Available online at www.sciencedirect.com
ScienceDirect
Nuclear Engineering and Design 237 (2007) 1909–1922
Nuclear Engineering and Design
www.elsevier.com/locate/nucengdes

The 2006 CHF look-up table

D.C. Groeneveld[a,b,*], J.Q. Shan[c], A.Z. Vasić[b], L.K.H. Leung[b], A. Durmayaz[d], J. Yang[a,b], S.C. Cheng[a], A. Tanase[a]

[a] University of Ottawa, Department of Mechanical Engineering, Ottawa, Ont., Canada
[b] Chalk River Laboratories, Atomic Energy of Canada Ltd., Chalk River, Ont., Canada K0J 1J0
[c] Department of Nuclear Engineering, Xi'an Jiaotong University, P.R. China
[d] Istanbul Technical University, Institute of Energy, Istanbul, Turkey

Received 2 May 2006; received in revised form 26 February 2007; accepted 26 February 2007

Abstract

CHF look-up tables are used widely for the prediction of the critical heat flux (CHF). The CHF look-up table is basically a normalized data bank for a vertical 8 mm water-cooled tube. The 2006 CHF look-up table is based on a database containing more than 30,000 data points and provides CHF values at 24 pressures, 20 mass fluxes, and 23 qualities, covering the full range of conditions of practical interest. In addition, the 2006 CHF look-up table addresses several concerns with respect to previous CHF look-up tables raised in the literature. The major improvements of the 2006 CHF look-up table are:

- An enhanced quality of the database (improved screening procedures, removal of clearly identified outliers and duplicate data).
- An increased number of data in the database (an addition of 33 recent data sets).
- A significantly improved prediction of CHF in the subcooled region and the limiting quality region.
- An increased number of pressure and mass flux intervals (thus increasing the CHF entries by 20% compared to the 1995 CHF look-up table).
- An improved smoothness of the look-up table (the smoothness was quantified by a smoothness index).

A discussion of the impact of these changes on the prediction accuracy and table smoothness is presented. The 2006 CHF look-up table is characterized by a significant improvement in accuracy and smoothness.

1. Introduction

The critical heat flux (CHF) normally limits the amount of heat transferred, both in nuclear fuel bundles and in steam generators. Failure of the heated surface may occur once the CHF is exceeded. The number of empirical CHF correlations has increased over the past 50 years and has reached well over 1000, just for tubes cooled by water. The present proliferation of CHF prediction methods clearly indicates that the CHF mechanism is complex; no single theory or equation can be applied to all CHF conditions of interest. The complexity involved in predicting the CHF increases significantly when additional factors such as transients, non-uniform flux distributions, and asymmetric cross sections are introduced. This has led to the development of the CHF look-up table.

The CHF look-up table is basically a normalized data bank, that predicts the CHF as a function of the coolant pressure (P), mass flux (G) and thermodynamic quality (X). An updated version of the CHF look-up table is appended to this paper.

The CHF look-up table method has many advantages over other CHF prediction methods, e.g., (i) simple to use, (ii) no iteration required, (iii) wide range of application, (iv) based on a very large database, and (vi) eliminates the need to choose among many CHF prediction methods currently available for tubes cooled by water.

Although the CHF look-up table has been quite successful and has been adopted widely, several concerns have been raised, including

* Corresponding author at: University of Ottawa, Department of Mechanical Engineering, Ottawa, Ont., Canada. Tel.: +1 6135843142.
E-mail address: groeneveldd@aecl.ca (D.C. Groeneveld).

0029-5493/$ – see front matter © 2007 Elsevier B.V. All rights reserved.
doi:10.1016/j.nucengdes.2007.02.014

Nomenclature

AECL	Atomic Energy of Canada Limited
CHF	critical heat flux ($kW\,m^{-2}$)
D	inside diameter (m)
G	mass flux ($kg\,m^{-2}\,s^{-1}$)
H	enthalpy ($kJ\,kg^{-1}$)
H_{fg}	latent heat ($kJ\,kg^{-1}$)
ΔH_{in}	inlet subcooling = $(H - H_{in})/H_{fg}$ ($kJ\,kg^{-1}$)
ID	inside diameter
L, L_h	heated length (m)
LQR	limiting quality region
LUT	look-up table
p	pressure at CHF (kPa)
q_{cr}	critical heat flux ($kW\,m^{-2}$)
T	fluid temperature (°C)
X	thermodynamic quality

Greek letter

Ω	smoothness index

Subscripts

CHF	pertaining to the CHF
exp	experimental
in	inlet conditions
lim	limiting quality as explained in Appendix A

- Fluctuations in the value of the CHF with pressure, mass flux and quality. This can cause difficulties when using look-up tables inside safety analysis codes in which iteration is required.
- Large variations in CHF between the adjacent table entries, especially in the region of the so-called limiting quality (this region is discussed in Appendix A).
- Prediction of CHF at unattainable conditions (e.g., critical flow, CHF at qualities greater than 1.0).
- Lack or scarcity of data at certain conditions (e.g., high sub-coolings and high flow, near zero flows).

An initial attempt to construct a standard table of CHF values for a given geometry was made by Doroshchuk et al. (1975), using a limited database of 5000 data points. This table, and all subsequent tables, contains normalized CHF values for a vertical 8-mm water-cooled tube at various pressures, mass fluxes and qualities. Since then, CHF table development work has been in progress at various institutions (e.g., CENG-Grenoble, University of Ottawa, IPPE-Obninsk, and AECL-Chalk River) using an ever-increasing database. The most recent CHF look-up table, hereafter referred to as the 1995 CHF look-up table (Groeneveld et al., 1996) employed a database containing about 24,000 CHF points and provides CHF values for an 8-mm ID, water-cooled tube at 21 pressures, 20 mass fluxes, and 23 critical qualities, covering, respectively, ranges of 0.1–20 MPa, 0–8 $Mg\,m^{-2}\,s^{-1}$ (zero flow refers to pool-boiling conditions) and −50 to 100% (negative qualities refer to subcooled conditions).

During the past 10 years, further enhancements have been made to the CHF look-up table and its database, culminating in the 2006 CHF look-up table. This paper summarizes the enhancements and presents the improvements in prediction accuracy of the 2006 CHF look-up table.

2. Database

Following the development of the 1995 CHF look-up table, a total of 33 new data sets containing 7545 data were acquired and included in the University of Ottawa's CHF data bank. Not all of these data were used in the derivation of the new CHF look-up table. The database was first subjected to the following screening criteria (summarized in Table 1):

(i) Acceptable values for diameter (D), ratio L/D, pressure (P), mass flux (G) and quality (X).
(ii) Ensuring that the data satisfied the heat balance (reported power should be approximately equal to [flow] × [enthalpy rise]).
(iii) Identification of outliers using the slice method (Durmayaz et al., 2004): the "slice" method was introduced to examine all the data behind each table entry in the look-up table. For each nominal look-up table pressure P_i and nominal mass flux G_j, a CHF versus critical quality plot was created showing all the experimental CHF values falling within the pressure and mass flux ranges of $(P_{i-1}+P_i)/2 < P_{exp} < (P_{i+1}+P_i)/2$ and $(G_{j-1}+G_j)/2 < G_{exp} < (G_{j+1}+G_j)/2$ after normalization to P_i and G_j and $D = 8$ mm. Data that did not obviously agree with the bulk of the data and the previous CHF look-up table were labelled "outliers" and were excluded in the CHF look-up table derivation process. Fig. 1 shows an example of a slice. The same slice approach was used for the CHF versus pressure (P) and CHF versus mass flux (G) plots.
(iv) Identification of duplicate data using the "slice" method (the same data sets may have been reported by more than one author).
(v) Removal of data sets which display a significant scatter and generally disagree with the bulk of the data. These "bad" data sets may be due to "soft" inlet conditions, which can give rise to flow instabilities or a poorly performed experiment (e.g., large uncertainties in instrumentation).

As can be seen from Table 1, a total of 8394 data points, representing 25% of the total number of CHF data available, were considered unsuitable for use in the 2006 CHF look-up table derivation and were removed through the screening process.

3. Skeleton table

The derivation of the CHF look-up table requires a skeleton table to provide the initial estimate of the CHF look-up table values. The skeleton CHF values are used for evaluating the slopes of CHF versus P, G or X. The slopes are used for extrapolating selected CHF measurement to the surrounding look-up table values of P, G and X as was described by Groeneveld et al.

Table 1
Data selection criteria for look-up table derivation

Parameter	1995 selection criteria	2006 selection criteria	Number of data removed due to 2006 selection criteria
# of data in the database	25,630	33,175	
# of data sets in the database	49	82	
D (mm)	$3<D<25$	$3<D<25$	1420
P (kPa)	$100<P<20,000$	$100<P<21,000$	37
G (kg m^{-2} s^{-1})	$0<G<8000$	Same	912
X	$X_{CHF}<1.0$	Same	368
Inlet temperature (°C)	$T_{in}>0.01$	Same	10
L/D, $X_{in}<0$	$L/D>80$	$L/D>50$ for $X_{cr}>0$, $L/D>25$ for $X_{cr}<0$	2214
L/D, $X_{in}>0$	Not accepted	$L/D>100$	154
Heat balance	Error > 5%	Error > 5%	619
Other data removal criteria	Duplicates	Duplicates	1284
		Outliers as identified by the "slice" method	326
"Bad" data sets removed	Mayinger (1967), Era et al., 1967, Bertoletti (1964)	Bertoletti (1964), Ladislau, 1978	522
# of data accepted for LUT derivation	23,114	24,781	Total of above: 8394

(1996). The skeleton table also provides the default CHF values at conditions where no experimental data are available.

The skeleton table is primarily based on the 1995 CHF look-up table but with corrections to the subcooled region. These corrections were necessary because the skeleton table for the 1995 CHF look-up table was primarily based on the Katto equation (1992), which was subsequently found to contain discontinuities or trend reversals at certain conditions as shown in Fig. 1.

Values in the skeleton table for $G=0$ kg m^{-2} s^{-1} and $X<0$ are predicted using the Zuber (1959) correlation with the correction

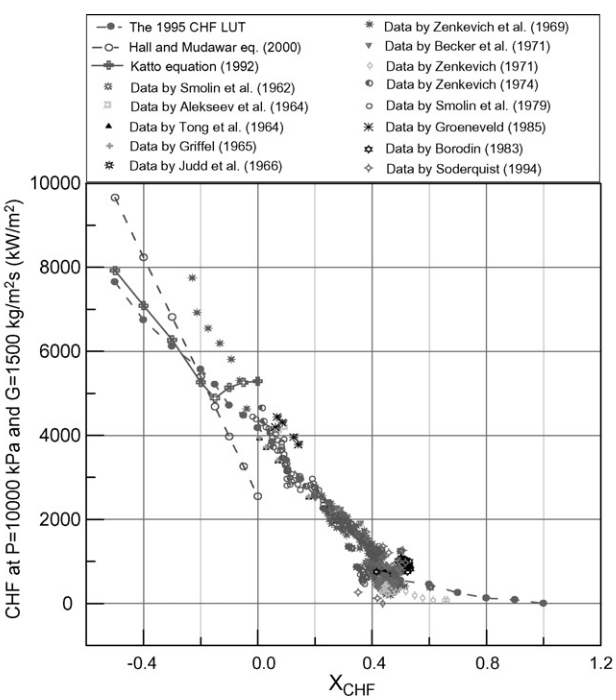

Fig. 1. CHF vs. X_{CHF} containing a slice of the 1995 CHF look-up table and the experimental data at $9500<P_{exp}\leq 10,500$ kPa, $1250<G_{exp}\leq 1750$ kg m^{-2} s^{-1} after normalization to $P=10,000$ kPa, $G=1500$ kg m^{-2} s^{-1}.

factor derived by Ivey and Morris (1962). The skeleton table values for $G>300$ kg m^{-2} s^{-1} and $X<0$ are either maintained or replaced with the predicted values by Hall and Mudawar (2000) equation, based on a visual observation of the plots produced by slicing the look-up table and the data trends (Durmayaz et al., 2004).

For $0<G<500$ kg m^{-2} s^{-1} and $X<0$, the table CHF values are established using a linear interpolation between those at zero flow and 500 kg m^{-2} s^{-1}. This provides a smooth transition.

