REFERENCE

1. A. J. Goldman, A feasibility study of fast $U^{233}$–Th breeder reactors. NDA 2134-3 (October 10, 1960).

Arthur J. Goldman

*Nuclear Development Corporation of America*
*White Plains, New York*
*Received December 30, 1960*

## Re: The Application of Statistical Methods of Analysis for Predicting Burnout Heat Flux

The statistically derived prediction method for burnout heat flux proposed by Jacobs and Merrill in the December issue (*1*) appears to contain certain features which call for further elaboration. The over-all correlation (*1*), Formula No. 8 of Fig. 12, e.g., contains 14 positive and 10 negative terms, and the burnout heat flux is obtained numerically as an often small difference between two large numbers. The associated sensitivity of the solution can be considerable for certain combinations of the variables.

Of particular interest is the effect of tube diameter on burnout heat flux when all other independent variables are held constant at their midranges, shown in Fig. 14 of reference 1. The large dependence shown completely lacks substantiation. In fact, direct experimental studies of the diameter effect have been made at the Savannah River Laboratory (*2*), and for subcooled low-pressure water flow in heated annuli with the flow gap varied from $\frac{1}{16}$ to $\frac{3}{8}$ in. and heated length fixed at 24 in., no effect on burnout was observed. Similar studies have been reported in the Russian literature (*3*) for subcooled water at 40 atmospheres flowing in a rectangular test section; as flow gap was decreased from 0.079 to 0.008 in., no effect on burnout was noted until the gap reached 0.028 in. Other Russian studies (*4*) with high-pressure water and tubular test sections of 0.157 to 0.473 in. i.d. indicated the same absence of a diameter effect. These three independent studies, made with annular, rectangular, and tubular test sections in a pressure range of 3 to 220 atmospheres, strongly suggest that a diameter effect is encountered only when the flow gap dimension becomes comparable to bubble dimensions. In the individual studies used for development of the burnout correlation of reference 1, diameter was held constant; and the apparent diameter effect, obtained by correlation of different sets of data, appears spurious.

The inapplicability of the prediction method (with the present constants) to rectangular channels is indicated by comparisons we have made between recent pertinent ORNL data (*5*) and the prediction equation. With all variables selected within the ranges used for development of the equation, the experimental values are $\backsim$1.7-fold larger than the corresponding calculated values. Whereas $L$ and $D$ are associated with surface area for round tubes, thereby incorporating, indirectly, enthalpy increase to the burnout point and allowing use of inlet bulk temperature, such is not the case with the length and equivalent diameter of rectangular channels.

Extrapolation of the proposed correlation (*1*) beyond the range of the data used in its development should scrupulously be avoided, as indicated by the authors. To illustrate the extreme danger inherent in carrying such an arbitrarily derived relation beyond its stated limits, a particular example may be cited. In a very high velocity (172 fps) subcooled burnout test conducted at ORNL (*6*), an experimental burnout heat flux of $17.25 \times 10^6$ Btu/hr ft$^2$ was attained. The conditions of this test were such that only the tube diameter was in the recommended variable range for the prediction equation, which gave a positive error of 1127%. The simpler "local phenomenon"-type equations of Gunther (*7*) and of Bernath (*8*) [a type of equation much chastised in reference (*1*)] gave errors of $-30.9\%$ and $-18.9\%$, respectively. It would thus appear that some of the functional relations expressed by Formula No. 8 of reference 1 are seriously in error. If so, one might question the adequacy of the variable ranges cited as an application criterion, and use of the correlation in an untested region of Fig. 13 (*1*) could give erroneous results.

The authors should state where the coolant pressure is to be evaluated, since axial pressure gradients may be large enough to make site selection important. An extreme combination of the recommended variable ranges gives an isothermal $\Delta P$ of 70 psi, too large to be neglected. Similarly, a statement should be made concerning the applicability of the correlation to the bulk-boiling regime. The data in references 7 and 14 of the paper, e.g., primarily relate to tests with net steam generation, with only 8 of the tests of reference 14 conducted in the subcooled region. I assume that the method is applicable only to local-boiling burnout.

REFERENCES

1. R. T. Jacobs and J. A. Merrill, *Nuclear Sci. and Eng.* **8,** 480 (1960).
2. S. Mirshak and W. S. Durant, private communication to W. R. Gambill, January 29, 1960.
3. N. L. Kafengauz and I. D. Bauaror, *Teploenergetica,* **3,** 76–78 (1959).
4. B. A. Zenkevich, *J. Nuclear Energy,* Part B: Reactor Technology, **1,** 137 (1959).
5. W. R. Gambill and R. D. Bundy, ORNL report, 1960 (not yet released).
6. W. R. Gambill, R. D. Bundy, and R. W. Wansbrough, ORNL-2911, Table 2 (test No. 10) (1960).
7. F. C. Gunther, *Trans. Am. Soc. Mech. Engrs.* **73,** 115 (1951).
8. L. Bernath, Preprint No. 110, Third National Heat Transfer Conference, ASME-AIChE, Storrs, Connecticut (August, 1959).

