AN ASSESSMENT OF PREDICTION METHODS OF CHF IN TUBES WITH A LARGE EXPERIMENTAL DATA BANK

L.K.H. Leung and D.C. Groeneveld
Chalk River Laboratories
AECL Research
Chalk River, Ontario
K0J 1J0

Abstract

An assessment of prediction methods of CHF in tubes has been carried out using an expanded CHF data bank at Chalk River Laboratories (CRL). It includes eight different CHF look-up tables (two AECL versions and six USSR (or Russian) versions) and three empirical correlations. These prediction methods were developed from relatively large data bases and therefore have wide range of application. Some limitations, however, were imposed in this study, to avoid any invalid predictions due to extrapolation of these methods. Therefore, these comparisons are limited to the specific data base that is tailored to suit the range of an individual method. This has resulted in a different number of data used in each case.

The comparison of predictions against the experimental data is based on the constant inlet-condition approach (i.e., the pressure, mass flux, inlet fluid temperature and tube geometry are the primary parameters). Overall, the AECL tables have the widest range of application. They are assessed with 21 771 data points and the root-mean-square error is only 8.3%. About 60% of these data were used in the development of the AECL tables. The best version of the USSR/Russian CHF table is valid for 13 300 data points with a root-mean-square error of 8.8%. The USSR/Russian table that has the widest range of application covers a total of 18 800 data points, but the error increases to 9.3%. The range of application for empirical correlations, however, are generally much narrower than those covered by the CHF tables. The number of data used to assess these correlations is therefore further limited. Among the tested correlations, the Becker and Persson correlation covers the least amount of data (only 7 499 data points), but has the best accuracy (with a root-mean-square error of 9.71%).

1. INTRODUCTION

In the thermal analyses of water-cooled nuclear reactors, critical heat flux (CHF) is a key parameter for establishing the safety margin and operating level. While several bundle-specific correlations have been derived for predicting CHF in a normal string of 37-element CANDU bundles under normal operating conditions, a subchannel code (such as ASSERT [Kiteley et al., 1991]) is the ideal tool for thermalhydraulic analysis of a fuel channel containing abnormal bundle geometries and conditions beyond the bundle-specific data bases. The most common examples of geometric variation are the increase in element size due to fuel-clad diametral strain, and in pressure-tube size due to diametral creep strain.

A subchannel code is used mainly to calculate the local parameters (i.e., pressure, mass flux, and quality) in individual subchannels within a bundle. Based on these parameters, the subchannel CHF is determined from either empirical prediction methods or semi-analytical models derived for tubular geometries. Therefore, the success of a well-validated subchannel code in predicting CHF (dryout power or critical channel power) in a bundle string depends strongly on the accuracy of the CHF prediction method or model used. The semi-analytical CHF models are usually not recommended, due to their complex nature.

A review of available prediction methods for CHF has been presented by Groeneveld and Snoek [1986]. As far as semi-analytical models are concerned, only a few are available and each of them is derived for a specific dryout mechanism. No model is available for the transition region between different mechanisms. CHF models are usually not recommended in subchannel codes, due to their complex nature and limited range of validity. In contrast to CHF models, there is an overwhelming number of empirical CHF correlations in existence. Groeneveld and Rousseau [1982] estimated a total of about 400 correlations available for predicting CHF in tubes. Most of these correlations are derived from limited data bases and therefore are restricted to their range of application only. Extrapolation of these correlations to conditions outside the data base, though unjustified, is common practice, and often results in unrealistic predictions (e.g., negative CHF). During the past decade, effort has been focused on deriving generalized prediction methods that are valid for a wide range of flow conditions. Among them, the AECL CHF look-up table, developed by Groeneveld et al. [1986], covers the widest range.

The AECL 1986 CHF look-up table presents CHF values, for an 8-mm uniformly heated tube with an internal upward flow of water, for discrete pressures, mass fluxes and qualities. Correction factors were introduced to account for various parametric effects on CHF: tube-diameter values other than 8 mm, horizontal flow, flow transients, non-uniform heat-flux profiles (both circumferentially and axially), etc. This table has been independently assessed and recommended by HTFS [1992] and ESDU [Smith, 1986]. It is presently employed in reactor-safety and subchannel codes such as RELAP5/Mod3 [Weaver et al., 1991], CATHARE [Bestion, 1990], CATHENA [Richards, 1992], ASSERT [Kiteley et al., 1991] and THERMOHYDRAULIK [Ulrych, 1993]. When using the fluid-to-fluid modelling parameters [Groeneveld et al., 1992], the look-up table has also been found valid for fluids other than water.

