

# *Update on RELAP5-3D CHF Geometry Correction Factors*

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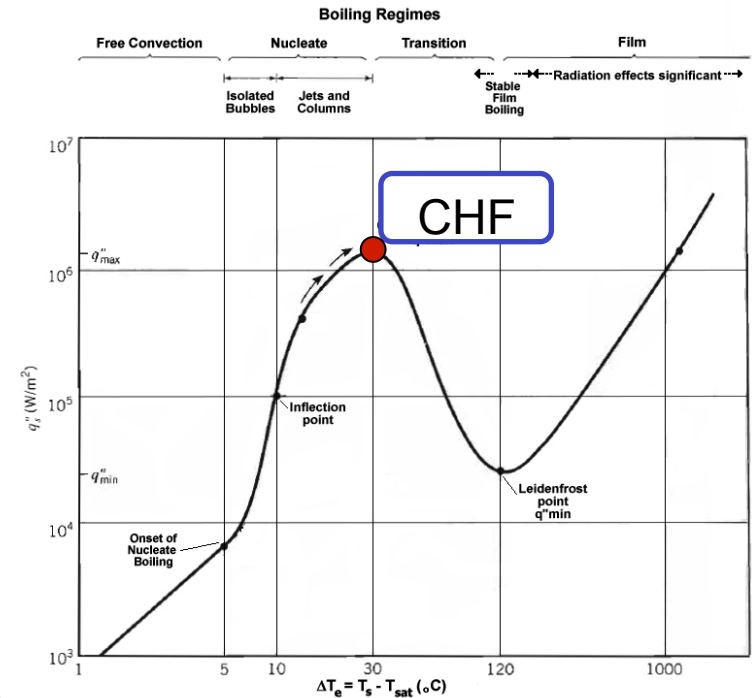
# Critical Heat Flux and Look up table

- Heat flux when DNB occurs

- Local over-heating → Failure / Accident
- Reactors designed to avoid CHF
- CHF value from empirical correlations and **look up tables**

- CHF Look up table (LUT)

- Normalized CHF value data bank for water
- Standard table by Groeneveld et al.,
  - 1986** version : ~15000 data points (**chftab.F**)
  - 2006** version : ~30000 data points (**chftab06.F**)
- CHF look up table is function of pressure (P), mass flux (G) and quality (X)
  - 3D interpolation needed for exact value



Pressure [kPa]	Mass Flux [kg m <sup>-2</sup> s <sup>-1</sup> ]	CHF [kW m <sup>-2</sup> ]																						
		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
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

## ***CHF Look up table geometry correction factor***

- **CHF values from LUT need correction factors**
  - Factors correct given CHF value based on geometry and flow type, and range of pressure (pressure range factor in 1986 version)
- **RELAP5-3D is designed to calculate appropriate correction factors for each case**
- **Status of correction factors in chftab06.F of RELAP5-3D v434**
  - K1: Sub-channel/tube diameter, cross-section geometry (**not updated**)
  - K2: Bundle geometry (**updated**)
  - K3: Mid-plane space factor for 37 elements bundle (CANDU) (**same as 1986**)
  - K4: Heated length factor (**same as 1986**)
  - K5: Axial flux distribution factor (**same as 1986**)
  - K6: Radial or circumferential flux distribution factor (**not updated**)
  - K7: Horizontal flow orientation factor (**not updated**)
  - K8: Vertical low flow factor (**updated**)

## *User problem feedback*

- **#179: 2006 version still uses 1986 version of K1 factor**
  - For 2006 version (chftab06.F), K1 factor still uses 1986 version
  - 1986 version
    - $K1=(0.008/D)^{0.33}$  for  $D<0.016\text{m}$ ,  $K1=(0.008/0.016)^{0.33} = 0.79$  for  $D>0.016\text{m}$
  - 2006 version
    - $K1=(0.008/D)^{0.5}$  for  $0.003<D<0.025\text{m}$ ,  $K1=(0.008/0.025)^{0.5} = 0.57$  for  $D>0.025\text{m}$
  - **Update of K1 factor is completed**
- **#186: Manual update needed for chftab06.F**
  - Description on CHF Look up table geometry correction factors of 2006 version is insufficient
  - K6, K7 and K8 are not correctly defined in chftab06.F
  - **Above factors are updated and documented (for draft manual)**
- **Test on updated chftab06.F was also performed**

