $i(t)$: $RMS = \frac{1}{i} \sqrt{\overline{i^2}} |z|$. On the other hand the RMS value is connected with the local void content according to

$$RMS = c \left\{ \alpha^2(z) + g \left(\frac{\Delta\alpha(z)}{\Delta z} \cdot \Delta z \right)^2 \right\}$$

- with:
- $\alpha(z)$ = steam content at z
 - $\Delta\alpha(z)$ = increase of steam content at z due to additional bubbles created at z
 - g = weighting factor
 - c = constant

The first term corresponds to the transport of bubbles, the second to the additionally created bubbles.

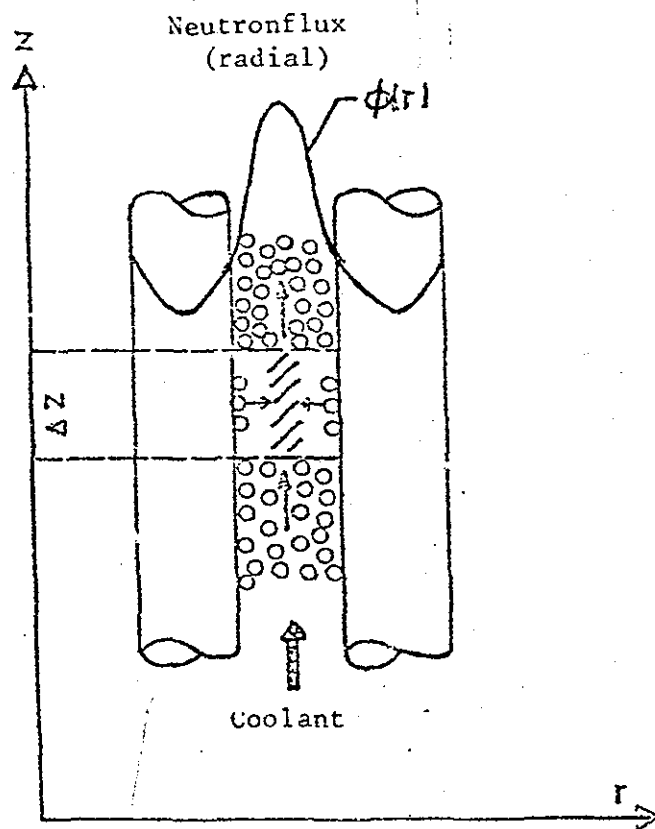


Fig. 2: Local Void Content

The frequency interval to be investigated in this content is between 2 and 40 cps.

Results

In Fig. 3 one of the results obtained in KWL is shown. The curve to the left shows the axial neutron flux profile. The steam bubble velocity, as seen in the curve to the right, varies between 2.9 m/s to 7.4 m/s. The stronger variations in this curve occur near spacer grids.