Since 1986, the CHF data base at Chalk River Laboratories (CRL) has increased significantly. New data have recently been introduced (e.g., Yin et al. [1988], Dell et al. [1969], etc.) into the data base. Also, a data-exchange agreement was arranged with IPPE, Obninsk, resulting in a transfer of 14 787 CHF data points of steam-water flow in vertical tubes to CRL. After eliminating duplicate data (data with the same run name, pressure, mass flux, quality and CHF) from the two data bases (i.e., CRL and IPPE), the total number of CHF data in the CRL data base increased to 28 017.

With this expanded data base, a re-assessment of available prediction methods for CHF is carried out to examine the validity of previous recommendation. The objective of this paper is to present the results of the assessment for 11 different CHF prediction methods for tubular geometries.

2. CHF DATA BASE

The CHF data contained in the CRL data base were obtained from a number of laboratories and universities in many countries. As indicated above, a large number of data was recently added to the data base through an exchange with IPPE, Obninsk, Russia. Some duplications were noted among the combined data base, as part of the data contained in the Russian data base were present in the original CRL data base. The complete data base was examined and duplicate data removed. A screening process, based on a 5% maximum difference criteria between the experimental CHF and the heat-balance heat flux, was also introduced, to eliminate data that do not meet the heat-balance calculation. The heat-balance heat flux is expressed as

$$q_{heat-balance} = \frac{(x\, H_{fg} + \Delta H_{in})\, G\, D}{4\, L} \qquad (1)$$

where x is the thermodynamic quality, H_{fg} is the latent heat of vaporization in $J.kg^{-1}$, ΔH_{in} is the inlet subcooling in $J.kg^{-1}$, G is the mass flux in $kg.m^{-2}.s^{-1}$, and D and L are the diameter and heated length of the tube, respectively, in m. A total of 28 017 data from 45 different studies are included in the CRL data bank. The overall range of conditions is:

Diameter : 0.620 - 92.40 mm
Heated Length : 0.011 - 20.00 m
Pressure : 0.100 - 21.20 MPa
Mass Flux : 0.006 - 24.27 $Mg.m^{-2}.s^{-1}$
Dryout Quality : -1.652 - 1.577 -
Inlet Subcooling : -1211. - 2711. $kJ.kg^{-1}$

Most of the CHF data are obtained within a relatively narrow range of conditions. Figure 1 shows the range of conditions covered by the data base. A high density of data is observed in the high-pressure/high-quality, high-mass-flux/low-quality, low-mass-flux/high-quality regions, and for a diameter range between 4 and 12 mm.

A quick examination of the above range of conditions indicates the presence of questionable data; e.g., a few experimenters reported (after applying a heat balance) CHF measurements at qualities greater than 100%, while others reported a very short heated length (as low as 11 mm). To avoid the effect of heated length on CHF, data having a small heated-length/diameter ratio, where the local-condition approach becomes invalid [Collier, 1981], are not included in this analysis. The selection of criteria for this ratio is also difficult. Doroshchuk et al. [1975a] suggested that the effect of heated length on CHF diminishes when the ratio is larger than 20. However, the experimental data shown in Collier [1981] indicate a much larger ratio (to about 80). In this study, a value of $\geq$ 80 is used as the criteria, to ensure that the heated-length effect will not be a factor. Furthermore, data obtained with a two-phase flow at the inlet are not used, because the measured CHF values may be affected by the type of mixing devices used to combine the two phases. As a result, only 21 921 CHF data are used in the assessment.

Some of the data sets included in the data base may have a high uncertainty, due to the inferior loops or instrumentation and/or questionable test procedures. However, it is difficult to categorise any set as good or bad data. Thompson and Macbeth [1964] discarded and corrected some of the inconsistent data in their collection. Their compilation of data (2356 data points) may be more reliable and, therefore, is used in this study instead of the original data. Unless specifically reported by the authors, there is usually insufficient evidence to discard any data set. Unfortunately, the presence of the less accurate data sets will increase the uncertainty in CHF predictions.

3. ASSESSMENT OF CHF LOOK-UP TABLES

A number of CHF look-up tables have been developed recently. They are listed below chronologically.