Compared to the 1995 look-up table three additional pressures (2, 4 and 21 MPa) and one mass flux (750 kg m^{-2} s^{-1}) were added to the look-up table. The skeleton CHF values for conditions of 2 and 4 MPa pressures and of 750 kg m^{-2} s^{-1} mass flux were obtained from linear interpolation. The skeleton CHF values for 21 MPa were interpolated using the CHF versus pressure trend of the Zuber equation, which was found to approximately agree with CHF versus P trends for flow boiling (Groeneveld et al., 1986).

4. Derivation of the CHF look-up table

The primary building blocks for the CHF look-up table are the screened database, described in Section 2, and the skeleton table, described in Section 3. The following steps were taken in the look-up table derivation process:

- The 1995 CHF look-up table, modified as described in the previous section, was used as the skeleton table.
- The expanded database was screened as described in Section 2.
- The effect of tube diameter on CHF is accounted for using the diameter correction factor: $CHF_D/CHF_{D=8\,mm}=(D/8)^{-1/2}$ for the range of $3<D<25$ mm. Outside this range the diameter effect appears to be absent (Wong, 1994).
- For each set of look-up table conditions (each combination of P_x, G_y and X_z), all experimental data falling within the range $P_{x-1}<P_{exp}<P_{x+1}$, $G_{y-1}<G_{exp}<G_{y+1}$

Table 2
Impact of polynomial order on prediction accuracy and smoothness

Polynomial order	Constant local conditions			Constant inlet conditions			Smoothness index	
	No. of data	Error (%)		No. of data	Error (%)		Avg. (−)	rms (%)
		Avg.	rms		Avg.	rms		
1	24,781	3.50	38.34	24,781	0.35	8.23	0.090	11.5
2	24,781	5.53	38.27	24,781	0.78	8.11	0.101	10.8
3	24,781	6.94	38.42	24,781	1.00	8.32	0.107	11.6
4	24,781	6.60	37.24	24,781	0.98	8.32	0.116	13.1
5	24,781	6.44	36.54	24,781	0.99	8.28	0.138	15.7

and $X_{z-1} < X_{\exp} < X_{z+1}$ were selected. Each experimental CHF point was corrected for the differences in pressure ($P_{\exp} - P_x$), mass flux ($G_{\exp} - G_y$) and quality ($X_{\exp} - X_z$), using the slopes of the skeleton table. The corrected point was given a weight, which was proportional to $[1 - \{(P_{\exp} - P_x)(G_{\exp} - G_y)(X_{\exp} - X_z)\}/\{(P_{x+1} - P_x)$ $(G_{y+1} - G_y)(X_{z+1} - X_z)\}$ for each of the quadrants surrounding P_x, G_y and X_z and the weighted averaged CHF value for all corrected data surrounding each table entry was used to replace the skeleton CHF value.

The updated CHF table is not smooth and displays an irregular variation (without any physical basis) in the three parametric ranges: pressure, mass flux and quality. These fluctuations are attributed to data scatter, systematic differences between different data sets, and possible effects of second-order parameters such as heated length, surface conditions and flow instability. Sharp variations in CHF were also observed at some of the boundaries between regions where experimental data are available and regions where correlations and extrapolations were employed. Prior to finalizing the look-up table, a smoothing procedure developed by Huang and Cheng (1994) was applied. The principle of the smoothing method is to fit three polynomials to six table entries in each parametric direction. The three polynomials intersect each other at the table entry, where the CHF value is then adjusted. This resulted in a significant improvement in the smoothness of the look-up table. A third-order polynomial was used for the smoothing of the 1995 CHF look-up table. However, recent comparisons have shown that a first-order polynomial results in a smoother table with no significant loss in prediction accuracy, see Table 2 (the smoothness index and root-mean-square (rms) values will be discussed in Section 5.2).

Applying the smoothing process to the table entries at all conditions suppressed the discontinuity at the boundaries of the limiting quality region (LQR), as described in Appendix A, resulting in non-representative trend to the experimental data. To maintain the physical trend of the table entries at the LQR, an intermediate table was created that maintained the more abrupt changes at the boundaries of the LQR, extrapolated to the nearest look-up table qualities. Also between the maximum quality of the LQR and $X = 0.9$ a gradual change towards the skeleton table values was applied. Some smoothing needed to applied subsequently to avoid a fluctuation in CHF with pressure and mass flux. Fig. 2 illustrates the intended change in the look-up table prior to applying the additional smoothing.

The final CHF look-up table is included as Appendix B. Four levels of shading have been applied to highlight regions of uncertainty. The unshaded entries represent areas that were derived directly from the experimental data and hence have the least uncertainty. The light grey regions represent calculated values based on selected prediction methods that provide reasonable predictions at neighboring conditions where experimental data are available. The uncertainty in this region depends on the level of extrapolation from data-based regions. It is expected to be small at conditions slightly beyond the range of data but becomes large as the extrapolation is further beyond this range. The medium gray regions represent conditions where CHF values were often impossible to obtain, including (i) conditions where critical flow may exist, and (ii) coolant enthalpies where the bulk of the liquid starts to become solid ($T_{\text{bulk}} < 0.01$) and (iii) $G = 0$ where the concept of flow quality becomes imaginary. Those regions are included only to improve interpolation accuracy of other regions. Extrapolation into medium gray region should be avoided. Finally the entries having a black background represent the LQR, where rapid changes in CHF versus quality curve can be observed. Note that the LQR does not occur at all pressures and mass fluxes. Because of space limitations CHF values at some intermediate pressures are not shown in Appendix B.

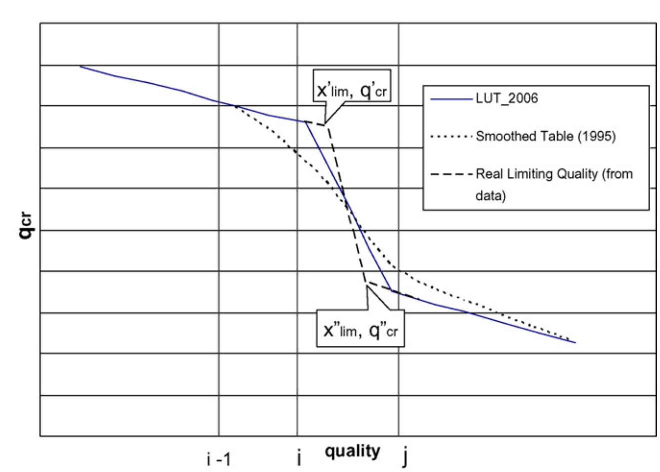

Fig. 2. Illustration of derivation of 2006 CHF look-up table values at the LQR.

5. Look-up table prediction accuracy and smoothness

5.1. Prediction accuracy

There are two methods for assessing the prediction accuracy of the CHF look-up table: (i) based on constant local conditions (i.e., constant critical quality), and (ii) based on constant inlet conditions (i.e., constant inlet temperature or inlet enthalpy). Method (i) is sometimes referred to as the direct substitution method (DSM), while method (ii) is also referred to as the heat balance method (HBM).

The CHF prediction based on constant local conditions is the simplest to apply. The predicted CHF for each experimental data point in question (D_{exp}, P_{exp}, G_{exp}, X_{exp}) is first found using the CHF look-up table at local flow conditions for a tube of 8-mm diameter using direct interpolation between matrix values of P, G, and X. Next, the CHF is corrected for the diameter effect as follows:

$$\mathrm{CHF}(D_{exp}, P_{exp}, G_{exp}, X_{exp}) = \mathrm{CHF}(D = 8, P_{exp}, G_{exp}, X_{exp})\left(\frac{D_{exp}}{8}\right)^{-1/2} \quad (5.1)$$

The CHF prediction based on constant inlet conditions is obtained via iteration with the heat-balance equation using the following steps:

- Estimate the heat flux (if unsure how to make an estimate, assume CHF = 500 kW m^{-2})
- Calculate the quality based on the estimated heat flux, mass flux and inlet subcooling:

$$X = \frac{H - H_f(P_{exp})}{H_{fg}(P_{exp})} = 4\frac{q_{est}}{G_{exp}H_{fg}(P_{exp})}\frac{L_{h,exp}}{D_{exp}} - \frac{\Delta H_{in,exp}(T_{in,exp})}{H_{fg}(P_{exp})} \quad (5.2)$$

- Note that the quality as defined above is the thermodynamic quality, which will be negative for subcooled conditions.
- The first estimate of CHF is calculated from the CHF look-up table at local flow conditions (D = 8 mm, P_{exp}, G_{exp}, X) corrected for diameter

$$q_{pred}(D_{exp}, P_{exp}, G_{exp}, X) = \mathrm{CHF}(8, P_{exp}, G_{exp}, X)\left(\frac{D_{exp}}{8}\right)^{-1/2} \quad (5.3)$$

- Re-evaluate the quality using the average of the predicted value and the previous heat flux value, and again find the CHF.
- Continue this iteration process until the heat flux value starts converging to a single value.

The prediction errors are calculated for each data point from the database. The mean (arithmetic average) and rms errors are evaluated for data subsets and for the complete database based on either constant local quality and constant inlet condition. The error histograms in Fig. 3 based on the enlarged database show that the 2006 look-up table has a more peaked error distribution. Details of the error distributions are presented in Table 3. The table shows that using the enhanced database, the rms and average errors of the 2006 CHF look-up table are less than those for the 1995 CHF look-up table.

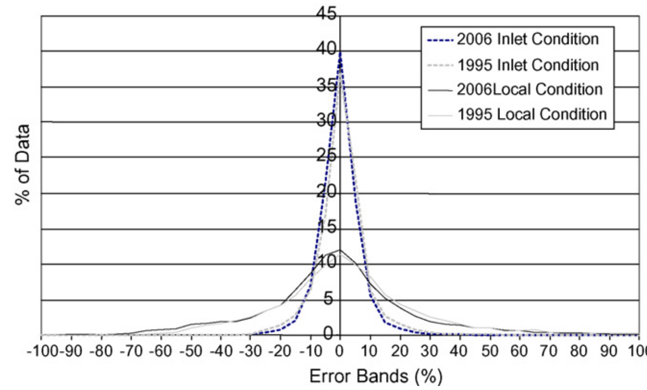

Fig. 3. Error histograms of the 1995 and 2006 CHF look-up tables for all selected data (% of data is for each error band of −100 to −90%, −90 to −80%, −80 to −70%, etc.).

The improvement in prediction accuracy is most pronounced for subcooled conditions (X < 0) and in the limiting quality region ($X'_{lim} < X < X''_{lim}$) where the rms errors based on constant inlet conditions decrease from 11.13 to 7.08% and from 10.88 to 6.71%, respectively. The reductions in error for X < 0 are due to the improvements to the skeleton table for X < 0 (described in Section 3) by reducing the dependence on the Katto equation The reduction in error in the LQR is primarily due to the maintaining to some degree a sharper variation in CHF values as was shown in Fig. 2. The rms error in Region III was also reduced significantly: from 11.34 to 8.01%.

These error comparisons are based on the total number of data points (i.e., 25,217). The 2006 CHF look-up table has also been compared to additional data obtained at pressures up to 21 MPa, but adding the extra data affects the errors by less than 0.03%.

A separate error analysis of the outliers (as identified by the "slice method", see Fig. 1) showed that their rms errors are more than three times those of the above table. This indicates that the selection criteria have been effective in removing suspect data.

The error distribution based on the constant inlet-flow conditions approach for the 2006 CHF look-up table with respect to pressure, mass flux and critical quality are shown in Fig. 4. Slight systematic errors are present at low pressures and very low and high mass velocities and high qualities. A more detailed examination showed that the high errors were primarily at pressures less than 250 kPa and mass velocities less than 750 kg m^{-2} s^{-1}. The scatter among these low flow and low-pressure data is very large due to possible flow instability at these conditions. Table 3 shows the impact on prediction errors after excluding these data from the error analysis. The rms error at constant inlet-flow conditions for the 2006 CHF look-up table reduces from 7.10 to 5.86%.