## ***K1 sub-channel / tube-diameter, cross section geometry factor (Updated in 2016)***

1986 version	2006 version
$K1=(0.008/D)^{0.33}$ for $D<0.016m$ $K1=(0.008/0.016)^{0.33} = 0.79$ for $D>0.016m$	$K1=(0.008/D)^{0.5}$ for $0.003<D<0.025m$ $K1=(0.008/0.025)^{0.5} = 0.57$ for $D>0.025m$

$K1(86') > K1(06')$

## ***K2 bundle geometry factor***

- Already updated in v434

1986 version	2006 version
$K2=\min[0.8, 0.8\exp(-0.5X_{lim}^{0.33})]$ for rod bundles $X_{lim}=\min[1, \max(0, X_e)]$ $K2=1.0$ for other surfaces	$K2 = \min\left[1, \left(\frac{1}{2} + \frac{2\delta}{D}\right) \exp\left(\frac{-(X_e)^{1/3}}{2}\right)\right]$ where $\delta$ =minimum rod spacing (=P-D)

## ***K3, K4 and K5 factors are same in 1986 and 2006***

- **K3 Grid spacer factor (for 37 CANDU element bundle)**

$$K3 = 1 + A \cdot \exp(-B \cdot L_{SP} / D_e)$$

$$\text{where } A = 1.5 K_{loss} 0.5 (G/1000)^{0.2}, \quad B = 0.1$$

- **K4 Heated-length factor**

For  $L/D_e > 5$

$$K4 = \exp\left[\left(\frac{D_e}{L}\right) \exp(2\alpha_h)\right], \text{ where } \alpha_h = \frac{X_e \rho_f}{X_e \rho_f + (1 - X_e) \rho_f}$$

- **K5 Axial flux distribution factor**

For  $X_e < 0$ ;  $K5 = 1.0$  and

For  $X_e > 0$ ;  $K5 = q''/q''_{bla}$

## ***K6 factor : new in 2006 version (added in 2016)***

- **K6 Radial or circumferential flux distribution factor**

- Newly added in 2006 Look up table correction factor

For  $X_e < 0$ ;  $K6 = 1.0$  and for  $X_e > 0$ ;  $K6 = q''(z)_{max}/q''(z)_{avg}$

- K6 could be added by multiplication with K5, “Local boiling factor”.

- 1CCCG80X W8(R) → K5×K6
- Therefore, the user can implement this factor

## ***K7 horizontal flow factor (updated in 2016)***

- In 1986 version, horizontal flow factor defined as K6

1986 version	2006 version
K6=1 if vertical K6=0 if horizontal stratified K6=1 if horizontal high flow K6=interpolate if medium flow	$K7 = 1 - \exp(-(T_1/3.0)^{0.5})$ $\text{where } T_1 = \left( \frac{1 - X_e}{1 - \alpha} \right)^2 \frac{f_L G^2}{g D_e \rho_f (\rho_f - \rho_g) \alpha^{0.5}}$ Friction factor of the channel, $f_L$ , is suggested as; $f_L = 0.046 \text{Re}^{-0.2}$