1971 - Becker tabulated a dimensional parameter calculated with his complex correlation for a 10-mm tube [Becker and Persson, 1963] as functions of pressure and quality. The correction factor for diameter difference was presented graphically for diameter values ranging from 4 to 25 mm. This table was not published [Becker and Soderquist, 1992].

1975 - Doroshchuk et al. [1975b] developed the first CHF look-up table. The correction factor for diameter was based on

$$\frac{CHF_D}{CHF_{D=8\ mm}} = \left[\frac{D}{8} \right]^n \tag{2}$$

where $CHF_{D=8\ mm}$ is the CHF for a tube of 8-mm inside diameter (obtained from the CHF table), and D is the inside diameter in mm for the tube of interest. A value of -0.5 was suggested for the exponent, n, for diameters from 4 to 16 mm.

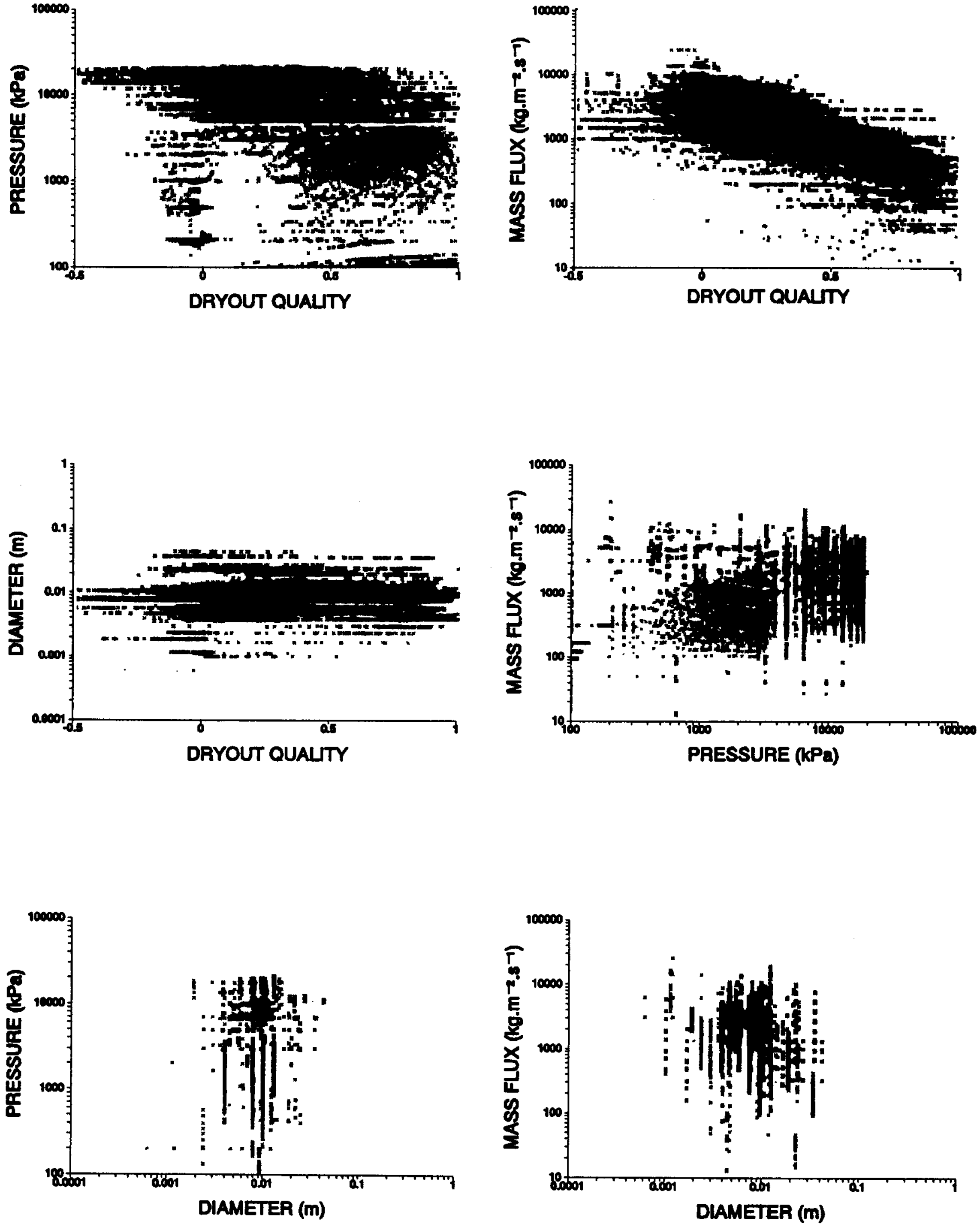

Figure 1 : Range of Conditions Covered by the CRL Data Bank.