Table 3
Error statistics of the 1995 and 2006 CHF look-up tables

Data selection (# of data)	All selected (25,217)	Except $P<250$, $G<750$ (24,552)	$X<0$ only (1845)	Region I: $X < X'_{\rm lim}$ or no LQR (19,856)	Region II: LQR, $X'_{\rm lim} < X < X''_{\rm lim}$ (4565)	Region III: $X > X'_{\rm lim}$ (796)
1995 CHF look-up table						
Avg. error, $X=C$	7.63	7.27	−2.95	6.10	13.81	9.40
rms error $X=C$	42.96	42.10	18.00	37.42	58.89	57.28
Avg. error, $\Delta H_{\rm in}=C$	0.75	0.62	−2.93	0.505	1.37	1.383
rms error, $\Delta H_{\rm in}=C$	9.18	8.66	11.13	8.62	10.88	11.34
Smoothness index				0.098		
Smoothness rms				0.132		
2006 CHF look-up table						
Avg. error, $X=C$	4.09	5.81	0.85	2.31	14.53	−12.4
rms error $X=C$	38.92	37.21	14.74	31.13	60.8	47.52
Avg. error, $\Delta H_{\rm in}=C$	0.08	0.48	0.10	−0.07	1.14	−2.28
rms error, $\Delta H_{\rm in}=C$	7.10	5.86	7.08	7.15	6.71	8.01
Smoothness index				0.095		
Smoothness rms				0.133		

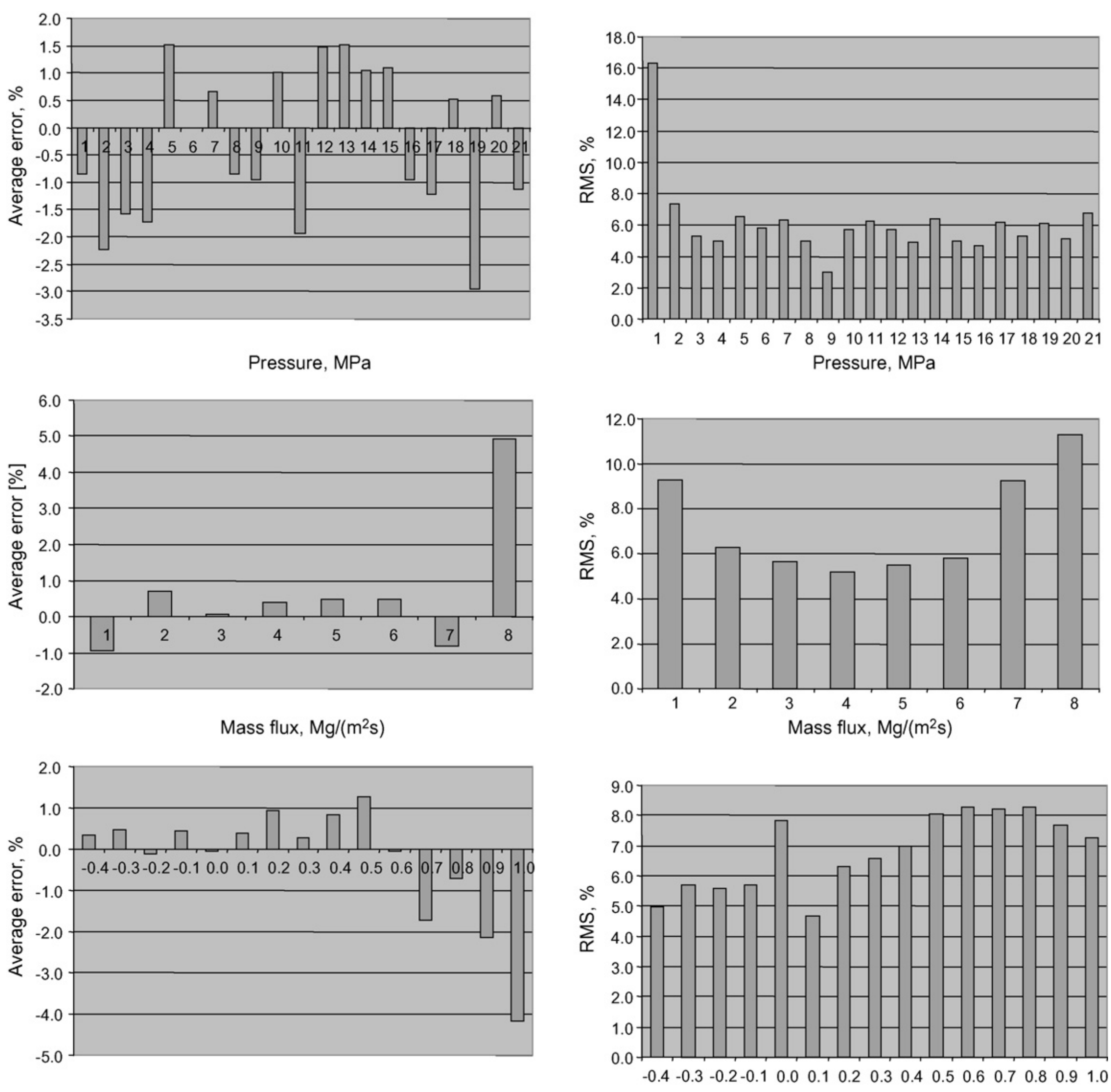

Fig. 4. Error distributions for the 2006 CHF look-up table with respect to P, G and X.

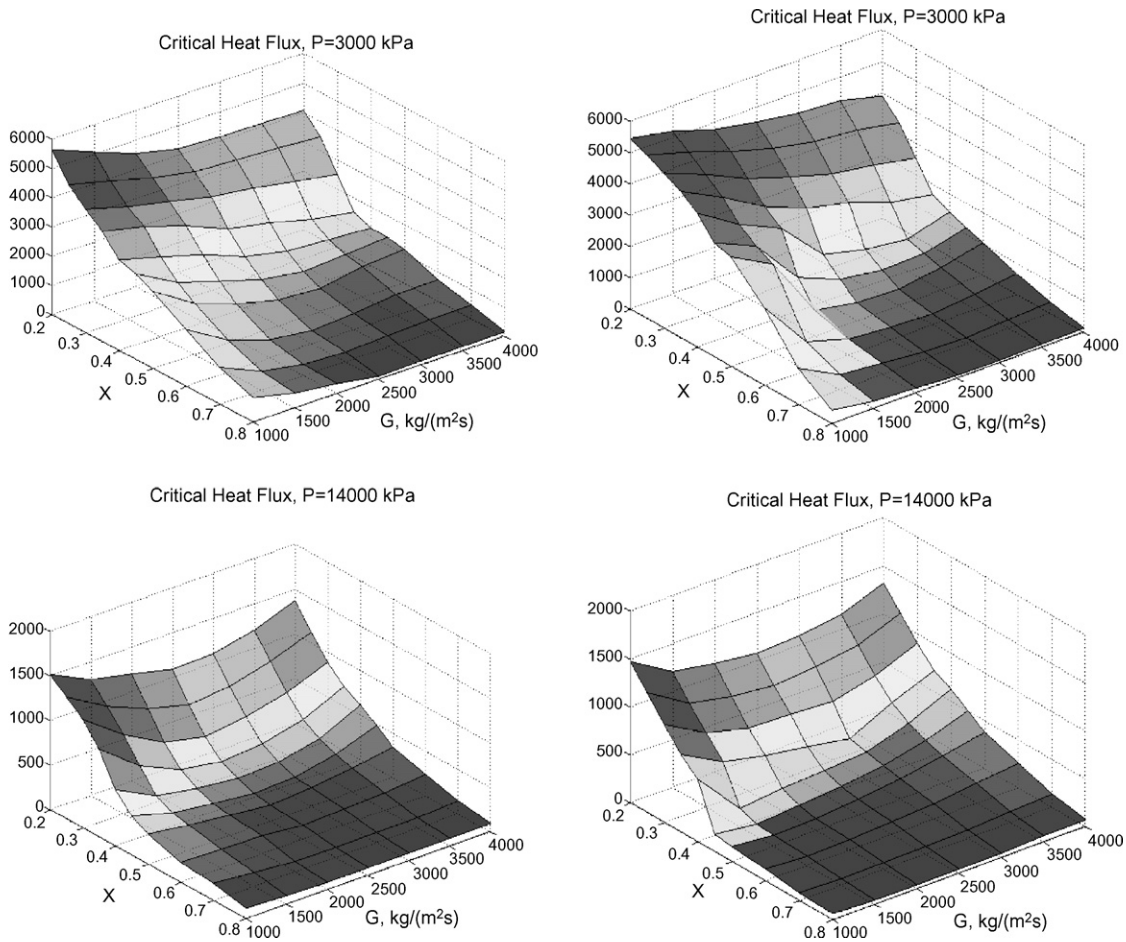

Fig. 5. Comparison of the 1995 CHF look-up table and the 2006 CHF look-up table (left: 1995; right: 2006).

5.2. Smoothness

Fig. 5 compares 3-D representations of the 1995 and 2006 CHF look-up tables for three pressures. Both tables appear reasonably smooth. The only obvious non-smooth trend for the 2006 CHF look-up table was the LQR, which was "smoothed out" in the 1995 CHF look-up table. Aside from the LQR it is difficult to see which region is smoother, making it difficult to judge which of the two tables is smoother. Hence it was decided to quantify the smoothness using the following approach (this approach was not applied to the transition at the LQR boundary).

Since the grid numbers in these CHF look-up tables for P, G, and X are roughly the same, as a first approximation, the grid indexes were used as the normalized parameters for the look-up table smoothness assessment. Assuming that the look-up table has P_i, G_j, and X_m as its grid points, with $i = 1, 2, \ldots, I$; $j = 1, 2, \ldots, J$; and $m = 1, 2, \ldots, M$, the local smoothness of the look-up tables is simply presented by the average of the absolute value of the relative slope differences at each direction of a local grid point.

$$\omega_{q_{cr}}(P_i, G_j, X_m) = \frac{1}{3}\left[\left|\left(\frac{1}{\bar{q}_{cr}}\frac{\partial q_{cr}}{\partial i}\right)_+ - \left(\frac{1}{\bar{q}_{cr}}\frac{\partial q_{cr}}{\partial i}\right)_-\right| + \left|\left(\frac{1}{\bar{q}_{cr}}\frac{\partial q_{cr}}{\partial j}\right)_+ - \left(\frac{1}{\bar{q}_{cr}}\frac{\partial q_{cr}}{\partial j}\right)_-\right| + \left|\left(\frac{1}{\bar{q}_{cr}}\frac{\partial q_{cr}}{\partial m}\right)_+ - \left(\frac{1}{\bar{q}_{cr}}\frac{\partial q_{cr}}{\partial m}\right)_-\right|\right]_{P_i, G_j, X_m} \quad (5.4)$$

where "+" refers to the forward slope, and "−" refers to the backward slope, q_{cr} is the CHF, and $\bar{q}_{cr}$ is the average CHF at its corresponding interval. The smoothness index for the entire look-up table is defined as the overall average of the local smoothness at all internal grid points.

$$\Omega_{q_{cr}} = \frac{\sum_{i=2}^{I-1}\sum_{j=2}^{J-1}\sum_{m=2}^{M-1}\omega_{q_{cr}}(P_i, G_j, X_m)}{(I-2)(J-2)(M-2)} \quad (5.5)$$

The rms of the smoothness is calculated in a similar manner:

$$\mathrm{rms}_{\omega_{q_{cr}}} = \sqrt{\frac{\sum_{i=2}^{I-1}\sum_{j=2}^{J-1}\sum_{m=2}^{M-1}[\omega_{q_{cr}}(P_i, G_j, X_m) - \Omega_{q_{cr}}]^2}{(I-2)(J-2)(M-2)}} \quad (5.6)$$

Table 3 shows that the smoothness index and the rms of the smoothness for the 2006 CHF look-up table are improved compared to the corresponding values for the 1995 CHF look-up table.

6. Conclusions and final remarks

The tube CHF database has been expanded since the derivation of the 1995 CHF look-up table with 33 additional data sets containing 7545 new data points.

The screening process of the CHF data has been enhanced significantly resulting in a larger fraction (∼25%) of data being excluded from the table development.

The 2006 CHF look-up table is a significant improvement over the 1995 CHF look-up table; the rms errors were reduced and the smoothness of the look-up table was improved. The largest improvements in prediction accuracy was obtained in the subcooled CHF region where local subcooling trend now agrees better with the Hall–Mudawar equation, and in the limiting quality region where the smoothing has been removed. The rms errors decreased by approximately 4% in these regions.

Despite the large number of CHF studies performed in directly heated tubes during the past 50 years, significant gaps in the data remain, where CHF predictions are based on extrapolation and models predictions. Additional CHF experiments are required to fill these gaps.

Acknowledgements

The financial assistance for the development of the new 2006 CHF look-up table was provided by NSERC. The development of previous versions of the CHF look-up table was supported by AECL, ANSL, EPRI, CEA and the IAEA.