## K8 Vertical low flow factor

- In 1986 version, vertical flow factor defined as K7

1986 version	2006 version
For $G < -400$ or $G > 100 \text{ kg/m}^2\text{s}$ ; $K7 = 1.0$	For $G < -400 \text{ kg/m}^2\text{s}$ or $X_e \ll 0$ ; $K8 = 1.0$
For $-50 < G < 10 \text{ kg/m}^2\text{s}$ $K7 = (1 - \alpha_h)$ for $\alpha_h < 0.8$ $K7 = (1 - \alpha_h) \frac{0.8 + 0.2\rho_f/\rho_g}{\alpha_h + (1 - \alpha_h)\rho_f/\rho_g}$ CHF table value at $G=0, X_e=0$	For $-400 < G < 0 \text{ kg/m}^2\text{s}$ ; Linear interpolation between table value  $CHF_0 = CHF_{G=0, X_e=0} (1 - \alpha_h) C_1$ For $\alpha_h < 0.8$ ; $C_1 = 1.0$ For $\alpha_h > 0.8$ ;
For $10 < G < 100 \text{ kg/m}^2\text{s}$ or $-400 < G < -50 \text{ kg/m}^2\text{s}$ interpolate	$C_1 = \frac{0.8 + 0.2\rho_f/\rho_g}{\alpha_h + (1 - \alpha_h)\rho_f/\rho_g}$

## K9 Pressure out-range factor

- Remain from 1986 version (added to chftab06.F)

$$K9 = \frac{\text{prop(out)}}{\text{prop(border)}} \quad \text{where} \quad \text{prop} = \rho_g^{0.5} h_{fg} [\sigma(\rho_f - \rho_g)]^{0.25}$$



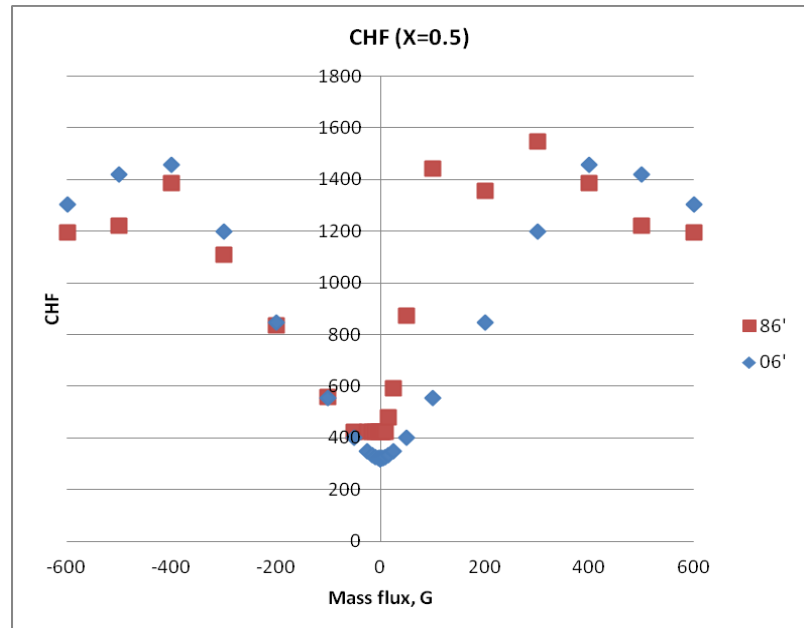
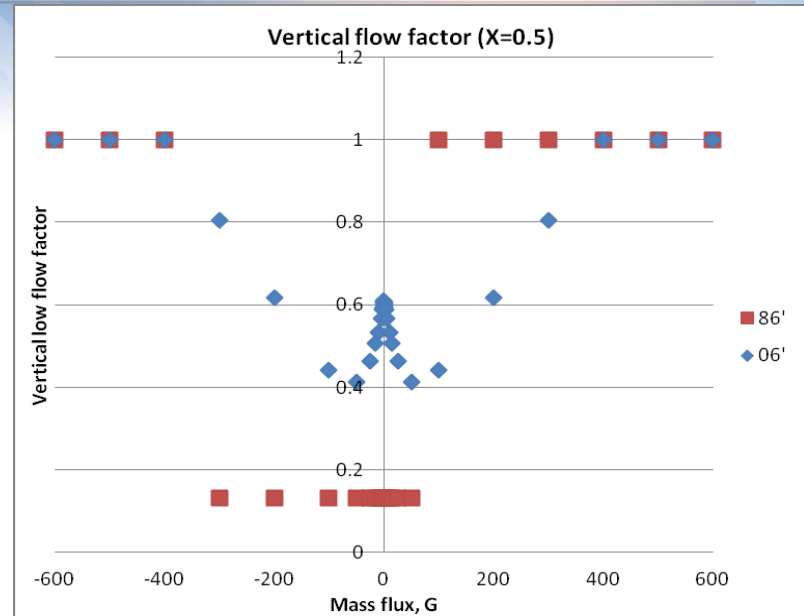
# Vertical low flow factor test