1976 - An update of Doroshchuk's table was published by the USSR Academy of Science [1977]. It covered a slightly wider range of conditions than Doroshchuk's table. The same correction factor for diameter as suggested by Doroshchuk was used.

1982 - Groeneveld [1982] derived a more extensive CHF table, with about 10 000 data points. A value of -1/3 is recommended for the exponent in Equation (2), to correct for the diameter effect on CHF.

1983 - Groeneveld and Munday [1983] updated the Groeneveld 1982 table and included the low-pressure data of Cheng et al. [1983].

1986 - Groeneveld et al. [1986] published the 1986 AECL-UO table based on over 15 000 data points covering the widest range of application. Different values of exponent in Equation (2) were assessed for the derivation of the correction factor for diameter. A value of -1/3 was shown to result in the least prediction error when compared with their data base within the range of diameter from 4 to 16 mm. Smith [1986] extended the range to 32 mm tubes.

1988 - Wong and Groeneveld [1988] refined the discretization of the Groeneveld 1986 table at a pressure range from 7 and 12 MPa, mass-flux range from 1 and 7.5 $Mg.m^{-2}.s^{-1}$ and quality range from -0.2 and 0.55. Their table is valid for these ranges only. The same correction factor for diameter as in Groeneveld et al. [1986] was used.

1989 - Kirillov et al. [1989a] derived another CHF table based on their data base (close to 15 000 data points), which covers a range similar to Doroshchuk's table. They introduced a new methodology to evaluate the diameter correction factor where different exponents are used for various dryout types. Five different regions were identified, but only two transition points were provided for the three regions at high-quality conditions.

1989 - Kirillov et al. [1989b] updated their table by slightly expanding the range of application. The method for correcting the diameter effect on CHF is similar to the one recommended by Kirillov et al. [1989a]. A modification, however, was introduced to the high-pressure conditions. The calculations for three of the four transition points (except for the transition between the highly subcooled-boiling and the nucleate-boiling regions) were introduced.

1990 - Leung and Groeneveld [1990] modified the parametric trends and refined the range of discretization of the AECL 1986 table. They presented an updated CHF table with the same correction factor for diameter as recommended by Groeneveld et al. [1986].

1991 - Kirillov et al. [1991a] expanded their CHF table to a much wider range of conditions than their previous tables. However, their table range is still narrower than those of Groeneveld et al. [1986] and Leung and Groeneveld [1990]. The same correction factor for diameter as suggested by Kirillov et al. [1989b] was used. All four transition points between the five regions were provided.

1991 - Kirillov et al. [1991b] revised the calculation of diameter correction factor by introducing the pressure effect in determining the exponent. Only three transition points were given. The range of conditions for this CHF table, however, have been reduced compared to the previous one (i.e., Kirillov et al. [1991a]).

A comparison of the tabulated CHF values and the parametric trends between the Groeneveld et al. [1986] and the Kirillov et al. [1989a] CHF tables has recently been carried out by Zeggel et al. [1992]. While similarities were noted in regions where data are available, they observed a significant difference between these tables in other regions, particularly the parametric trends of CHF.

The prediction capability of CHF tables presented by Doroshchuk [1975b], USSR Academy of Sciences [1977], Groeneveld et al. [1986], Leung and Groeneveld [1990], Kirillov et al. [1989a], Kirillov et al. [1989b], Kirillov et al. [1991a] and Kirillov et al. [1991b] are assessed against the experimental data. The Becker CHF table [Becker and Soderquist, 1992], which is merely a tabular form of the Becker correlation [Becker and Persson, 1963], will not be considered in this comparison. (The Becker correlation, however, is examined in the next section.) As the Groeneveld [1982] and Groeneveld and Munday [1983] tables were the intermediate steps towards the 1986 CHF table, they are not assessed in this study. The Wong and Groeneveld [1988] table was not assessed, due to its limited range of application. The comparisons were limited to the specific data base corresponding to the range of validity of each individual table. This resulted in a different number of data used in each case.