Appendix A. Limiting quality region

The limiting quality phenomenon (LQR) is characterized by a fast decrease in CHF with an increase of steam quality. The LQR usually occurs in the intermediate steam quality region. To illustrate the limiting quality phenomenon, Doroshchuk et al. (1970) and Bennet et al. (1967) divided the critical heat flux versus quality curve into three regions as is illustrated in Fig. A1. The annular flow regime occurs in all three regions, but it is postulated (e.g. Bennet et al., 1967) that in region I the primary mechanism responsible for CHF occurrence is droplet entrainment from the thick liquid film. This mechanism is quite effective in reducing the film thickness thus depleting the annular film flow rate until the film breaks down. Region III in characterized by a very thin liquid film which is replenished by deposition from the entraiment laden vapor stream. Since the entrainment rate from a thin liquid film is virtually zero, CHF occurs when the evaporation rate (q/H_{fg}) exceeds the deposition rate, which explains the low CHFs in region III. The intermediate region II is referred to as the limiting quality region because of the steep CHF versus X slope.

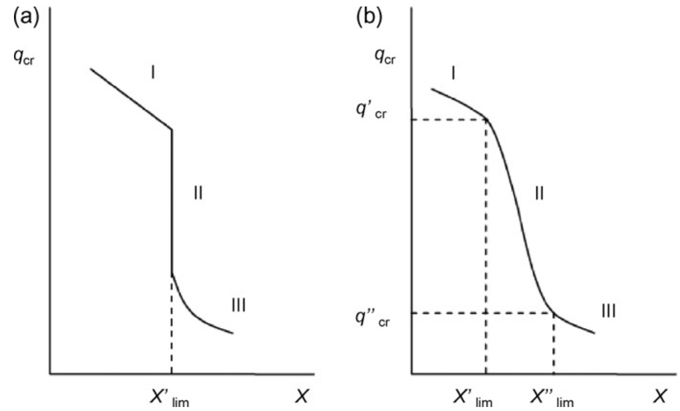

Fig. A1. Schematic representation of the limiting quality region.

Peng et al. (2004) reviewed the available literature on the LQR and, using the UofO data bank, he tabulated the LQR boundaries. A similar approach was recently undertaken at the University of Ottawa using Durmayaz's et al. (2004) "slice" method. The boundaries were defined as shown in Fig. A1(b): the point where the slope first showed a significant change ($q'_{cr}X'_{lim}$) was considered typical of the start of the LQR while the point of the next slope change combined with a low CHF ($q''_{cr}X''_{lim}$) was considered the end of the LQR.

Appendix B. 2006 CHF look-up table

Pressure [kPa]	Mass Flux [$kg\ m^{-2}\ s^{-1}$]	CHF [$kW\ m^{-2}$]																						
	X→	-0.50	-0.40	-0.30	-0.20	-0.15	-0.10	-0.05	0.00	0.05	0.10	0.15	0.20	0.25	0.30	0.35	0.40	0.45	0.50	0.60	0.70	0.80	0.90	1
100	0	8111	7252	6302	4802	4086	3057	1990	1142	637	415	284	223	188	165	152	142	133	123	114	110	96	55	0
100	50	8317	7271	6326	5035	4236	3453	2420	1570	1011	784	641	587	553	531	475	443	419	387	347	277	239	204	0
100	100	8390	7295	6371	5322	4586	3640	2942	2103	1558	1275	1013	885	847	811	789	758	745	715	700	600	459	359	0
100	300	10698	9288	7795	6020	5009	3865	3196	2479	1961	1707	1317	1177	1172	1159	1150	1100	1085	1041	1031	675	517	366	0
100	500	12882	10946	9224	6791	5348	3938	3369	2685	2087	1808	1412	1347	1311	1303	1282	1260	1212	1193	1071	605	450	295	0
100	750	16982	14405	11641	7496	5662	4234	3471	2780	2229	1970	1649	1606	1591	1563	1510	1495	1400	1280	595	415	243	206	0
100	1000	19441	16278	13255	8232	5971	4495	3533	3012	2653	2349	2070	2000	1980	1930	1715	1550	1359	1165	503	322	172	105	0
100	1500	22781	19225	15465	9100	6603	5358	3741	3524	3166	2917	2635	2572	2467	2378	1908	1350	1005	815	302	210	126	51	0
100	2000	25268	21321	17143	9141	7059	6036	4074	3855	3556	3402	3167	2986	2720	2549	1696	1105	805	595	247	105	87	39	0
100	2500	28026	23599	18346	9503	7506	6516	4502	4047	3852	3599	3228	3019	2676	2458	1148	956	708	485	290	120	46	22	0
100	3000	30294	25465	19383	9779	8063	7088	4826	4182	3976	3389	2968	2706	2369	1829	940	846	665	532	302	159	55	20	0
100	3500	32227	27043	21068	10156	8518	7302	5113	4384	4106	3196	2769	2557	2311	1729	1158	891	817	670	402	210	75	28	0
100	4000	33928	28471	22722	10512	8728	7528	5582	4709	4228	3119	2736	2504	2282	1850	1470	1160	1030	823	475	248	96	38	0
100	4500	35406	29774	23890	10945	9088	8067	6267	5013	4272	3287	2769	2541	2304	1972	1718	1405	1185	969	585	289	129	61	0
100	5000	36808	30988	24979	11185	9592	8576	6748	5113	4342	3410	2890	2629	2355	2066	1779	1498	1247	1030	647	347	167	81	0
100	5500	38232	32141	25791	11929	10084	8940	6867	5175	4389	3465	2954	2680	2406	2128	1848	1595	1334	1118	729	409	206	101	0
100	6000	39525	33222	26637	13026	10396	9347	6919	5241	4423	3580	2921	2681	2447	2170	1908	1651	1418	1204	807	468	244	121	0
100	6500	40727	34244	27480	14371	10748	9701	6995	5295	4491	3620	2918	2694	2477	2209	1965	1719	1493	1281	878	523	282	142	0
100	7000	41950	35224	28165	15045	11091	10522	7062	5370	4513	3668	2958	2724	2501	2247	2013	1780	1559	1349	943	576	319	162	0
100	7500	43448	36075	28604	15822	11538	10726	7087	5381	4585	3699	2996	2751	2526	2285	2060	1838	1622	1414	1000	615	347	180	0
100	8000	44338	36803	29089	16599	12085	10900	7313	5392	4689	3780	3031	2778	2553	2320	2103	1890	1679	1473	1054	651	371	196	0
	X→	-0.50	-0.40	-0.30	-0.20	-0.15	-0.10	-0.05	0.00	0.05	0.10	0.15	0.20	0.25	0.30	0.35	0.40	0.45	0.50	0.60	0.70	0.80	0.90	1
300	0	8027	7043	6206	4761	4106	3131	2483	1374	883	606	420	313	248	205	180	165	148	141	135	131	125	67	0
300	50	8153	7058	6287	5304	4564	3729	2847	2071	1587	1315	1052	871	709	599	516	499	457	389	372	362	274	207	0
300	100	8418	7315	6499	5509	4883	4013	3238	2638	2150	1869	1528	1373	1262	1183	1127	1065	1057	1033	902	691	502	394	0
300	300	10397	9094	7805	6085	5320	4107	3429	3011	2617	2263	1862	1657	1614	1576	1513	1480	1446	1403	1193	722	572	419	0
300	500	12787	10894	9193	6962	5664	4134	3563	3285	2821	2405	2001	1832	1688	1663	1610	1610	1520	1504	1112	616	452	297	0
300	750	16084	13658	11132	7493	5853	4282	3743	3512	2987	2538	2062	1868	1698	1676	1636	1598	1447	1300	656	440	253	207	0
300	1000	17866	15378	12753	8194	6038	4572	3898	3610	3224	2791	2450	2230	2070	1990	1805	1570	1369	1173	523	334	184	112	0
300	1500	21559	18208	14718	9252	7091	6091	4818	4243	3557	3134	2981	2720	2658	2491	2042	1365	1016	813	308	210	130	57	0
300	2000	23993	20257	16367	10134	8179	6790	5171	4462	3759	3490	3410	3232	2894	2672	1803	1108	822	599	254	118	88	41	0
300	2500	26215	22280	18013	10477	8534	7134	5245	4519	3951	3681	3444	3248	2846	2521	1168	981	732	488	292	132	47	23	0
300	3000	27747	23975	19028	10840	8691	7393	5326	4551	4081	3502	3082	2977	2523	1868	945	852	681	534	304	161	56	21	0
300	3500	29254	25440	20427	10948	8793	7585	5600	4681	4195	3283	2967	2695	2389	1788	1170	895	820	675	410	226	76	29	0
300	4000	30763	26771	21520	11006	8997	8017	6253	5184	4271	3344	2951	2648	2383	1960	1500	1170	1050	850	499	264	97	39	0
300	4500	32150	27994	22599	11137	9388	8517	6725	5594	4329	3504	2981	2677	2408	2094	1746	1423	1228	998	600	304	126	59	0
300	5000	33465	29133	23700	11600	9705	8845	7103	6052	4369	3655	3048	2739	2449	2139	1843	1542	1289	1061	665	358	165	80	0
300	5500	34919	30223	24325	12512	10147	9115	7281	6122	4427	3720	3070	2776	2501	2200	1881	1636	1377	1153	748	418	206	100	0
300	6000	36122	31241	25169	13522	10870	9576	7398	6323	4481	3685	3104	2773	2543	2247	1942	1708	1462	1241	828	476	244	121	0
300	6500	37231	32198	25960	14708	11330	10024	7446	6440	4571	3705	3123	2783	2578	2288	2004	1783	1543	1320	902	532	268	142	0
300	7000	38099	33093	26558	15513	11759	10532	7599	6469	4650	3772	3155	2812	2605	2327	2037	1844	1611	1391	970	586	303	150	0
300	7500	38989	34027	27283	16123	12062	10765	7689	6500	4702	3784	3221	2839	2625	2361	2095	1898	1673	1456	1029	627	331	166	0
300	8000	39744	34510	27900	16757	12891	11128	7784	6544	4760	3892	3228	2867	2649	2395	2126	1946	1728	1514	1083	664	356	181	0
	X→	-0.50	-0.40	-0.30	-0.20	-0.15	-0.10	-0.05	0.00	0.05	0.10	0.15	0.20	0.25	0.30	0.35	0.40	0.45	0.50	0.60	0.70	0.80	0.90	1
500	0	7743	6834	5910	4720	4136	3342	2518	1607	1129	798	557	404	308	245	209	188	163	159	157	156	137	105	0
500	50	7983	7004	6274	5355	4711	3853	2989	2170	1731	1344	1119	958	852	775	684	556	495	465	407	395	282	235	0
500	100	8478	7421	6632	5627	5080	4057	3317	2754	2270	1988	1704	1399	1316	1229	1188	1122	1116	1109	940	711	523	417	0
500	300	10280	8983	7804	6235	5491	4193	3498	3165	2835	2537	2243	2028	1826	1647	1611	1545	1503	1464	1255	749	592	449	0
500	500	12694	10885	9073	7008	5780	4281	3671	3339	3157	2811	2462	2253	1933	1711	1651	1630	1534	1506	1177	676	476	300	0
500	750	15186	12992	10624	7610	5957	4356	3855	3630	3442	2994	2680	2379	1982	1740	1699	1615	1469	1307	684	503	274	209	0
500	1000	17460	14778	12051	8057	6145	4629	4062	3870	3684	3304	3109	2885	2613	2251	1927	1599	1399	1179	540	362	186	119	0
500	1500	20438	17191	13972	9365	7340	6298	5248	4711	4048	3594	3491	3278	3149	2774	2123	1382	1056	833	310	215	134	65	0
500	2000	22719	19293	15591	10327	8310	7309	5675	5017	4215	3772	3693	3578	3169	2795	1850	1115	832	603	260	132	89	43	0
500	2500	25104	20961	17081	10751	8703	7675	5987	5151	4435	3863	3759	3478	3017	2647	1176	1009	780	492	296	145	48	24	0
500	3000	26621	22486	18273	11002	8920	8034	6194	5168	4595	3955	3690	3216	2761	1905	948	862	698	560	306	163	58	22	0
500	3500	28248	23838	19186	11141	9008	8154	6399	5384	4757	3992	3489	3066	2723	1856	1201	899	825	681	420	229	77	30	0
500	4000	29719	25071	20019	11201	9267	8238	6955	5858	4922	4029	3355	2991	2692	2090	1540	1180	1060	870	532	271	98	39	0
500	4500	31075	26215	20508	11429	9919	8968	7201	6212	5083	4098	3257	2958	2663	2204	1776	1437	1240	1003	612	315	124	54	0
500	5000	32376	27279	21190	11913	10245	9208	7321	6399	5162	4132	3186	2907	2639	2230	1858	1551	1310	1085	693	368	153	70	0
500	5500	33684	28306	22359	12695	10581	9306	7407	6209	5291	4141	3175	2896	2637	2259	1927	1651	1401	1178	772	423	186	86	0
500	6000	34756	29261	23302	14018	11114	9598	7526	6332	5399	4190	3180	2913	2652	2287	1985	1728	1482	1263	850	478	220	103	0
500	6500	35781	30153	24141	14945	11567	9948	7751	6496	5481	4230	3246	2935	2666	2319	2029	1797	1560	1342	927	534	254	121	0
500	7000	36804	30962	24952	15581	12151	10333	8027	6828	5588	4307	3294	2939	2682	2361	2077	1864	1632	1416	997	588	288	139	0
500	7500	38036	31979	25663	16185	12686	10753	8176	6845	5700	4370	3351	2947	2697	2398	2127	1918	1695	1480	1060	631	315	153	0
500	8000	39197	33017	26712	17016	13200	11107	8256	6896	5794	4485	3389	3069	2734	2442	2177	1967	1751	1540	1120	672	342	166	0
	X→	-0.50	-0.40	-0.30	-0.20	-0.15	-0.10	-0.05	0.00	0.05	0.10	0.15	0.20	0.25	0.30	0.35	0.40	0.45	0.50	0.60	0.70	0.80	0.90	1
1000	0	7347	6383	5570	4657	4175	3535	2776	2159	1820	1320	940	678	492	377	318	291	269	254	231	220	193	145	0
1000	50	7700	6956	6204	5406	4891	4169	3412	2702	2473	1966	1607	1351	1179	1068	933	770	723	706	586	522	369	282	0
1000	100	8581	7702	6906	5824	5173	4600	4000	3609	3069	2549	2380	2216	2087	1949	1798	1700	1652	1541	1280	1078	708	501	0