- **Comparison between versions**
  - $P=1e7Pa$ ,  $X=0.1, 0.2, 0.5$  and  $0.8$
  - 35 cases of different mass flux ( $G$ )
- **Vertical flow factor**
  - 1986 version factor is independent to mass flux (function of void fraction and density)
  - 2006 version factor from interpolated CHF

$$K8 = \frac{f_0 CHF_0 + (1 - f_0) CHF}{CHF}$$

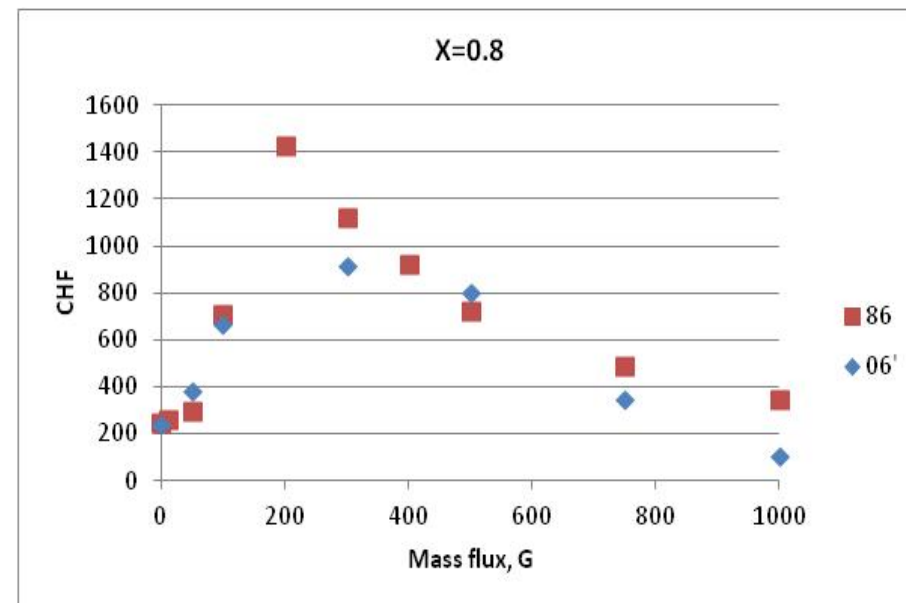
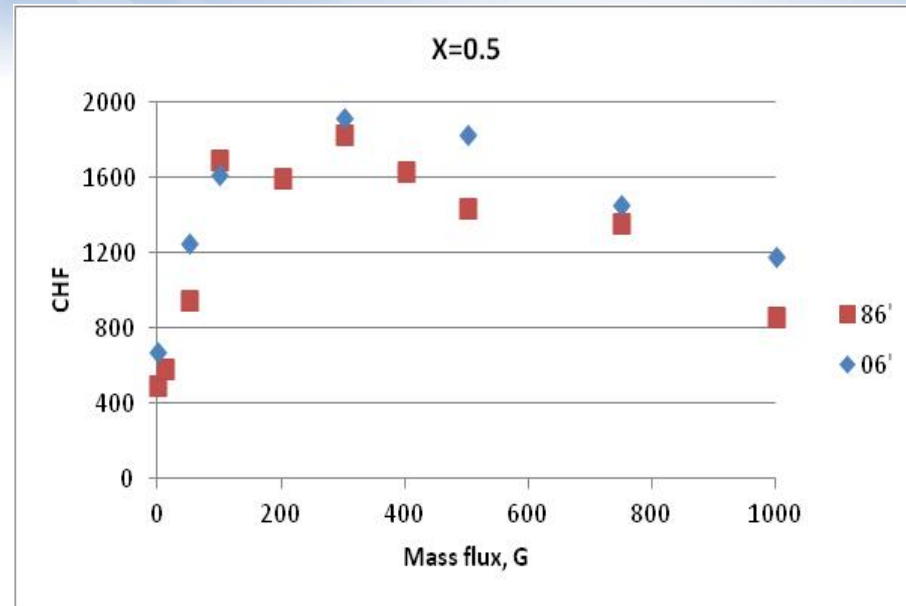
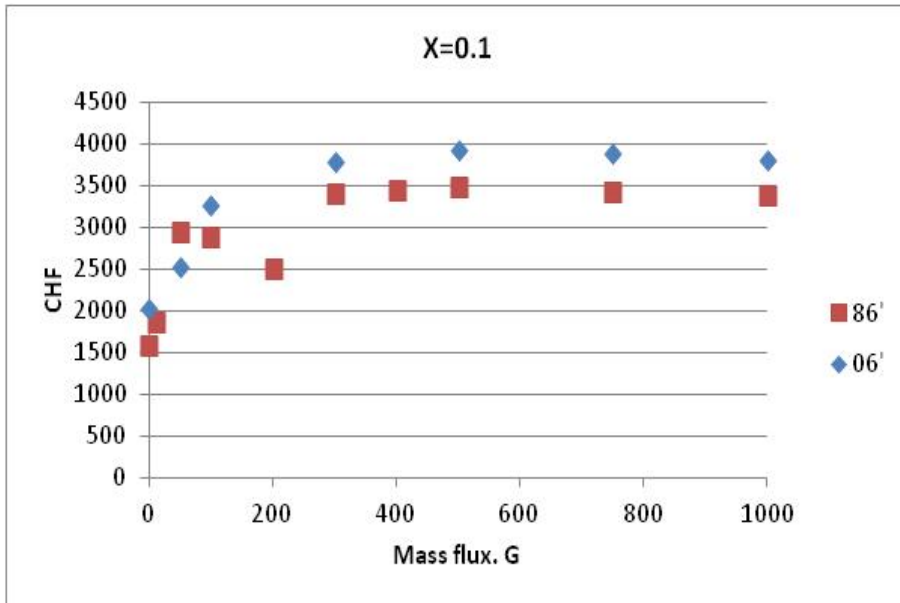
$$CHF_0 = CHF_{G=0, X=0} (1 - \alpha_h) C_1, \quad f_0 = \frac{400 - |G|}{400}$$

- **CHF value with geometry factor**
  - Both version shows different behavior
    - 1986 CHF at  $-50 < G < 10 kg/m^2sec$
    - 1986 CHF around 100 and  $200 kg/m^2sec$