W. R. Gambill

*Oak Ridge National Laboratory*
*Oak Ridge, Tennessee*
*Received January 19, 1961*

## Re: The Application of Statistical Methods of Analysis for Predicting Burnout Heat Flux—Rebuttal

Mr. Gambill has raised several questions concerning the work reported in our recent article (*1*) which appeared in this journal. The following points have been raised·

1. Where was the pressure evaluated?

2. Is the equation applicable to the bulk boiling region?

3. The sensitivity of the equation is questioned when the burnout heat flux obtained is often a numerically small difference between two large numbers.

4. The effect of diameter in the equation lacks substantiation.

5. The equation is not applicable to rectangular cross-sectional channels.

6. The equation will not extrapolate past the limits of the data used in its derivation, and therefore, the functional relationship used must be wrong.

All data used evaluated pressure at the tube outlet. If inlet pressure had been available, we would have preferred its use over outlet pressure.

Of the 946 pieces of data used in the derivation, 317 pieces were for subcooled water at the outlet and 629 pieces were for quality outlet.

Concerning the question raised about the reliability of a result which is obtained by taking the difference between two fairly large numbers where the result is small in comparison with the two numbers being differenced; in general, if $C = A - B$, the question should not be the magnitude of $A$ and $B$ but rather the uncertainty associated with $A$ and $B$ as well as the covariance between $A$ and $B$ which together define the uncertainty in $C$. As long as the uncertainty in $C$ is acceptable in view of the requirements of the practical problem under consideration, then the process of taking $A$ minus $B$ should be acceptable. Based on the variances (and the covariances) of the estimated constants in the formula as well as an estimate of the experimental variance, a computer program has been written which will compute the uncertainty associated with a caculated burnout heat flux obtained using formula No. 8.

The authors are aware of the difficulties involved in analyzing data from several different experimenters which were not obtained according to an over-all experimental design. In an analysis of such data, it is possible to confound differences between experimenters with some of the effects to be estimated. Therefore, if systematic differences between experimenters were present in the data used for our analysis, then some of the coefficients in formula No. 8 could be in error thus providing biased predictions even when the formula is used within the ranges of the variables for which it was intended. In addition, data which has been obtained with no over-all design program to govern which experimental runs are required from the standpoint of the analysis of the data frequently have other deficiencies. Quite often the distribution of the data over the particular volume of the experimental space to be investigated is not adequate to provide high precision estimates of the effects. Also, because of poor distribution of the data, it is possible to have confounding of effects.

The effect of diameter that is found in formula No. 8 may be spurious because of the above reasons. However, it is interesting to note that in a similar analysis of the rectangular channel data from the WAPD-188 (*2*) report which we have recently made, the effect of spacing between plates (which would appear to be an effect similar to diameter) was found to be significant.

It should also be pointed out that length and diameter especially, as well as the other system parameters, have an entirely different functional relationship in a "local phenomenon" type of equation than they do in an equation where only independent system-describing variables are used. This may account for the fact that Mr. Gambill finds no diameter effect in his studies, while ours shows a definite effect.

As was reiterated by Mr. Gambill, our article pointed out that the correlations therein should not be used outside the range of variables in the set of data used for their derivation; but the fact that this method of correlation is questioned because it will not extrapolate and because it is not applicable to rectangular channels indicates that Mr. Gambill is looking upon our formula as a fundamental relationship that is supposed to be universal for all geometries, all heating patterns, and all levels of the variables. But, it is our contention that differences in geometry and heating patterns should be recognized as significant variables. Since the authors do not know of a set of variables which can successfully be employed to bridge the gap between different cross-sectional geometries and different heating patterns, these different cases are considered as separate problems and no attempt was made to derive a universal formula. Instead a polynomial type approximation to an unknown (and the authors believe a complicated) functional relationship was derived, using, in so far as possible, only independent variables of the system for a specific heating pattern, a specific geometry, and a specific range of the variables. No claim is made that the formula is applicable to other systems. Since the data used in the analysis performed by the authors did not, in many ways, conform to an optimum design, the authors make no claim that formula No. 8 is the ultimate answer for burnout in the range of parameters studied. Given data from a designed experimental program, more precise estimates of the parameters in a polynomial approximation could be obtained, and the possibility of spurious correlations could be removed. Also, even in those cases where a polynomial is a reasonably good approximation of a complicated functional relationship in one region of parameter ranges, there is no guarantee that it will do an adequate job of representing the function in other regions. Therefore, when approximations are employed, extrapolation can never be recommended.

The object of our work was to point out a general method of analysis for burnout heat flux data. It was hoped that the successful attainment of a closer correlation for a wider range of data than had heretofore been done would be an indication that the goal of precise burnout heat flux predictions with accompanying limits of uncertainty could be successfully attained by statistically designed experiments.

## REFERENCES


*1.* R. T. Jacobs and J. A. Merrill, *Nuclear Sci. and Eng.* **8**, 480 (1960).

*2.* R. A. DeBortoli, S. J. Green, B. W. LeTourneau, M. Troy, and A. Weiss, Forced convection heat transfer burnout studies for water in rectangular and round tubes at pressures above 500 psia. WAPD-188 (October, 1958).



R. T. Jacobs
J. A. Merrill

*Phillips Petroleum Company*
*Idaho Falls, Idaho*

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