Pressure [kPa]	Mass Flux [kg m^{-2} s^{-1}]	CHF [kW m^{-2}]																						
1000	300	10093	8830	7796	6476	5710	4793	4140	4013	3901	3685	3471	3372	3276	3172	2993	2871	2766	2594	1727	1302	815	514	0
1000	500	12148	10478	8703	7200	6004	4837	4259	4124	4063	3995	3980	3953	3938	3790	3678	3579	3537	3445	1564	1067	649	377	0
1000	750	14675	12510	10033	7775	6255	4896	4378	4337	4228	4200	4162	4083	3997	3851	3810	3473	3291	3102	832	623	322	213	0
1000	1000	17023	14042	11114	8024	6275	4978	4804	4736	4616	4351	4177	4099	3998	3896	3708	3148	2620	1199	636	391	189	128	0
1000	1500	20026	16859	13366	9481	7659	6918	6497	5831	5246	4610	4271	4057	3704	3655	3049	1601	1238	843	315	218	138	75	0
1000	2000	22495	18764	14921	10539	9084	7740	6830	6373	5480	4704	4407	3992	3596	3330	1957	1122	873	624	268	155	90	46	0
1000	2500	24717	20601	16332	11001	9794	8318	7090	6583	5633	4794	4338	3811	3566	2927	1197	1012	823	521	300	149	49	26	0
1000	3000	26264	22053	17370	11532	10209	8496	7195	6673	5671	4871	4244	3718	3325	2007	977	895	701	583	313	168	59	24	0
1000	3500	27894	23473	18245	11516	10075	8480	7278	6704	5714	4887	4229	3597	3109	1924	1223	919	831	690	431	247	80	33	0
1000	4000	29406	24586	18990	11029	9419	8550	7359	6714	5752	4750	4075	3520	3031	2210	1620	1230	1090	890	545	300	101	40	0
1000	4500	30773	25743	19791	11226	9952	9143	7572	6924	5778	4571	3881	3430	2986	2349	1805	1456	1249	1030	629	331	122	51	0
1000	5000	31994	26863	20592	12193	10358	9185	7623	6934	5919	4492	3722	3317	2924	2357	1874	1562	1337	1109	703	372	146	64	0
1000	5500	33271	27872	21588	13122	10898	9280	7551	6744	6006	4590	3694	3272	2887	2358	1938	1664	1428	1200	781	427	173	78	0
1000	6000	34314	28814	22490	14247	11388	9491	7633	6655	6024	4616	3548	3236	2856	2372	2006	1746	1506	1280	856	477	204	95	0
1000	6500	35402	29678	23127	14949	11882	9883	7866	6765	6151	4649	3592	3194	2864	2403	2060	1829	1587	1362	935	530	236	112	0
1000	7000	36417	30478	23637	15247	12338	10051	8088	6875	6185	4676	3617	3231	2818	2445	2122	1909	1670	1445	1008	583	269	129	0
1000	7500	37289	31065	24195	16170	12803	10604	8228	6965	6238	4694	3628	3251	2897	2480	2219	1968	1736	1512	1074	630	291	140	0
1000	8000	38003	31712	25017	17157	13534	11049	8426	6995	6294	4822	3674	3301	2917	2547	2272	2021	1794	1573	1136	668	312	150	0
	X→	-0.50	-0.40	-0.30	-0.20	-0.15	-0.10	-0.05	0.00	0.05	0.10	0.15	0.20	0.25	0.30	0.35	0.40	0.45	0.50	0.60	0.70	0.80	0.90	1
2000	0	7060	6243	5413	4622	4189	3713	3173	2594	2165	1704	1302	970	745	587	491	438	380	361	323	317	232	170	0
2000	50	7497	6756	6040	5351	4927	4460	3982	3450	3005	2552	2160	1834	1613	1447	1331	1209	1089	1069	924	845	658	373	0
2000	100	8767	7820	7040	6207	5946	5556	5241	4757	4071	3657	3326	3072	2933	2801	2599	2487	2393	2313	1996	1720	1123	594	0
2000	300	9784	8590	7775	7108	6722	6403	6064	5659	5220	4908	4646	4362	4026	3725	3563	3475	3375	3276	2998	2266	1252	690	0
2000	500	11464	9687	8430	7528	6977	6611	6260	6084	5540	5280	4924	4584	4373	4197	4076	3929	3828	3695	3362	1898	1109	609	0
2000	750	13730	11557	9579	7868	7076	6656	6388	6097	5696	5338	5083	4870	4700	4590	4478	4396	4033	3811	1948	1194	700	229	0
2000	1000	16027	13171	10583	7982	7118	6692	6371	6185	5781	5417	5197	5083	4992	4961	4792	4196	3311	2751	1260	597	359	174	0
2000	1500	18947	15537	12233	9416	8215	7670	7342	6660	6095	5463	5141	4871	4766	4524	4389	2926	1903	897	512	288	163	97	0
2000	2000	21106	17297	13588	10513	9584	8982	8305	7261	6199	5406	4996	4595	4283	3824	3026	1357	1172	682	418	196	97	60	0
2000	2500	23353	19098	14933	11161	10279	8996	8116	7196	5976	5302	4856	4552	3943	3328	1613	1237	958	556	313	157	53	29	0
2000	3000	25197	20509	15816	11602	10578	8792	7549	7112	5860	5169	4798	4483	3798	2570	1185	1020	731	594	331	172	59	27	0
2000	3500	26816	21723	16526	11317	10169	8672	7475	7057	5794	5042	4687	4310	3476	2403	1342	979	839	697	442	254	83	36	0
2000	4000	28328	22765	16902	10802	9806	8752	7542	7103	5878	4951	4485	3868	3301	2367	1642	1318	1147	996	606	318	104	40	0
2000	4500	29717	23920	17644	10857	9984	8899	7663	7149	5913	4875	4223	3760	3206	2375	1758	1445	1258	1062	653	340	119	47	0
2000	5000	30638	24767	18164	11811	10290	9037	7624	7195	5997	4789	4069	3605	3089	2389	1803	1545	1346	1131	712	380	134	56	0
2000	5500	32102	25866	18832	12769	10862	9069	7652	7041	6021	4783	3970	3532	3006	2379	1897	1647	1440	1212	781	412	153	67	0
2000	6000	33085	26751	19986	13576	11244	9316	7681	6987	6065	4800	3812	3481	2959	2391	1992	1742	1516	1287	848	452	177	80	0
2000	6500	34156	27592	20946	14138	11703	9812	7927	6933	6099	4851	3728	3431	2947	2452	2094	1842	1602	1371	928	499	205	95	0
2000	7000	35131	28383	21563	14625	12253	10016	8186	6988	6134	4932	3753	3344	2933	2513	2190	1935	1692	1458	1006	551	233	110	0
2000	7500	35897	29010	22130	15499	12704	10558	8396	7041	6198	5027	3844	3322	2983	2581	2286	2013	1767	1530	1073	599	247	118	0
2000	8000	36663	29609	22628	16442	13306	10940	8676	7070	6292	5167	3886	3403	3098	2696	2363	2077	1827	1595	1134	633	259	123	0
	X→	-0.50	-0.40	-0.30	-0.20	-0.15	-0.10	-0.05	0.00	0.05	0.10	0.15	0.20	0.25	0.30	0.35	0.40	0.45	0.50	0.60	0.70	0.80	0.90	1
3000	0	6741	6001	5272	4593	4213	3873	3447	2943	2431	1979	1551	1181	929	741	615	539	482	443	396	350	247	178	0
3000	50	7222	6535	5910	5303	4961	4653	4297	3850	3325	2890	2482	2126	1884	1693	1549	1449	1361	1333	1219	1105	704	429	0
3000	100	8514	7599	6831	6315	6057	5809	5525	5121	4495	3921	3575	3415	3262	3171	3010	2948	2926	2771	2483	2059	1264	672	0
3000	300	9536	8324	7523	7171	7064	6874	6780	6474	6115	5666	5165	4849	4508	4218	3971	3752	3545	3485	3140	2620	1630	893	0
3000	500	10708	9149	8018	7426	7188	7073	6950	6649	6453	5959	5439	5061	4767	4432	4259	4150	3967	3742	3589	2645	1604	956	0
3000	750	12850	10680	8910	7794	7444	7249	7010	6753	6553	6159	5644	5287	4988	4677	4591	4477	4271	3926	3069	1951	930	382	0
3000	1000	14637	12105	9835	7934	7668	7280	7085	6777	6547	6178	5762	5420	5207	4928	4690	4459	3879	3581	2405	1146	587	270	0
3000	1500	17032	14038	11355	9127	8517	8118	7806	7186	6517	6030	5546	5170	4998	4699	4281	3622	3030	2756	755	656	256	139	0
3000	2000	18967	15630	12632	10069	9300	8626	8094	7373	6337	5718	5192	4738	4342	3782	3448	2612	1739	938	499	279	115	82	0
3000	2500	21002	17244	13569	10901	9793	8745	7997	7221	6085	5432	4993	4483	3959	3547	2900	1819	978	657	342	169	63	39	0
3000	3000	22678	18551	14553	11208	10022	8672	7642	6860	5771	5187	4839	4355	3698	3152	2289	1188	774	578	348	179	63	32	0
3000	3500	24225	19619	15027	10936	9909	8471	7428	6681	5567	5023	4646	4230	3567	2745	1684	1107	859	717	458	268	92	39	0
3000	4000	25515	20591	15544	10471	9773	8428	7236	6508	5489	4877	4475	3897	3404	2484	1609	1338	1175	1004	625	334	110	41	0
3000	4500	26660	21487	15956	10512	9920	8426	7206	6588	5452	4690	4299	3747	3179	2366	1680	1410	1235	1079	668	355	119	47	0
3000	5000	27501	22290	16371	11621	10005	8768	7328	6596	5395	4583	4141	3624	3095	2314	1740	1498	1329	1142	717	382	131	54	0
3000	5500	28809	23183	17231	12402	10644	8980	7486	6632	5297	4509	3993	3593	3009	2318	1828	1606	1429	1215	781	400	147	63	0
3000	6000	29772	24039	18048	13154	11082	9224	7628	6695	5194	4444	3860	3543	2963	2333	1936	1719	1506	1282	839	434	168	75	0
3000	6500	30660	24751	18858	13660	11303	9721	7856	6714	5329	4555	3791	3514	2974	2439	2068	1835	1598	1364	917	479	194	89	0
3000	7000	31524	25478	19488	14216	11986	10000	8174	6762	5540	4605	3787	3398	2974	2535	2197	1944	1696	1457	999	531	223	104	0
3000	7500	32450	26191	20150	14817	12357	10509	8486	6885	5646	4685	3850	3328	3008	2644	2326	2034	1775	1531	1067	574	239	112	0
3000	8000	33419	26895	20708	15335	12944	10989	8752	6939	5798	4902	3882	3428	3160	2801	2418	2105	1838	1597	1129	605	253	119	0
	X→	-0.50	-0.40	-0.30	-0.20	-0.15	-0.10	-0.05	0.00	0.05	0.10	0.15	0.20	0.25	0.30	0.35	0.40	0.45	0.50	0.60	0.70	0.80	0.90	1
5000	0	6044	5513	4986	4500	4239	3976	3666	3277	2677	2242	1808	1417	1154	944	795	694	619	561	456	366	257	191	0
5000	50	6547	6028	5573	5138	4921	4675	4407	4046	3467	3055	2662	2309	2065	1869	1715	1595	1493	1387	1330	1160	608	385	0
5000	100	7615	6922	6388	6040	5888	5703	5517	5192	4529	3997	3709	3524	3374	3240	3148	3053	3000	2837	2575	2202	1460	753	0
5000	300	8492	7453	6937	6709	6623	6510	6401	6207	5915	5395	4980	4709	4502	4302	3938	3662	3502	3255	2890	2511	1670	989	0
5000	500	9226	7886	7222	6839	6746	6655	6577	6460	6113	5594	5196	4866	4637	4339	4140	3882	3686	3517	3085	2490	1880	1104	0
5000	750	10677	9042	7794	7085	6908	6789	6666	6491	6126	5749	5213	4906	4675	4350	4160	3851	3574	3330	2760	2380	1519	814	0
5000	1000	12213	10204	8466	7447	7095	6989	6834	6568	6028	5726	5182	4796	4545	4194	3883	3496	3281	2974	2476	1683	690	379	0

