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NUCLEATE BOILING CHARACTERISTICS AND THE CRITICAL HEAT FLUX OCCURRENCE IN SUBCOOLED AXIAL-FLOW WATER SYSTEMS

by

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basis of a stratified bubble flow, the separative action of the flow-stream-velocity profile tending to segregate the bubbles in a sub-boundary layer adjacent to the zone of interfacial turbulence. With the degree of segregation increasing directly with mass velocity, the sub-boundary bubble layer increasingly absorbs the mixing action of the nucleation turbulence, with resulting decreases in the heat transfer, critical heat flux, and flow friction.

Gunther,[11] whose low-pressure, critical heat flux data show a steep dependency on linear subcooling similar to that in Fig. 10, reports visual observation of bubble segregation on or near the transfer surface at high local subcoolings, the bubbles traveling at approximately 80% of the flow stream velocity. Figure 16 shows a correlation of these data in a form similar to that of Eq. (7), the differing flow regimes requiring changes in the coefficient, mass velocity, and subcooling terms:

$$Q_c''/10^6 = 1.75\ D_e^{-1/2}\ (H_{fg}/10^3)(1 + G/10^6)^{1/2} \left(\frac{H_f - H}{100}\right) \quad . \qquad (8)$$

With the equivalent diameter evaluated on the basis of the boiling surface only, the validity of the latent heat and equivalent-diameter terms is illustrated by the comparison with the ANL and BMI data from small tubes at 200 and 2000 psia. The mass-velocity term was empirically determined, and its proportional difference from Gunther's original velocity term is generally small; the linear approximation of the subcooling is retained from the original.

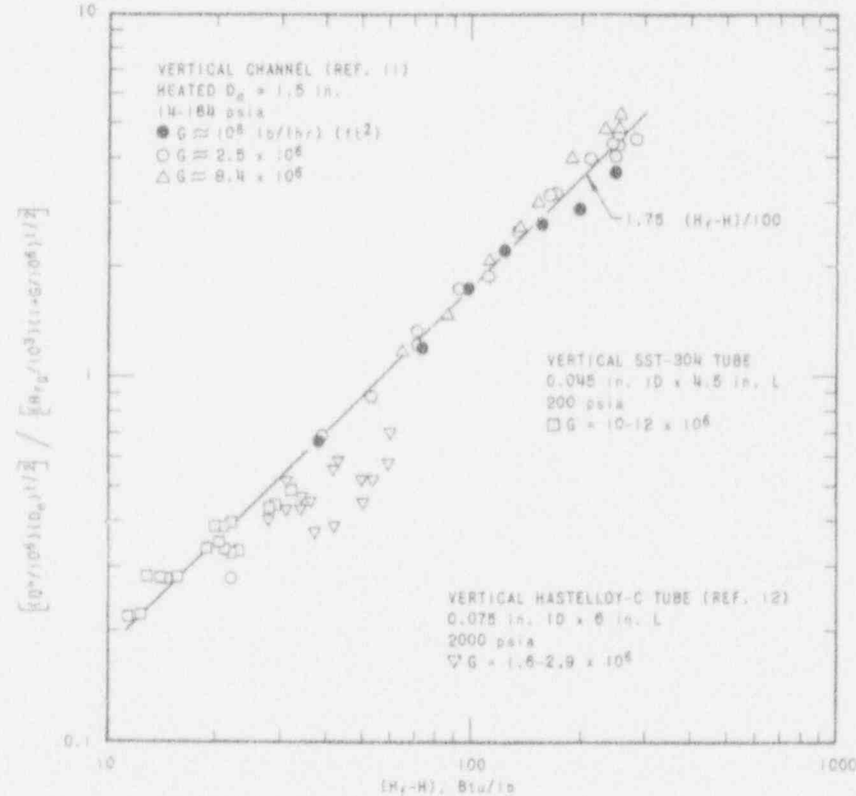

Fig. 16. Comparison of Low- and High-pressure Critical Heat Flux Data with Eq. (8)