Transition points between various dryout types are required for all CHF tables of Kirillov et al. However, only Kirillov et al. [1991a] provided equations for all four points. Unless otherwise specified, these equations are also used for the previous tables by Kirillov et al.

Table 1 shows the results from the error assessment of various CHF tables based on the constant inlet-subcooling approach. Overall, the Groeneveld et al. [1986] and the Leung and Groeneveld [1990] tables cover the widest range of flow conditions, and have been compared against 21 921 points. The CHF table of Kirillov et al. [1991a] is applicable for over 18 400 data, while their latest version [Kirillov et al., 1991b] covers only about 16 000 data. It appears that their latest version did not result in any improvement over their earlier one. The error assessments, based on the constant inlet-subcooling approach, for data predicted within the ±50% range (to eliminate those obviously inconsistent data) are also shown in Table 1 for each CHF table. This results in a significant improvement (a reduction of more than 10% in root-mean-square error). Figure 2 shows the distribution of data over each error range.

Table 1 : Assessment of Various CHF Tables.

	No. of Data Tested	Error (%)		No. of Data within ±50%	Error (%)	
		Avg.	Rms		Avg.	Rms
Doroshchuk et al. [1975b]	3 744	-3.39	13.92	3 705	-3.00	12.27
USSR Academy of Science [1977]	4 926	2.28	10.56	4 901	10.56	9.78
Groeneveld et al. [1986]	21 863	2.54	17.12	21 710	1.54	8.07
Kirillov et al. [1989a]	12 225	3.73	21.36	12 129	2.32	9.97
Kirillov et al. [1989b]	13 387	1.86	19.10	13 300	0.67	8.76
Leung and Groeneveld [1990]	21 921	2.02	16.38	21 771	1.08	8.29
Kirillov et al. [1991a]	18 447	2.53	17.45	18 335	1.57	9.27
Kirillov et al. [1991b]	17 000	2.53	18.05	16 900	1.53	9.49

4. ASSESSMENT OF PREDICTION ACCURACY FOR SELECTED CORRELATIONS

The prediction accuracy of the Biasi et al. correlation [1967], the Becker and Persson correlation [1963], and the Bowring correlation [1972] are also assessed. These correlations apply to a narrower range of conditions than the CHF tables. Table 2 shows the results from the comparison of the predictions of these correlations within their range of application against the experimental data. The prediction accuracy seems to be better for the Becker correlation, which has the least overall rms error and the majority of data within the ±10% range of error. However, this correlation also has the narrowest range of validity.

Table 2 : Assessment of Various CHF Correlations within Their Ranges of Application.

	No. of Data Tested	Error (%)		No. of Data within ±50%	Error (%)		No. of Data within ±10%
		Avg.	Rms		Avg.	Rms	
Biasi et al. correlation [1967]	11 868	9.41	31.95	10 992	5.44	20.08	4 104
Becker and Persson correlation [1963]	7 571	4.32	22.59	7 499	2.65	9.71	5 702
Bowring correlation [1972]	11 167	8.58	35.72	10 474	5.30	20.34	3 846