Pressure [kPa]	Mass Flux [kg m^{-2} s^{-1}]	CHF [kW m^{-2}]																						
5000	1500	14030	11668	9617	8115	7597	7296	7024	6470	5710	5375	4875	4438	4167	3795	3357	2941	2531	2290	914	592	393	200	0
5000	2000	15633	12936	10401	8530	7889	7408	6946	6107	5170	4836	4340	3913	3599	3257	2909	2412	1979	1182	638	354	188	130	0
5000	2500	17335	14268	11308	8887	7972	7432	6712	5661	4880	4445	4017	3662	3295	2876	2689	1915	955	651	447	195	99	51	0
5000	3000	18794	15433	12150	9231	8180	7463	6490	5427	4718	4265	3857	3476	3104	2578	2283	1429	708	533	405	179	73	41	0
5000	3500	19936	16374	12894	9768	8306	7477	6368	5026	4484	3984	3644	3312	2932	2394	1781	1164	910	706	513	290	103	42	0
5000	4000	20949	17217	13569	9991	8683	7658	6295	4783	4200	3584	3367	3140	2745	2274	1402	1188	1060	922	593	320	111	44	0
5000	4500	21962	18016	14114	10137	9063	7837	6323	4905	4130	3522	3305	3023	2672	2065	1424	1245	1128	1046	649	346	117	46	0
5000	5000	22867	18766	14525	10880	9540	8183	6486	5030	4103	3487	3287	3017	2684	2024	1455	1329	1224	1112	695	362	124	51	0
5000	5500	23661	19456	15309	11569	10048	8548	6741	5245	4051	3480	3299	3060	2672	2047	1628	1480	1351	1176	743	379	135	57	0
5000	6000	24391	20103	15958	12239	10650	8921	7328	5430	4008	3507	3314	3079	2696	2057	1747	1598	1449	1240	793	405	152	67	0
5000	6500	25098	20718	16511	12734	10892	9511	7643	5637	4183	3523	3357	3128	2771	2258	1947	1783	1549	1314	855	437	172	78	0
5000	7000	25860	21312	16907	13189	11608	9908	7949	5781	4373	3553	3386	3182	2857	2430	2136	1893	1639	1396	926	482	197	91	0
5000	7500	26597	21982	17360	13563	11914	10298	8281	6006	4572	3786	3444	3201	2944	2603	2250	1988	1716	1466	990	512	211	98	0
5000	8000	27254	22428	17865	13912	12316	10851	8676	6217	4805	4010	3629	3362	3178	2817	2409	2068	1783	1533	1052	543	225	105	0
	X→	-0.50	-0.40	-0.30	-0.20	-0.15	-0.10	-0.05	0.00	0.05	0.10	0.15	0.20	0.25	0.30	0.35	0.40	0.45	0.50	0.60	0.70	0.80	0.90	1
7000	0	5445	5059	4676	4323	4139	3937	3677	3322	2696	2256	1848	1479	1243	1036	891	778	692	621	525	389	267	209	0
7000	50	5919	5536	5191	4863	4698	4520	4306	3998	3399	2986	2624	2264	2042	1859	1712	1588	1477	1366	1151	1010	473	325	0
7000	100	6912	6301	5871	5584	5462	5261	5095	4849	4271	3776	3499	3290	3142	3034	2906	2850	2651	2486	2123	1673	1205	768	0
7000	300	7445	6709	6259	6020	5914	5761	5662	5495	5182	4752	4464	4070	3764	3611	3417	3250	3028	2738	2286	1994	1408	869	0
7000	500	7842	6895	6435	6188	5996	5931	5818	5672	5408	4922	4521	4196	3989	3812	3602	3459	3221	2905	2482	1985	1547	869	0
7000	750	9129	7841	6867	6263	6154	5998	5895	5776	5430	4987	4538	4131	3918	3709	3464	3327	3118	2770	2312	1904	1400	742	0
7000	1000	10186	8774	7390	6532	6313	6276	6162	5864	5366	4920	4399	3935	3723	3447	3112	2884	2713	2432	2085	767	506	341	0
7000	1500	11920	10072	8460	7262	6915	6647	6308	5729	5059	4561	4039	3612	3279	2991	2698	2490	2264	1591	599	372	318	191	0
7000	2000	13294	11209	9172	7557	7279	6769	6187	5327	4570	4020	3552	3174	2864	2566	2353	1919	1406	793	483	267	197	134	0
7000	2500	14680	12245	9774	7920	7382	6765	5895	4977	4178	3639	3207	2867	2552	2211	1941	1487	813	521	342	177	103	58	0
7000	3000	15871	13214	10463	8259	7522	6778	5785	4761	3971	3366	3014	2640	2333	2111	1685	951	493	429	307	157	77	43	0
7000	3500	16889	14072	11223	8783	7744	6972	5738	4518	3739	3127	2816	2482	2188	1798	1357	851	631	531	388	224	96	44	0
7000	4000	17783	14824	11868	9277	8077	7118	5593	4226	3539	2855	2616	2362	2104	1710	1251	957	789	681	444	255	99	44	0
7000	4500	18619	15498	12439	9619	8281	7208	5381	4156	3422	2650	2472	2268	2057	1647	1239	1006	867	779	487	266	102	45	0
7000	5000	19434	16132	12870	10084	8686	7415	5486	4350	3409	2611	2486	2251	2040	1619	1279	1052	950	854	526	277	106	47	0
7000	5500	20138	16733	13579	10563	9272	7844	6153	4649	3405	2688	2460	2325	2076	1662	1397	1217	1065	933	576	298	115	52	0
7000	6000	20703	17309	14047	11354	9947	8657	6697	4756	3417	2725	2487	2353	2087	1697	1476	1339	1184	1018	637	327	131	60	0
7000	6500	21284	17855	14610	11951	10355	9156	7135	4905	3437	2733	2525	2442	2241	1938	1688	1515	1303	1103	702	360	149	69	0
7000	7000	21889	18357	15013	12260	10817	9456	7309	4949	3504	2872	2648	2499	2348	2094	1852	1615	1393	1182	771	401	170	80	0
7000	7500	22505	18841	15385	12539	11244	9779	7455	5004	3629	3017	2792	2596	2488	2263	2039	1776	1504	1264	838	433	182	86	0
7000	8000	23064	19305	15794	12917	11519	10059	7792	5163	3777	3222	3120	3063	2927	2605	2282	1893	1592	1345	904	463	193	91	0
	X→	-0.50	-0.40	-0.30	-0.20	-0.15	-0.10	-0.05	0.00	0.05	0.10	0.15	0.20	0.25	0.30	0.35	0.40	0.45	0.50	0.60	0.70	0.80	0.90	1
10000	0	4624	4375	4128	3896	3774	3627	3426	3122	2501	2018	1664	1365	1208	1041	910	809	734	677	582	404	244	205	0
10000	50	5040	4787	4542	4302	4182	4042	3857	3586	2977	2514	2217	1984	1824	1678	1583	1501	1402	1250	1018	758	386	281	0
10000	100	5711	5424	5083	4812	4696	4507	4371	4158	3699	3259	2970	2830	2654	2505	2354	2059	1840	1620	1293	999	668	467	0
10000	300	6240	5751	5329	5036	4934	4777	4690	4523	4197	3777	3361	3136	2994	2803	2635	2398	2250	1922	1707	1267	915	505	0
10000	500	6422	5774	5441	5059	4945	4837	4744	4583	4328	3920	3461	3206	3005	2804	2640	2386	2147	1830	1528	1203	806	431	0
10000	750	7259	6426	5740	5233	5035	4842	4761	4501	4263	3879	3404	3093	2879	2640	2443	2071	1760	1455	1080	713	347	238	0
10000	1000	8156	7090	6125	5478	5179	4985	4762	4439	4149	3793	3295	2886	2595	2280	1986	1783	1465	1183	356	156	108	105	0
10000	1500	9449	8185	7053	6227	5689	5217	4781	4311	3892	3446	2977	2526	2095	1865	1547	1203	378	295	176	79	59	51	0
10000	2000	10490	8949	7655	6479	5965	5398	4762	4131	3467	2960	2452	2020	1708	1391	1054	393	247	183	125	65	50	46	0
10000	2500	11536	9833	8292	6889	6216	5619	4784	4013	3282	2691	2188	1776	1469	1177	738	342	288	182	140	80	54	39	0
10000	3000	12449	10561	8790	7196	6491	5789	4822	3893	3116	2432	1939	1580	1354	998	675	396	337	232	176	98	50	32	0
10000	3500	13181	11191	9261	7712	6887	6007	4842	3862	2998	2277	1809	1526	1314	1076	775	528	406	365	254	131	75	38	0
10000	4000	13882	11788	9761	8080	7079	6163	4875	3813	2936	2079	1704	1521	1251	1153	881	694	525	445	299	153	76	39	0
10000	4500	14555	12363	10227	8450	7344	6374	4885	3798	2877	2027	1709	1562	1331	1279	1048	763	611	513	342	174	81	40	0
10000	5000	15087	12776	10637	8882	7723	6804	4955	3928	2889	2082	1715	1608	1460	1314	1073	832	683	575	395	200	87	42	0
10000	5500	15617	13257	11054	9422	8279	7203	5517	4119	2942	2106	1824	1763	1638	1478	1261	964	822	681	453	231	96	45	0
10000	6000	16191	13799	11553	9797	8723	7611	5821	4226	3014	2189	1975	1867	1723	1539	1323	1109	963	816	526	267	111	52	0
10000	6500	16692	14162	11890	10082	9097	7925	5990	4326	3023	2297	2073	2020	1843	1697	1500	1314	1098	923	595	305	129	60	0
10000	7000	17149	14598	12284	10292	9215	8047	6128	4397	3082	2339	2209	2103	2006	1850	1618	1394	1179	1004	658	343	147	70	0
10000	7500	17628	15027	12656	10529	9450	8245	6145	4440	3190	2370	2320	2190	2170	2000	1740	1491	1270	1084	719	373	159	75	0
10000	8000	18123	15428	12988	10706	9587	8466	6263	4626	3587	3056	2981	2800	2700	2347	2006	1665	1403	1174	781	402	170	80	0
	X→	-0.50	-0.40	-0.30	-0.20	-0.15	-0.10	-0.05	0.00	0.05	0.10	0.15	0.20	0.25	0.30	0.35	0.40	0.45	0.50	0.60	0.70	0.80	0.90	1
12000	0	4070	3883	3698	3525	3433	3322	3163	2914	2391	1936	1606	1334	1173	1026	909	814	745	694	588	397	225	141	0
12000	50	4436	4247	4061	3869	3770	3658	3506	3285	2784	2367	2081	1857	1694	1565	1498	1357	1200	1087	867	667	381	242	0
12000	100	5023	4806	4538	4290	4171	3983	3844	3645	3267	2878	2711	2500	2257	2069	1905	1622	1460	1290	977	772	446	301	0
12000	300	5366	5081	4741	4434	4269	4138	3950	3838	3516	3199	2912	2701	2467	2285	2108	1940	1830	1630	1250	840	500	316	0
12000	500	5647	5188	4869	4445	4298	4131	3988	3819	3555	3240	2951	2724	2500	2310	2160	1875	1678	1474	1011	423	296	205	0
12000	750	6233	5596	5072	4528	4310	4067	3904	3659	3418	3067	2773	2526	2277	2039	1798	1396	1180	989	312	251	211	131	0
12000	1000	7031	6267	5500	4700	4430	4100	3855	3447	3243	2878	2516	2291	1905	1640	1420	1073	920	310	214	118	78	76	0
12000	1500	8214	7105	6221	5242	4662	4271	3813	3405	2952	2526	2112	1723	1389	1096	918	377	315	205	105	41	39	36	0
12000	2000	8959	7711	6598	5472	4982	4417	3841	3375	2830	2300	1816	1410	1109	911	385	119	110	77	71	50	37	31	0
12000	2500	9851	8471	7225	5977	5407	4720	3900	3367	2739	2119	1603	1215	971	753	293	172	139	119	99	59	40	27	0
12000	3000	10436	9128	7655	6409	5706	4923	3949	3364	2690	1985	1492	1101	889	689	354	300	245	195	154	81	45	26	0