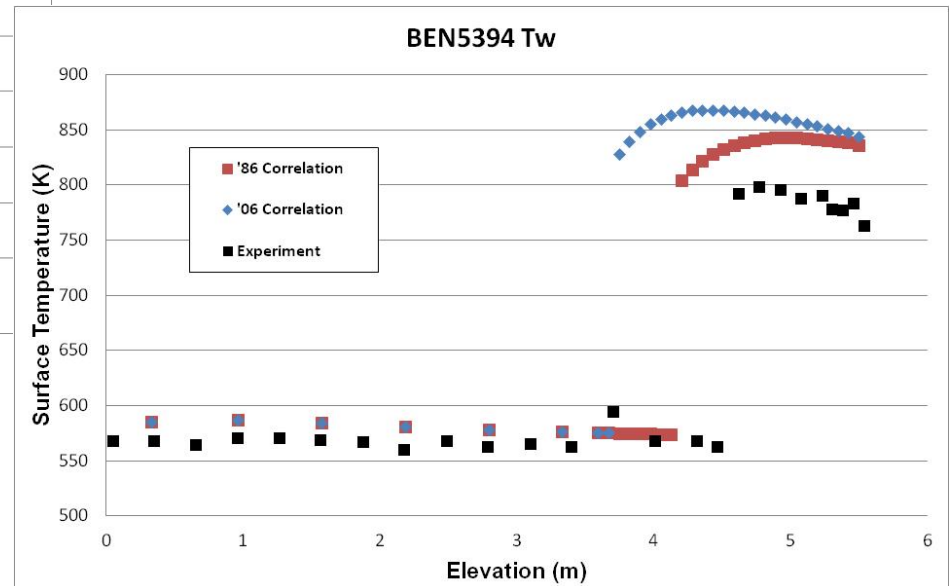
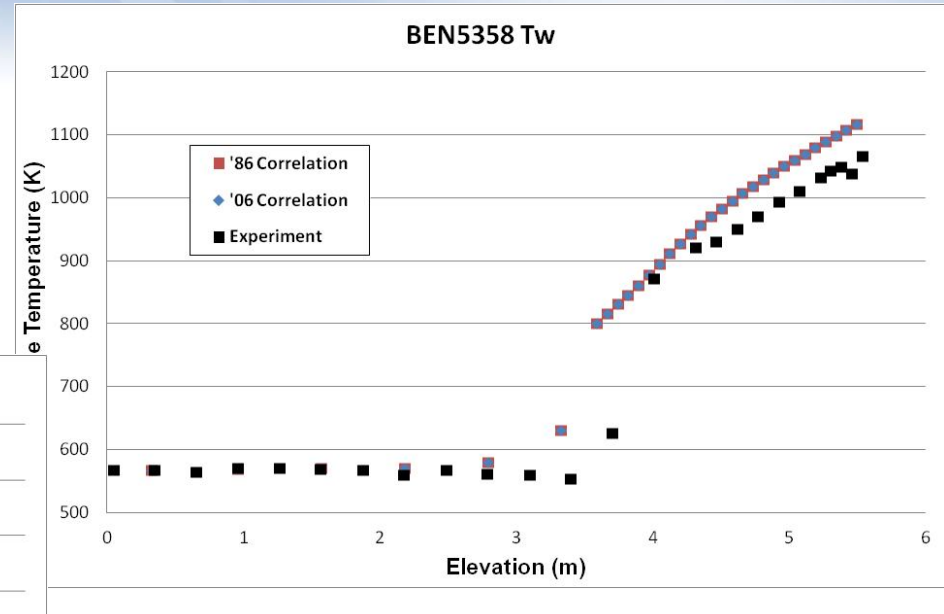
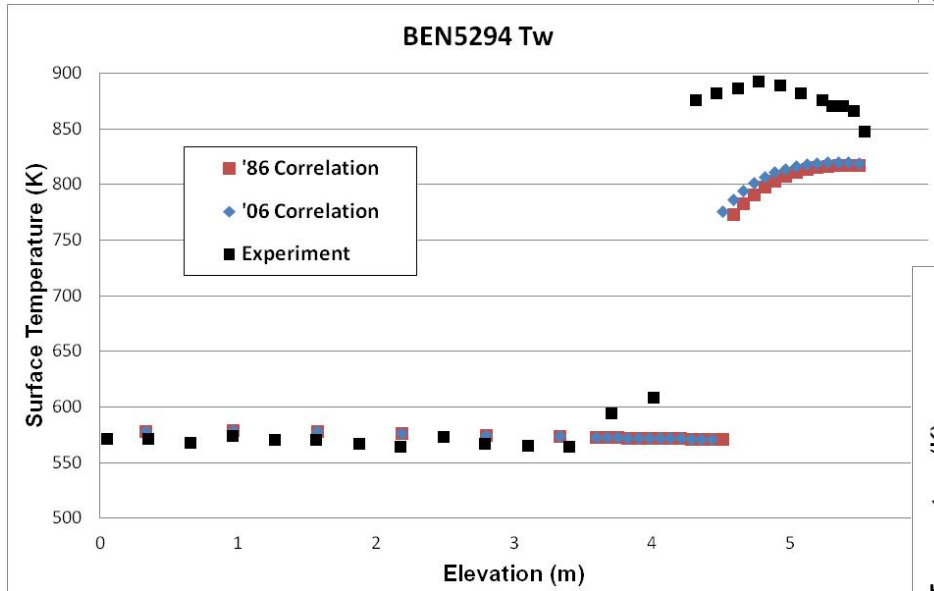
# CHF Look up table value comparison