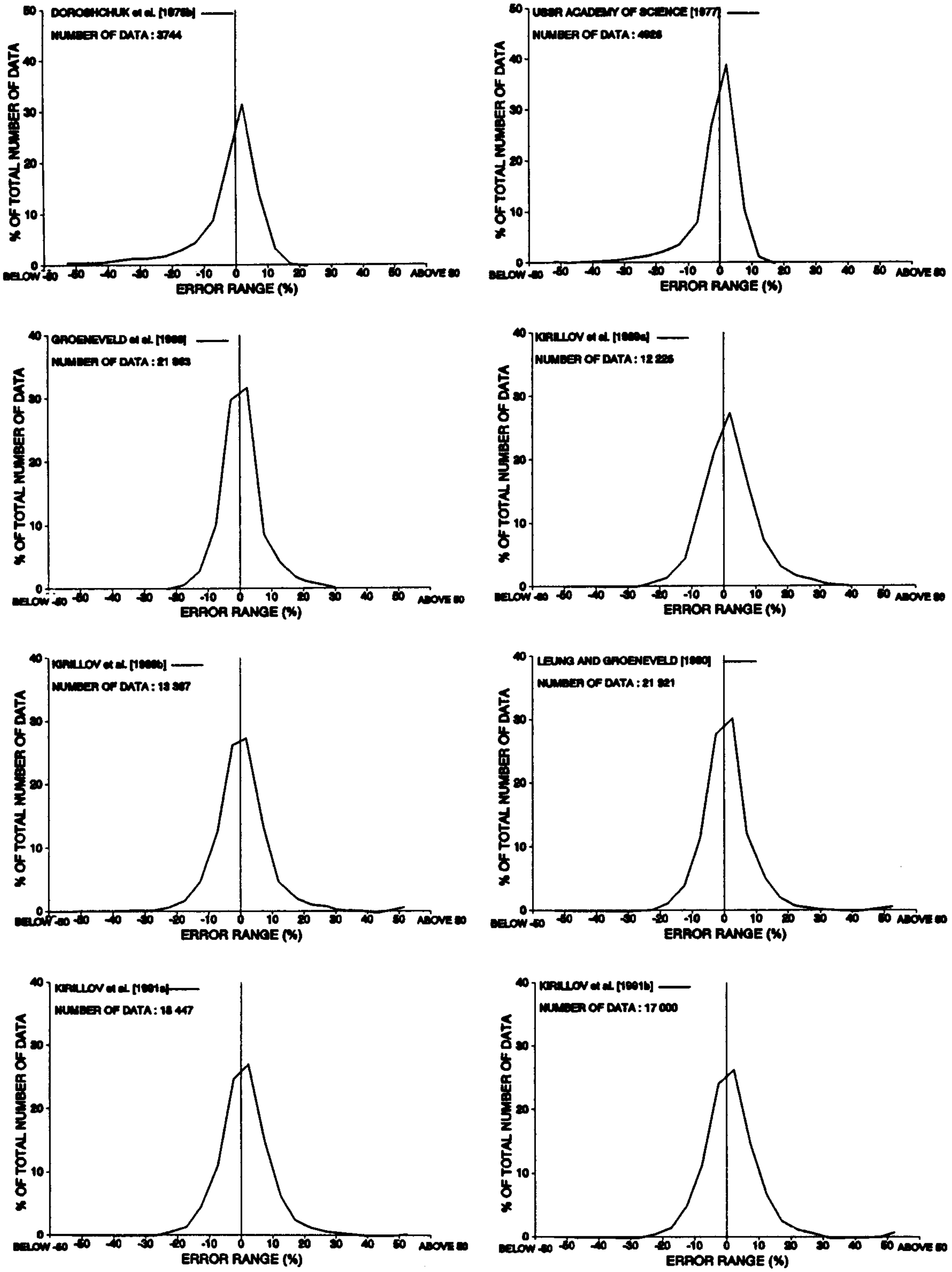

Figure 2 : Distribution of Data in Various Ranges of Error for Each CHF Table.

In view of the limited range of application for the CHF correlations, extrapolation is often introduced to conditions outside these ranges even though it is not recommended. Therefore, an assessment is made to assess the validity of extrapolation by comparing the predicted values of these correlations against the complete CRL data base. Two restrictions for these correlations have been introduced in this assessment, to avoid unrealistic errors: the range of dryout quality is limited to values between 0 and 1, and a positive prediction of CHF is required.

Table 3 shows the results of the comparison. After removing the limitations on the range of application, the number of assessed data has been increased. This increase is particularly noticeable for the Becker correlation, where 3 times as much data are tested. Similarly, a large increase in the number of data within the ±10% range is observed. However, the increase in rms error for data within the ±50% is larger for this correlation, compared to Table 2 (from 9.71 to 16.99%). Based on this assessment, the Becker correlation is potentially valid for extrapolation, but its accuracy may be reduced accordingly.

Table 3 : Assessment of CHF Correlations with All Data.

	No. of Data Tested	Error (%)		No. of Data within ±50%	Error (%)		No. of Data within ±10%
		Avg.	Rms		Avg.	Rms	
Biasi et al. correlation [1967]	15 317	11.69	36.30	13 680	6.59	21.23	4 786
Becker and Persson correlation [1963]	22 578	9.94	28.98	21 881	7.24	16.99	11 065
Bowring correlation [1972]	12 713	8.96	36.42	11 729	5.12	20.98	4 186

5. CONCLUSIONS

1. The prediction accuracy of various CHF tables and empirical correlations has been compared against a large experimental data bank. Overall, the AECL tables (two versions) have the best accuracy and the widest range of application. For 21 771 data points, the root-mean-square error is 8.3%. None of the correlations assessed in this study has a similar accuracy to or covers such a wide range as the CHF tables. Only the Becker correlation is potentially valid for extrapolation over a limited range of conditions; the Biasi and the Bowring correlations are not recommended.