Pressure [kPa]	Mass Flux [kg m^{-2} s^{-1}]	CHF [kW m^{-2}]																						
12000	3500	11000	9572	7966	6675	5958	5076	4002	3360	2680	1910	1409	1138	922	772	414	404	329	294	221	109	66	35	0
12000	4000	11291	9879	8449	7028	6239	5226	4061	3326	2680	1904	1456	1244	1077	923	693	586	454	361	251	131	70	36	0
12000	4500	11695	10442	8797	7329	6398	5397	4163	3353	2698	1927	1529	1383	1174	1097	862	685	539	418	294	154	75	38	0
12000	5000	12117	10856	9117	7579	6726	5903	4418	3478	2772	2010	1637	1431	1254	1154	921	726	573	465	341	183	82	40	0
12000	5500	12466	11071	9431	7831	7005	6089	4517	3728	2908	2140	1867	1621	1469	1345	1105	909	704	564	401	214	91	43	0
12000	6000	13176	11559	9782	8050	7166	6225	4603	3885	3060	2229	1986	1781	1627	1472	1254	1065	868	721	483	252	105	49	0
12000	6500	14034	12051	10061	8249	7390	6426	4668	3941	3128	2355	2150	1949	1811	1623	1447	1220	1023	852	558	290	122	57	0
12000	7000	14607	12508	10487	8532	7609	6605	4731	4011	3192	2432	2217	2093	1955	1730	1554	1342	1126	945	622	326	140	66	0
12000	7500	14975	12908	10907	8703	7863	6710	4821	4080	3250	2490	2284	2170	2077	1921	1676	1441	1227	1034	683	355	152	72	0
12000	8000	15432	13298	11407	8898	8033	6904	4932	4219	3398	2827	2737	2527	2420	2168	1912	1606	1370	1142	749	384	162	76	0
	X→	-0.50	-0.40	-0.30	-0.20	-0.15	-0.10	-0.05	0.00	0.05	0.10	0.15	0.20	0.25	0.30	0.35	0.40	0.45	0.50	0.60	0.70	0.80	0.90	1
14000	0	3505	3372	3240	3113	3046	2965	2846	2654	2242	1848	1544	1296	1129	992	884	799	736	691	585	384	202	113	0
14000	50	3808	3676	3552	3413	3338	3250	3129	2951	2557	2195	1919	1710	1527	1363	1230	1114	1035	930	790	565	310	185	0
14000	100	4244	4060	3897	3721	3617	3500	3371	3206	2909	2586	2280	1961	1791	1575	1469	1262	1193	1023	811	595	342	204	0
14000	300	4479	4268	4074	3858	3727	3586	3448	3301	2996	2701	2358	2100	1970	1756	1651	1481	1308	1143	842	615	347	217	0
14000	500	4680	4404	4184	3876	3713	3545	3401	3249	3001	2641	2373	2089	1825	1559	1422	1273	1087	1017	319	298	192	119	0
14000	750	5155	4929	4487	3917	3666	3417	3241	3056	2841	2505	2177	1849	1591	1332	1131	885	769	502	265	135	79	77	0
14000	1000	6001	5588	4980	4089	3670	3378	3049	2693	2399	2051	1731	1466	1244	1017	854	745	649	295	224	102	67	49	0
14000	1500	6787	6145	5185	4364	3798	3406	3003	2583	2218	1807	1498	1200	971	765	555	196	180	138	119	53	43	34	0
14000	2000	7188	6465	5394	4496	3995	3628	3201	2686	2221	1751	1444	1121	879	603	419	176	125	108	93	58	41	26	0
14000	2500	7630	6781	5886	4902	4465	4006	3295	2832	2224	1773	1391	1024	831	564	312	213	139	119	102	62	42	27	0
14000	3000	7824	7031	6139	5394	4701	4236	3320	2894	2333	1831	1396	1082	865	604	318	275	237	201	146	80	47	31	0
14000	3500	8111	7338	6268	5532	4884	4356	3417	2963	2433	1897	1444	1140	927	710	491	420	340	281	200	108	61	32	0
14000	4000	8329	7457	6488	5706	5185	4498	3518	2992	2511	2029	1603	1307	1103	854	722	590	467	365	245	125	65	33	0
14000	4500	8718	7543	6537	5730	5344	4748	3789	3092	2558	2105	1709	1449	1207	1005	835	676	558	421	287	148	70	34	0
14000	5000	8978	7649	6594	5732	5451	4912	3963	3214	2692	2161	1745	1510	1280	1062	916	746	599	465	329	174	76	36	0
14000	5500	9249	7760	6609	5753	5505	4944	4043	3419	3026	2433	1989	1746	1475	1298	1107	940	746	572	390	206	87	40	0
14000	6000	9831	8166	6738	5864	5509	4956	4110	3463	3170	2575	2209	1986	1686	1420	1253	1082	893	709	468	242	101	47	0
14000	6500	10687	8715	6808	5894	5553	4972	4129	3544	3208	2617	2326	2201	1908	1609	1448	1241	1034	834	539	280	118	55	0
14000	7000	11414	9448	7169	6008	5694	4993	4140	3605	3202	2682	2339	2261	2018	1745	1556	1343	1129	924	603	317	136	64	0
14000	7500	12199	10064	7714	6137	5700	5016	4159	3729	3240	2689	2350	2270	2120	1836	1638	1433	1216	1013	666	347	148	70	0
14000	8000	12874	10581	8108	6231	5878	5214	4370	3809	3276	2806	2508	2342	2217	2033	1803	1565	1338	1116	733	376	159	75	0
	X→	-0.50	-0.40	-0.30	-0.20	-0.15	-0.10	-0.05	0.00	0.05	0.10	0.15	0.20	0.25	0.30	0.35	0.40	0.45	0.50	0.60	0.70	0.80	0.90	1
16000	0	2869	2780	2691	2603	2556	2500	2417	2276	1978	1667	1411	1199	1036	903	820	739	668	640	535	317	165	92	0
16000	50	3101	3014	2934	2837	2785	2723	2645	2508	2242	1962	1719	1460	1271	1132	982	882	821	750	569	391	219	145	0
16000	100	3434	3308	3154	3001	2897	2804	2716	2551	2331	2102	1818	1590	1419	1254	1153	1024	951	846	617	418	244	166	0
16000	300	3612	3465	3314	3127	2988	2833	2733	2585	2414	2206	1909	1718	1562	1451	1257	1129	1019	859	618	463	259	164	0
16000	500	3761	3553	3386	3152	2997	2819	2693	2534	2417	2180	1909	1595	1406	1261	1052	926	793	598	392	286	127	90	0
16000	750	4113	3800	3588	3251	3055	2798	2610	2387	2251	1985	1703	1280	1113	978	780	694	578	432	229	150	89	69	0
16000	1000	4785	4471	4003	3460	3102	2756	2504	2201	1918	1634	1353	1039	952	814	665	530	455	325	192	90	59	45	0
16000	1500	5406	4726	4165	3659	3280	2939	2419	2111	1888	1505	1226	1005	879	671	522	364	231	168	134	67	46	33	0
16000	2000	5808	5019	4352	3777	3449	3071	2740	2250	1921	1623	1328	1118	918	715	502	244	203	172	127	84	51	28	0
16000	2500	6312	5514	4978	4407	3973	3504	2954	2494	2086	1747	1450	1213	1004	795	531	347	265	211	153	93	52	28	0
16000	3000	6858	5972	5429	4894	4332	3748	3146	2611	2209	1857	1533	1269	1101	817	655	481	380	300	216	113	57	29	0
16000	3500	7286	6326	5695	5018	4511	3907	3255	2653	2311	1956	1614	1345	1170	831	717	541	435	353	248	123	59	29	0
16000	4000	7568	6686	5875	5296	4700	4136	3392	2756	2428	2157	1828	1560	1325	1030	886	710	607	453	297	138	62	30	0
16000	4500	8015	6902	6071	5483	4889	4352	3511	2876	2569	2225	1960	1684	1465	1164	988	808	674	525	335	155	66	31	0
16000	5000	8249	7179	6183	5529	5058	4562	3707	3017	2698	2293	2024	1777	1574	1220	1041	890	731	567	377	182	72	33	0
16000	5500	8569	7489	6212	5601	5064	4609	3752	3226	2913	2638	2244	2036	1731	1424	1265	1067	870	666	427	207	84	39	0
16000	6000	9059	7714	6377	5610	5103	4624	3812	3382	3073	2798	2412	2191	1900	1600	1392	1180	981	764	491	246	99	46	0
16000	6500	9480	8189	6573	5714	5255	4650	3828	3484	3126	2883	2531	2275	2016	1716	1524	1290	1086	854	549	278	116	54	0
16000	7000	9832	8567	6874	5878	5336	4677	3850	3511	3183	2888	2549	2298	2068	1801	1573	1376	1167	933	607	314	135	63	0
16000	7500	10170	8880	7084	5947	5402	4698	3872	3520	3190	2890	2571	2325	2104	1848	1618	1440	1229	1012	662	344	147	69	0
16000	8000	10566	9241	7422	6073	5475	4741	3960	3663	3204	2928	2610	2356	2160	1938	1739	1538	1321	1098	722	373	158	74	0
	X→	-0.50	-0.40	-0.30	-0.20	-0.15	-0.10	-0.05	0.00	0.05	0.10	0.15	0.20	0.25	0.30	0.35	0.40	0.45	0.50	0.60	0.70	0.80	0.90	1
18000	0	2198	2136	2076	1999	1970	1955	1900	1809	1617	1402	1218	1063	936	822	732	660	599	569	434	260	138	84	0
18000	50	2377	2295	2209	2043	2002	1960	1886	1782	1647	1408	1260	1138	1042	922	824	744	684	620	474	310	177	117	0
18000	100	2416	2316	2220	2084	2003	1944	1847	1733	1653	1405	1278	1157	1065	958	886	784	744	648	521	331	185	132	0
18000	300	2566	2353	2230	2083	1952	1895	1783	1646	1558	1407	1285	1149	1076	1009	933	821	775	661	527	322	175	119	0
18000	500	2609	2392	2232	1998	1899	1775	1655	1447	1350	1196	1113	1025	938	826	732	648	579	454	297	214	142	66	0
18000	750	2878	2510	2247	1993	1892	1754	1607	1429	1277	1153	1052	903	794	680	578	516	450	334	169	144	90	49	0
18000	1000	3081	2635	2312	1971	1877	1728	1574	1448	1279	1145	1018	870	749	670	550	426	394	260	137	80	56	36	0
18000	1500	3760	3260	2858	2479	2206	2032	1847	1599	1404	1231	1102	903	794	681	524	379	274	215	151	90	53	29	0
18000	2000	4277	3648	3255	2811	2566	2287	2119	1844	1640	1469	1351	1222	1093	956	757	420	307	267	162	98	51	25	0
18000	2500	4845	4453	4036	3480	3095	2681	2407	2016	1838	1623	1470	1319	1149	1025	832	523	406	338	226	119	52	25	0
18000	3000	5472	4760	4329	3736	3279	2831	2533	2167	1945	1728	1516	1352	1216	1094	876	629	493	426	287	137	55	25	0
18000	3500	5983	5028	4457	3802	3381	2894	2615	2280	2042	1825	1550	1453	1243	1123	899	743	571	500	384	166	59	26	0
18000	4000	6459	5438	4798	4007	3533	3059	2685	2383	2241	2004	1738	1639	1446	1216	1029	876	710	621	453	183	61	27	0
18000	4500	6562	5560	4925	4189	3748	3266	2801	2496	2325	2136	1926	1736	1565	1316	1102	957	751	676	482	195	64	28	0
18000	5000	6719	5688	5048	4297	3973	3492	2895	2606	2414	2245	2083	1796	1648	1388	1186	1009	795	720	489	213	72	31	0