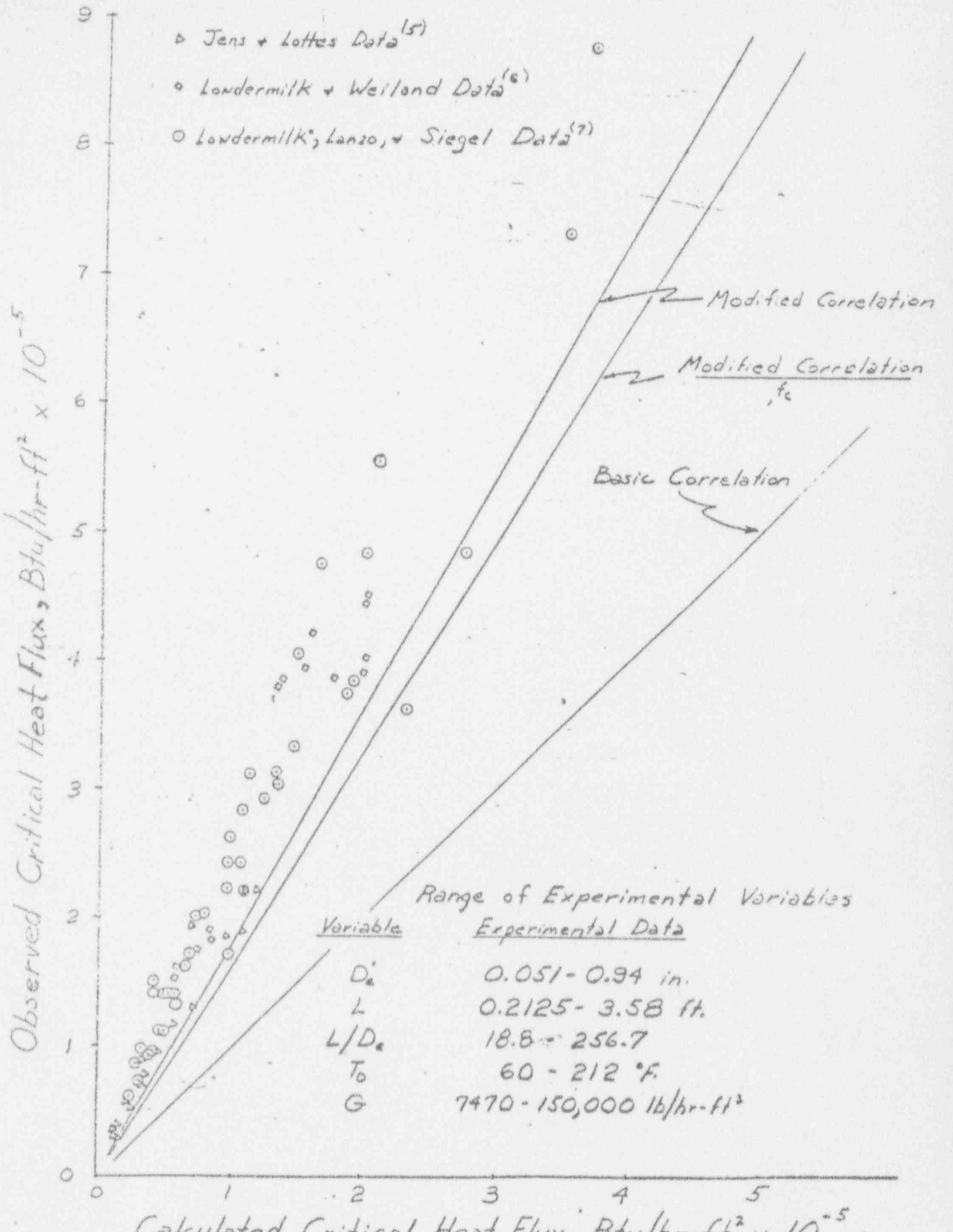

FIGURE 1 EXPERIMENTAL BURNOUT DATA COMPARED TO VALUES CALCULATED FROM BASIC CRITICAL HEAT FLUX CORRELATION

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RESEARCH REACTOR CORE CONVERSION FROM THE USE OF HIGHLY ENRICHED URANIUM TO THE USE OF LOW ENRICHED URANIUM FUELS

GUIDEBOOK

PREPARED BY A CONSULTANTS' GROUP,
COORDINATED AND EDITED BY THE
PHYSICS SECTION
INTERNATIONAL ATOMIC ENERGY AGENCY

A TECHNICAL DOCUMENT ISSUED BY THE
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Empirical Correlations

Whittle and Forgan [34] measured the mass flow, exit temperature, and pressure drop corresponding to the minima in the pressure drop versus flow rate curves for subcooled water flowing (upward and downward) in narrow heated channels (width 2.54 cm, thickness 0.14 to 0.32 cm, length 40 to 61 cm) under the following conditions:

$$17 \leq P_{exit} \leq 25 \text{ psia}$$

$$83 \leq \frac{L_H}{D_H} \leq 190$$

where

L_H = heated length of channel

D_H = heated equivalent diameter of channel

$$= 4 \times \frac{\text{Channel Flow Area}}{\text{Channel Heated Perimeter}} = 2\, t_w\, W/(t_w + W_H)$$

Based on these measurements the following correlation was proposed:

$$R = \frac{T_{out}-T_{in}}{T_{sat}-T_{in}} = \frac{1}{1+\eta\,\frac{D_H}{L_H}} \tag{19}$$

A value of $\eta = 25$ was determined as a best fit to their data. Further discussion of η is provided in the next subsection on bubble detachment and flow instability. The average heat flux at onset of flow instability can be expressed in terms of velocity, channel geometry, temperatures, and fluid properties:

$$\overline{q}_c = \frac{R}{2}\,\rho\, C_p\, \frac{W\, t_w}{W_H\, L_H}\, U\, (T_{sat} - T_{in}) \tag{20}$$

The peak critical heat flux can be obtained by multiplying $\overline{q}_c$ by the axial peak-to-average factor, f_a.