2. Overall, the CHF look-up table method is better than CHF correlations or semi-analytical models, because of:

    - better prediction accuracy,
    - wider range of application,
    - simpler to use (no fluid properties are needed),
    - easier to update, and
    - more correct parametric and asymptotic trends.

3. Application of the CHF table to cases other than a vertical, uniformly heated tube, cooled by a steam-water mixture, has been presented by Groeneveld et al. [1986], and revised by Leung and Groeneveld [1990] and Groeneveld et al. [1992]. It requires several correction factors accounting for various geometric and other effects on CHF. The use of empirically obtained correction factors is simple to apply and provides reasonable predictions of CHF.

4. An update of the AECL CHF table is in process with this large data bank, to further improve the predictive capability.

REFERENCES

Becker, K.M. and Persson, P., (1963), "An Analysis of Burnout Conditions for Flow of Boiling Water in Vertical Round Ducts", ASME Publication 63-WA-51.

Becker, K.M. and Soderquist, B., (1992), "Assessment of Round Tube CHF Tables", Paper Presented at the European Two-Phase Flow Group Meeting, Stockholm, June 1-3 (also KTH-NEL-55).

Bestion, D., (1990), "The Physical Closure Laws in the CATHARE Code", Nuclear Engineering and Design, Vol. 124, pp. 229-245.

Biasi, L., Clerici, G.C., Garribba, S., Sala, R. and Tozzi, A., (1967), "Studies on Burnout. Part 3: A New Correlation for Round Ducts and Uniform Heating and Its Comparison with World Data", Energia Nucleare, Vol. 14, pp. 530-536.

Bowring, R.W., (1972), "A Simple but Accurate Round Tubes, Uniform Heat Flux Dryout Correlation over the Pressure Range 0.7-17.0 MN/m^2", AEEW-R-789.

Cheng, S.C., Poon, K.T., Lau, P., Heng. K.T., Doan, T. and Chan, C.Y., (1983), "CHF Measurements and Construction of CHF Table", Final report submitted to AECL Research.

Collier, J.G., (1981), Convective Boiling and Condensation, McGraw-Hill Book Company, New York.

Dell, F.R., Hewitt, G.F., Keeys, R.K.F. and Stinchcombe, R.A., (1969), "Burnout Heat Flux Measurements in a Long Tube", AERE-M 2216.

Doroshchuk, V.E., Levitan, L.L. and Lantzman, F.P., (1975a), "Investigation into Burnout in Uniformly Heated Tubes", ASME Publication 75-WA/HT-22.

Doroshchuk, V.E., Levitan, L.L. and Lantzman, F.P., (1975b), "Recommendations for Calculating Burnout in a Round Tube with Uniform Heat Release", Teploenergetika, Vol. 22, No. 12, pp. 66-70.

Groeneveld, D.C., (1982), "A General CHF Prediction Method for Water, Suitable for Reactor Accident Analysis", C.E.N.G. Report DRE/STT/SETRE/82-2-E/DG.

Groeneveld, D.C., Cheng, S.C. and Doan, T., (1986), "1986 AECL-UO Critical Heat Flux Look-Up Table", Heat Transfer Engineering, Vol. 7, pp. 46-62.

Groeneveld. D.C., Joober, K., Leung, L.K.H., Doerffer, S., Rudzinski, K.F. and Wong, W., (1992), AECL Internal Report.

Groeneveld, D.C., et al., (1992), "CHF Fluid-to-Fluid Modelling Studies in Three Different Laboratories Using Different Modelling Fluids", Proc. of the 5th International Topical Meeting on Nuclear Reactor Thermalhydraulics, Salt Lake City, Utah, USA, September 21-25.

Groeneveld, D.C. and Munday, D.F., (1983), AECL Internal Report.

Groeneveld, D.C. and Rousseau, J.C., (1982), "CHF and Post-CHF Heat Transfer: an Assessment of Prediction Methods and Recommendations for Reactor Safety Codes", NATO Advances of Two-Phase Flows and Heat Transfer - The Advances of Two-Phase Flows and Heat Transfer, Editors: Kakac, S. and Ishii, M., Vol. 1, pp. 203-238.