- Different behavior shows around 100 and 200kg/m<sup>2</sup>sec
- 2006 LUT seems smoother



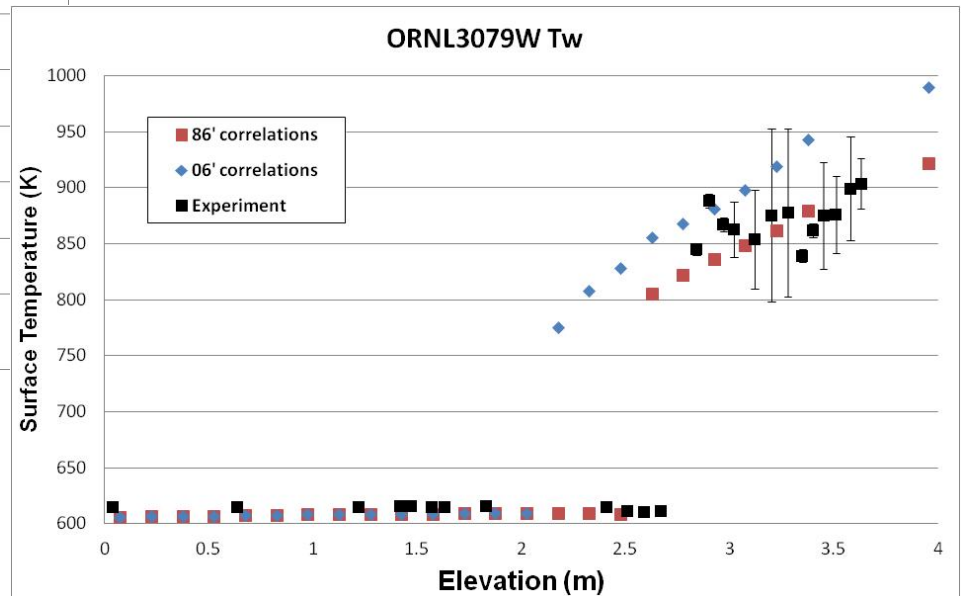
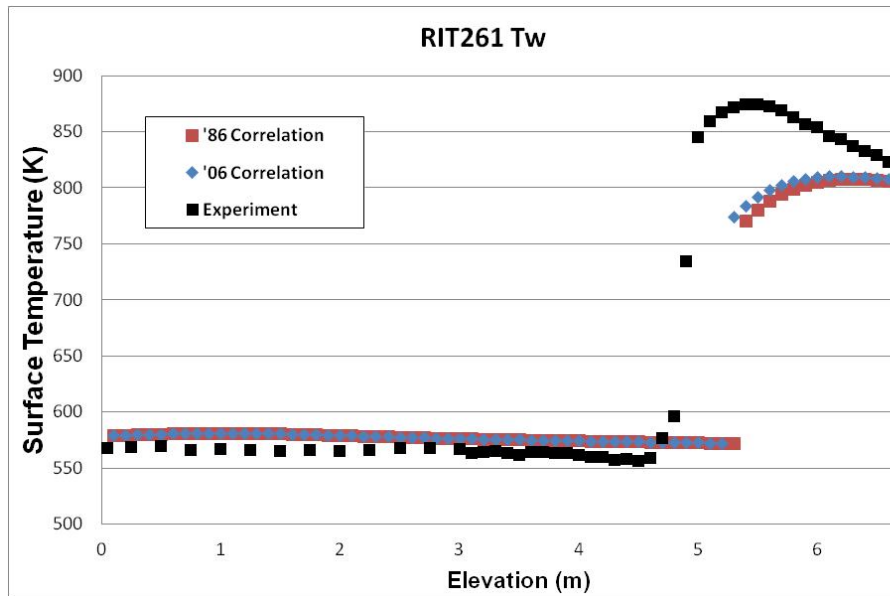
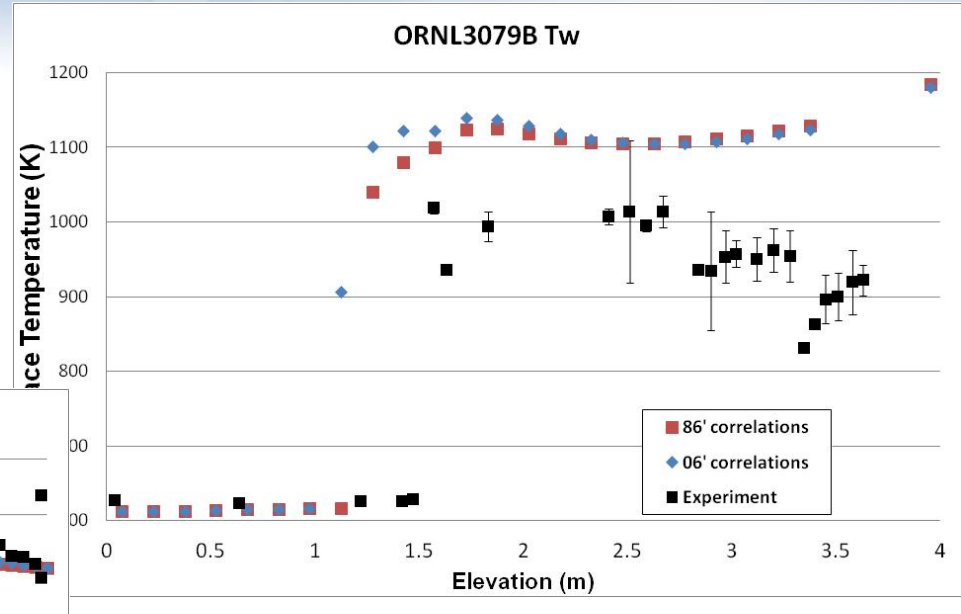
# Updated *chftab06.F* test

- Comparison with existing RELAP5-3D CHF test samples
  - Bennett heat tube



# Updated chftab06.F test

- Comparison with existing RELAP5-3D CHF test samples
  - ORNL THTF test
  - RIT tube test



## Conclusions

- **Update completed for chftab06.F**
  - K1: Sub-channel/tube diameter, cross-section geometry (**updated**)
  - K2: Bundle geometry (**updated**)
  - K3: Mid-plane space factor for 37 elements bundle (CANDU) (**same as 1986**)
  - K4: Heated length factor (**same as 1986**)
  - K5: Axial flux distribution factor (**same as 1986**)
  - K6: Radial or circumferential flux distribution factor (**updated via guideline**)
  - K7: Horizontal flow orientation factor (**updated**)
  - K8: Vertical low flow factor (**clarify mass flux range coding**)
  - K9: Pressure out-range factor (**remain from 1986 version**)
- **Test of updated chftab06.F is also performed**
  - 2006 CHF LUT is more conservative
- **Updates submitted for next code version**
- **Manual will be updated**