Pressure [kPa]	Mass Flux [kg m^{-2} s^{-1}]	CHF [kW m^{-2}]																						
18000	5500	6820	5875	5205	4521	4157	3696	3053	2937	2717	2510	2265	2077	1861	1603	1360	1192	966	770	539	237	84	37	0
18000	6000	7067	6118	5412	4662	4293	3757	3123	3002	2856	2696	2421	2216	1969	1727	1465	1300	1063	861	585	266	99	44	0
18000	6500	7342	6385	5570	4764	4337	3813	3140	3018	2907	2781	2531	2305	2073	1825	1560	1376	1158	912	611	292	116	53	0
18000	7000	7625	6606	5716	4835	4412	3893	3166	3061	2921	2794	2536	2308	2080	1840	1594	1415	1208	968	640	320	133	62	0
18000	7500	7930	6835	5901	4941	4486	3929	3216	3070	2954	2636	2471	2326	2095	1875	1609	1443	1248	1022	670	342	143	67	0
18000	8000	8158	7075	6071	5107	4545	4009	3308	3110	2958	2771	2602	2356	2130	1923	1698	1501	1304	1084	711	364	152	71	0
	X→	-0.50	-0.40	-0.30	-0.20	-0.15	-0.10	-0.05	0.00	0.05	0.10	0.15	0.20	0.25	0.30	0.35	0.40	0.45	0.50	0.60	0.70	0.80	0.90	1
20000	0	1654	1497	1378	1240	1185	1179	1141	1092	992	947	900	872	787	719	646	568	493	438	347	213	94	55	0
20000	50	1692	1489	1356	1213	1172	1163	1123	1077	1004	950	898	848	780	715	659	575	528	451	345	230	118	73	0
20000	100	1706	1438	1300	1188	1163	1141	1114	1072	1028	974	914	840	784	709	656	595	540	470	343	234	137	75	0
20000	300	1739	1427	1208	1130	1110	1080	1070	1020	990	945	900	830	780	700	640	600	542	468	288	224	131	72	0
20000	500	1744	1338	1183	1030	975	940	903	879	835	797	761	729	680	624	545	488	438	388	204	153	90	53	0
20000	750	1796	1502	1237	1106	1029	968	914	810	766	730	695	637	585	550	502	444	342	292	170	109	75	41	0
20000	1000	1882	1636	1409	1200	1133	1086	1026	965	876	817	761	650	607	561	508	419	293	246	126	74	49	27	0
20000	1500	2459	2183	1889	1665	1549	1428	1318	1166	1045	982	905	835	763	700	620	439	286	224	130	75	42	22	0
20000	2000	3017	2693	2372	2088	1927	1729	1584	1395	1284	1221	1133	1046	977	872	812	611	423	268	152	89	44	21	0
20000	2500	3580	3154	2849	2542	2239	1971	1775	1612	1465	1360	1230	1154	1105	971	853	688	473	377	228	117	46	21	0
20000	3000	3946	3437	3038	2636	2359	2051	1906	1702	1562	1423	1270	1202	1157	1033	915	703	569	450	290	134	50	21	0
20000	3500	4162	3558	3067	2640	2400	2139	2011	1828	1658	1510	1380	1264	1190	1069	961	791	617	536	367	159	54	22	0
20000	4000	4261	3767	3268	2802	2543	2280	2138	1992	1875	1702	1585	1465	1341	1244	1086	920	741	649	439	178	57	23	0
20000	4500	4358	3923	3486	2992	2700	2470	2247	2101	1915	1788	1674	1539	1441	1344	1129	992	819	690	457	189	61	24	0
20000	5000	4517	4139	3648	3114	2874	2595	2381	2211	1995	1818	1716	1631	1517	1390	1167	1081	829	739	476	208	68	28	0
20000	5500	4718	4385	3876	3323	3012	2758	2579	2409	2214	2051	1957	1834	1687	1561	1328	1215	987	799	521	230	79	33	0
20000	6000	4922	4545	3983	3420	3175	2922	2691	2519	2353	2183	2082	1969	1796	1639	1413	1311	1080	884	576	259	94	40	0
20000	6500	5124	4667	4071	3515	3249	3017	2812	2638	2469	2247	2159	2024	1893	1721	1514	1362	1155	939	607	280	109	47	0
20000	7000	5323	4730	4120	3536	3303	3069	2878	2731	2531	2333	2205	2098	1934	1757	1553	1404	1201	986	639	302	123	52	0
20000	7500	5538	4808	4165	3580	3336	3093	2892	2771	2599	2396	2282	2128	1964	1774	1588	1436	1244	1028	679	322	128	56	0
20000	8000	5768	4925	4220	3625	3375	3155	2951	2843	2697	2484	2345	2177	2017	1850	1667	1484	1289	1074	699	330	130	57	0
	X→	-0.50	-0.40	-0.30	-0.20	-0.15	-0.10	-0.05	0.00	0.05	0.10	0.15	0.20	0.25	0.30	0.35	0.40	0.45	0.50	0.60	0.70	0.80	0.90	1
21000	0	1584	1462	1324	1222	1184	1147	1084	1008	939	904	821	733	644	570	501	440	415	366	309	194	84	45	0
21000	50	1587	1456	1301	1194	1164	1119	1062	999	938	900	823	736	685	650	578	501	457	411	303	197	99	53	0
21000	100	1589	1439	1270	1177	1124	1111	1060	992	948	894	826	739	697	668	599	527	469	417	300	198	102	55	0
21000	300	1601	1314	1133	1114	1102	1069	1037	959	925	857	801	730	700	669	600	510	473	399	278	169	97	56	0
21000	500	1617	1307	990	981	959	925	878	828	789	727	661	608	587	556	524	459	400	327	180	142	70	50	0
21000	750	1643	1411	1153	1045	1007	949	900	799	712	652	616	553	530	515	479	418	324	236	115	97	57	33	0
21000	1000	1787	1566	1328	1211	1130	1045	992	908	807	765	708	628	583	533	470	375	280	209	111	69	42	21	0
21000	1500	2261	1991	1764	1570	1422	1344	1228	1115	998	943	894	800	758	675	545	404	251	209	117	71	36	17	0
21000	2000	2689	2248	1983	1711	1594	1490	1395	1327	1225	1193	1101	971	874	812	741	526	343	230	150	88	35	15	0
21000	2500	2997	2554	2223	1903	1733	1609	1519	1426	1314	1260	1183	1109	988	900	816	623	445	349	214	102	36	15	0
21000	3000	3238	2847	2465	2068	1880	1706	1644	1547	1457	1302	1193	1170	1053	958	884	681	535	425	286	119	39	15	0
21000	3500	3393	2953	2590	2193	2012	1859	1772	1672	1543	1397	1284	1215	1130	993	933	773	601	516	343	138	42	16	0
21000	4000	3482	3160	2776	2356	2159	2004	1924	1794	1654	1541	1428	1347	1256	1155	1027	891	726	627	389	155	45	17	0
21000	4500	3532	3270	2896	2517	2289	2142	2028	1906	1752	1624	1544	1500	1348	1274	1100	973	809	674	421	167	49	18	0
21000	5000	3660	3436	3101	2646	2456	2256	2172	2016	1834	1742	1660	1596	1457	1350	1160	1063	818	711	451	181	54	21	0
21000	5500	3803	3603	3229	2831	2608	2447	2288	2165	1973	1880	1808	1726	1603	1482	1300	1184	939	793	492	199	61	24	0
21000	6000	3955	3698	3320	2917	2733	2544	2379	2256	2073	1965	1884	1823	1695	1572	1379	1277	1038	867	544	221	70	28	0
21000	6500	4116	3784	3378	2975	2801	2599	2485	2355	2203	2056	1990	1903	1780	1652	1478	1334	1100	924	579	239	78	32	0
21000	7000	4275	3839	3393	2985	2850	2658	2529	2447	2294	2117	2050	1971	1835	1693	1523	1373	1163	969	601	254	85	35	0
21000	7500	4471	3887	3394	3000	2880	2700	2589	2496	2361	2216	2129	2033	1872	1737	1566	1403	1214	1003	640	272	91	39	0
21000	8000	4689	3970	3405	3030	2900	2740	2598	2498	2410	2287	2170	2067	1902	1790	1622	1439	1260	1026	667	290	96	42	0

References

Bennet, A.W., Hewitt, G.F., Kearsey, H.A., Keeys, R.K.F., Pulling, D.J., 1967. Studies of burnout in boiling heat transfer. Trans. Instrum. Chem. Eng. 45, T319–T333.

Bertoletti, S., 1964. Heat Transfer to Steam—Water Mixtures, CISE R-78.

Doroshchuk, V.E., Lantsman, F.P., Levitan, L.L., 1970. A peculiar type of burnout in evaporator tubes. In: Heat Transfer 1970. Elsevier Pub. Co, Amsterdam, Netherlands, Paper B6.1.

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

Durmayaz, A., Groeneveld, D.C., Cheng, S.C., 2004. Assessment of critical-heat-flux look-up tables, experimental data and selected correlations. In: Proceedings of the Sixth International Conference on Simulation Methods in Nuclear Engineering, October 12–15, Montreal.

Era, A., Gaspari, G.P., Hassid, A., Milani, A., Zavattarelli, R., 1967. Heat Transfer Data in the Liquid Deficient Region for Steam–Water Mixtures at 70 kg/sm^2 Flowing in Tubular and Annular Conduits, Report CISE R-184.

Groeneveld, D.C., Cheng, S.C., Doan, T., 1986. AECL-UO critical heat flux lookup table. Heat Transfer Eng. 7, 46–62.

Groeneveld, D.C., Leung, L.K.H., Kirillov, P.L., Bobkov, V.P., Smogalov, I.P., Vinogradov, V.N., Huang, X.C., Royer, E., 1996. The 1995 look-up table for critical heat flux in tubes. Nucl. Eng. Des. 163, 1–23.

Hall, D.D., Mudawar, I., 2000. Critical heat flux for water flow in tubes—II subcooled CHF correlations. Int. J. Heat Mass Transfer 43, 2605–2640.

Huang, X.C., Cheng, S.C., 1994. Simple method for smoothing multidimensional experimental data with application to the CHF and post dryout look-up tables. Numer. Heat Transfer, Part B 26 (4), 425–438.

Ivey, H.J., Morris, D.J., 1962. On the Relevance of the Vapour–Liquid–Exchange Mechanism for Subcooled Boiling Heat Transfer at High Pressures, AEEW-R-137.

Katto, Y., 1992. A prediction model of subcooled water flow boiling CHF for pressure in the range 0.1–20 MPa. Int. J. Heat Mass Transfer 35 (5), 1115–1123.

Ladislau, L., 1978. The influence of pressure on critical heat flux at medium diameter (4 mm). In: Teplofizicheskie Issledovanija dlja Obespechenija Nadyozhnosti I Bezopasnosti Jadernyikh Reaktorov Vodo-Vodyanogo Tipa. Institute of Power Nuclear Reactors, Bucharest, Romania.

Mayinger F., 1967. Investigations into the Critical Heat Flux in Boiling Water, EUR-3347.

Peng, S.W., Groeneveld, D.C., Liu, W., Cheng, S.C., 2004. Flow boiling CHF and limiting quality phenomenon in tubes. In: Proceedings of 2004 Annual Conference of Multiphase Flow, Chinese Society of Engineering Thermophysics, October 23–26, Shanghai, PR China, pp. 35–40.

Wong, W., 1994. Effect of diameter on the critical heat flux. M.A. Sc. thesis. Department of Mechanical Engineering, University of Ottawa.

Zuber, N., 1959. Hydrodynamic Aspects of Boiling Heat Transfer, Atomic Energy Commission Report AECU-4439.