Groeneveld, D.C. and Snoek, C.W., (1986), "A Comprehensive Examination of Heat Transfer Correlations Suitable for Reactor Safety Analysis", Multiphase Science and Technology, Vol. 2, pp. 181-274.

HTFS Handbook, (1992), Heat Transfer and Fluid-Flow Service (available to members only).

Kirillov, P.L., Bobkov, V.P., Boltenko, E.A., Vinogradov, V.N., Katan, I.B. and Smogalev, I.P., (1991a), "Lookup Tables of Critical Heat Fluxes", Atomnaya Energiya, Vol. 71, No. 1, pp. 18-28, July (in Russian).

Kirillov, P.L., Bobkov, V.P., Boltenko, E.A., Katan, I.B., Smogalev, I.P., Vinogradov, V.N., (1991b), "New CHF Table for Water in Round Tubes", Report IPPE-2225, Obninsk, Russia.

Kirillov, P.L., Bobkov, V.P., Vinogradov, V.N., Donisov, V.S., Ivashkevitch, A.A., Katan, I.B., Paniutchev, E.I., Smogalev, I.P. and Sal'nikova, O.B., (1989a), "On Standard Critical Heat Flux Data for Round Tubes", Proceedings of the 4th International Topical Meeting on Nuclear Reactor Thermalhydraulics, Karlsruhe, F.R.G., Vol. 1, pp. 103-108.

Kirillov, P.L., Bobkov, V.P., Boltenko, E.A., Vinogradov, V.N., Ivashkevitch, A.A., Katan, I.B. and Smogalev, I.P., (1989b), "A Method of the Development of Standard CHF Data for Tubes with Uniform Heat Flux", FEI-2030, Obninsk, USSR (in Russian).

Kiteley, J.C., Carver, M.B., Liner, Y., Bromley, B.P. and McCracken, I.K., (1991), "ASSERT-IV Thermalhydraulics Subchannel Analysis Code Simulation of Dryout Power and Pressure Drop in a Horizontal 37-Rod Bundle Fuel Channel Including the Effect of Pressure Tube Creep", Proceedings of the 16th Annual CNA Nuclear Simulation Symposium, St. John, New Brunswick, Aug. 25-27.

Leung, L.K.H. and Groeneveld, D.C., (1990), AECL Internal Report.

Richards, D.J., (1992), AECL Internal Memorandum.

Smith, R.A., (1986), "Boiling Inside Tubes: Critical Heat Flux for Upward Flow in Uniformly Heated Tubes", Engineering Science Data Unit International Ltd., ESDU Data Item No. 86032, London.

Thompson, B., and Macbeth, R.V., (1964), "Boiling Water Heat Transfer in Uniformly Heated Round Tubes: A Compilation of World Data with Accurate Correlations", AEEW-R-356.

Ulrych, G., (1993), "CHF Table Applications in KWV PWR Design", A paper presented at the International Workshop on CHF Fundamentals-CHF Table Improvements, Braunschweig, Germany, March 3-5.

USSR Academy of Science, (1977), "Tabular Data for Calculating Burnout when Boiling Water in Uniformly Heated Round Tubes", Thermal Engineering, Vol. 23, No. 9, pp. 77-79.

Weaver, W.L., Riemke, R.A., Wagner, R.J. and Johnsen, G.W., (1991), "The RELAP5/MOD3 Code for PWR Safety Analysis", Proceedings of the 4th International Topical Meeting on Nuclear Reactor Thermalhydraulic, Karlsruhe, Germany, Vol. 2, pp. 1221-1226.

Wong, Y.L. and Groeneveld, D.C., (1988), AECL Internal Report.

Yin, S.T., Liu, T.J., Huang, Y.D. and Tain, R.M., (1988), "Measurements of Critical Heat Flux in Forced Flow at Pressures up to the Vicinity of the Critical Point of Water", Proc. of the 25th National Heat Transfer Conference, Houston, Texas, July 24-27.

Zeggel, W., Bethke, S., Groeneveld, D.C. and Erbacher, F.J., (1992), "Analysis of Round Tube CHF Tables", Paper presented at the European Two-Phase Flow Group Meeting, June 1-3, Stockholm.