In order to clarify the use of Eq. 19, we note the following:

1. The effect of channel entrance losses, which is a strong stabilizing factor[35] for the system, is not included in the correlation. Thus, the system could be more stable than the correlation predicts.
2. Since pressure drop characteristics are not required, the accuracy of the prediction does not depend on two-phase correlations (subcooled void fraction, pressure drop, and heat transfer coefficient). All two-phase effects are included in the parameter η.
3. The phenomenon is sensitive to system pressure through the saturation temperature, T_{sat}.
4. The scatter in the Maulbetch and Griffith data[33] used by Forgan and Whittle to extend their correlation to lower ratios of L_H/D_H increases to about ± 30% at $L_H/D_H \sim 25$.

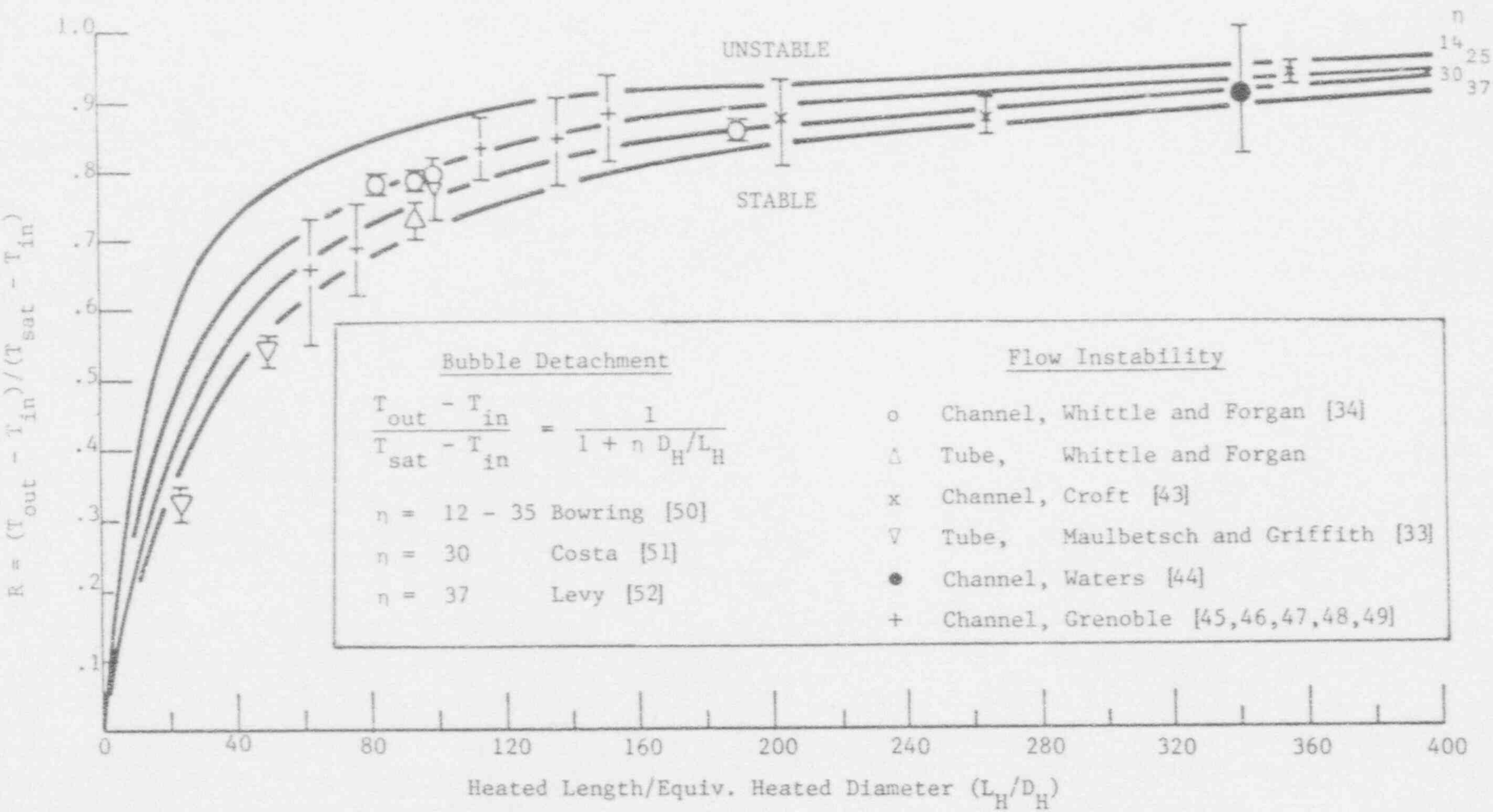

Figure A9. Correlation for Flow Instability and Bubble Detachment