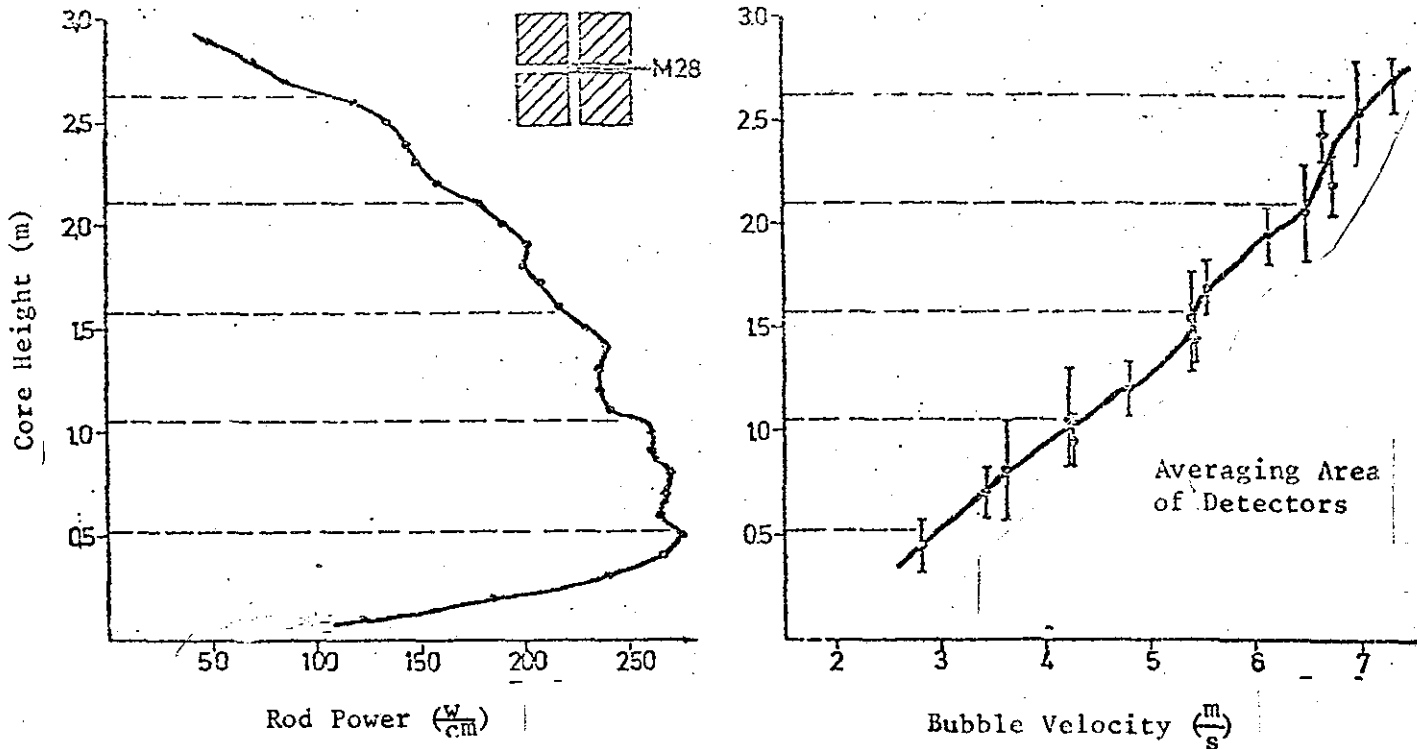


Fig. 3: Measured Average Bubble Velocity

In Fig. 4 calculated and measured bubble velocities are compared

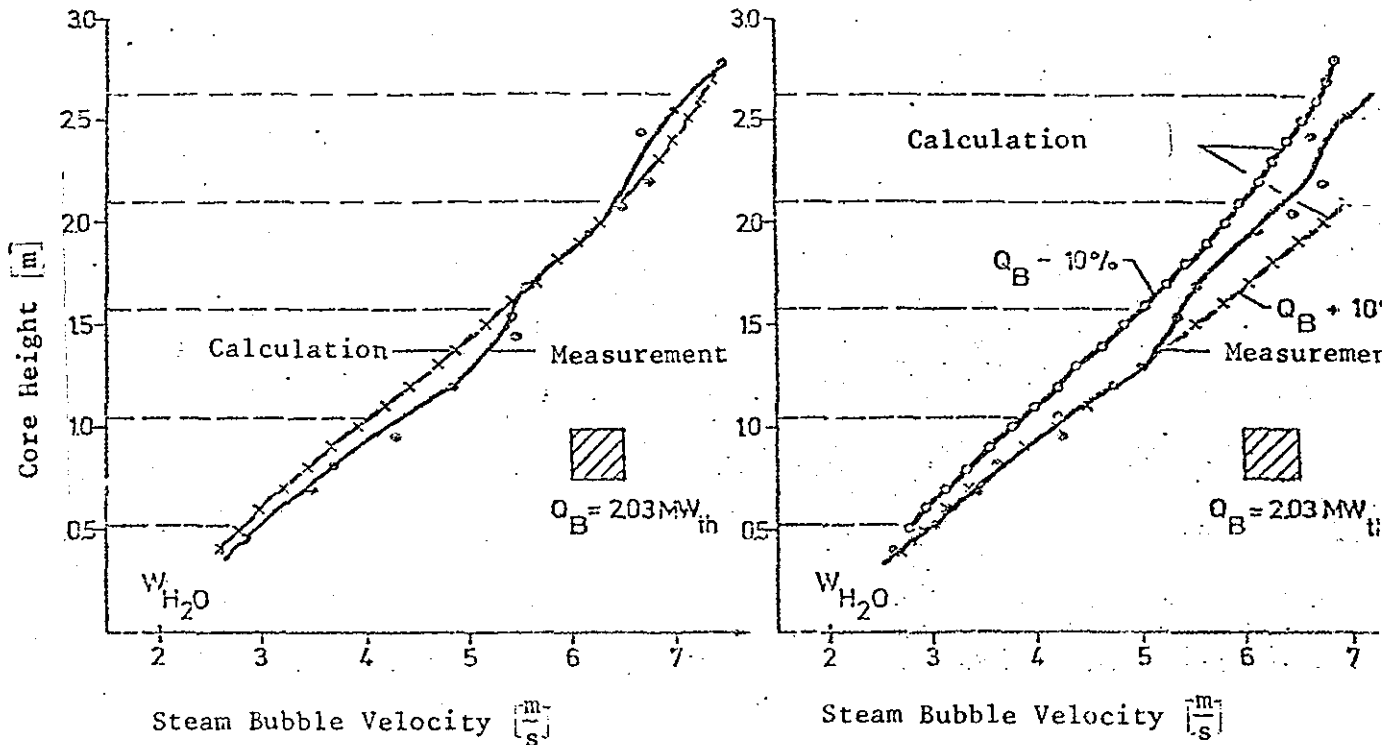


Fig. 4: Measured Averaged Bubble Velocity

The calculation is based on the thermohydraulic properties of a 6x6 fuel element with two phase flow, using the related thermodynamic relations from ref. /2/ to /5/. The best agreement between theory and measurement is obtained for a fuel element power of $Q_B = 2.03 \text{ MW}_{th}$ (Fig.4, left). In the right part of Fig. 4 The calculations were performed also for a 10 % higher and 10 % lower Q_B .

The measured local steam content is given in Fig. 5

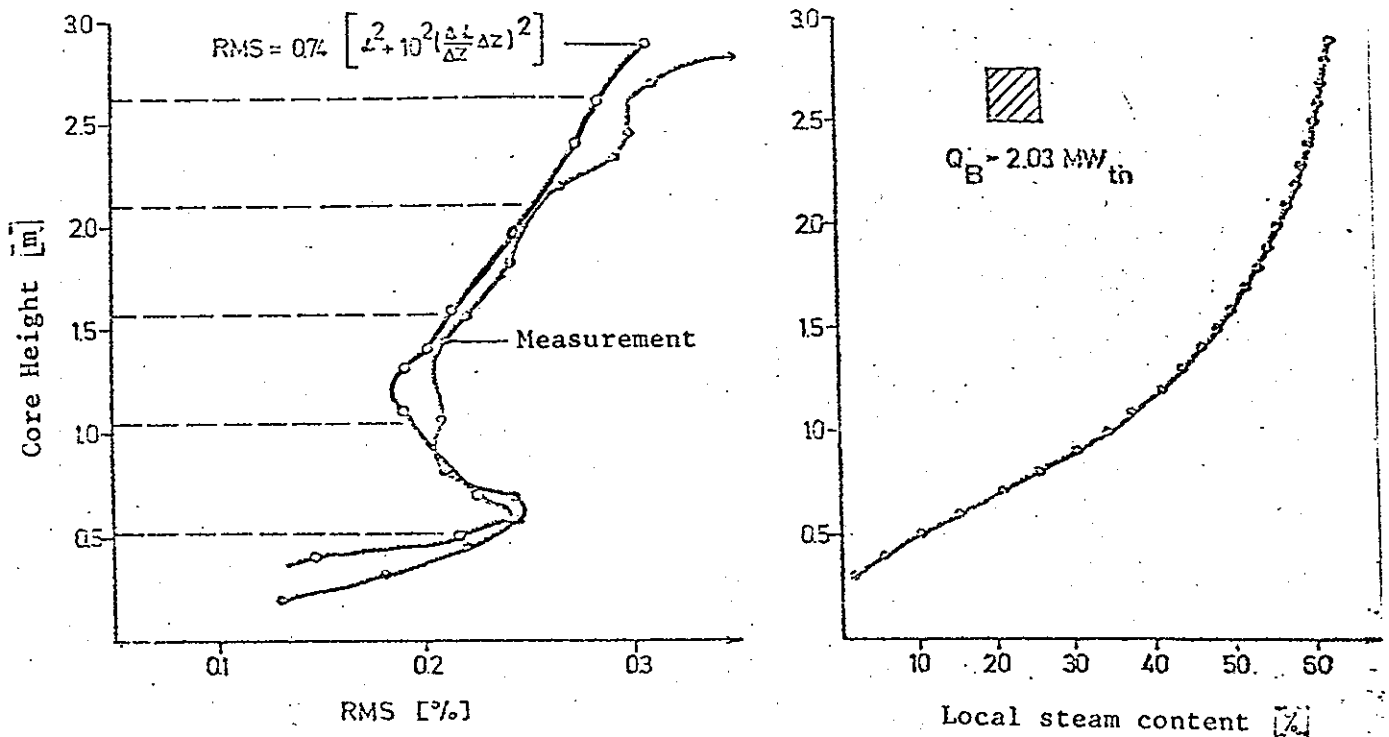


Fig. 5: Determination of Local Steam Content

The experimental curve shows a maximum at 65 cm above lower core edge. The theoretical curve agrees rather well with the experimental except near the positions of spacer gids, which are not included in the calculation.

The value of the local void content depends on the axial distribution of the power density, on the absolute value of the power density and on the coolant mass throughput.

In conclusion, the average steam bubble velocity can be determined to an accuracy of about 3 %; therefore changes in the thermohydraulic behaviour can be detected by the procedure outlined in this paper. The same is true via determination of local steam void contents. The sensitivity of these tools are not yet assessed completely.

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