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Hot channel factors evaluation for thermalhydraulic analysis of MTR reactors

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Abstract This paper addresses the hot channel factors for the thermalhydraulic analysis of Material Testing Reactors (MTR). The criteria for choosing the hot channel factors and their combination methods are presented and discussed. A method for the evaluation of the hot channel factors for the thermalhydraulic analysis is proposed. In the proposed method, the values of the hot channel factor are calculated in terms of their fraction of variation and the degree of dependency of the thermalhydraulic safety parameter of interest on these factors. The equations for the calculation of the thermalhydraulic safety parameters in the hot channel are presented along with discussions. The application of the proposed method has been illustrated by an example.

Key words hot channel factors • MTR • reactor safety • thermalhydraulic analysis • uncertainty

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Introduction

The thermalhydraulic safety parameters of concern in the design of the MTR are:

1) The temperatures of the reactor coolant bulk, film layer and fuel cladding.
2) The temperature of onset of nucleate boiling (ONB), T_{ONB}.
3) The heat fluxes that initiate critical phenomena: ONB heat flux, q_{ONB}, departure from nucleate boiling (DNB) heat flux, q_{DNB}, and the redistribution (RD) heat flux, q_{RD}.
4) Safety margins: ONB ratio, *ONBR*; DNB ratio, *DNBR*; and RD ratio, *RDR*.

The calculation of these parameters should take into account different kinds of uncertainties. The main sources of these uncertainties are the fuel fabrication tolerances, possible deviations in the operational conditions, errors in the experimental correlations used in the analysis, and errors due to simplifications made in the thermalhydraulic calculations. Consideration of these uncertainties in the thermal design of the reactor core is vital for the reactor safe and economical design and operation. The selection of these uncertainties as well as their treatment method can have a significant impact on the reactor safety margins. Some reactor designs have large safety margins, and large uncertainties can be assumed without any particular difficulty. Even in these cases the choice of overly conservative peaking factors can unnecessarily limit the range and usefulness of the reactor [11].

The uncertainties affecting the temperature rise, heat flux, or safety margins are usually evaluated and stated in terms of hot spot and hot channel factors when safety margins are evaluated.

Combination methods of hot channel factors

There exist a number of methods for combining the hot channel factors. In the multiplicative method, all the worst conditions are assumed to occur simultaneously at the same point. In this method, the individual subfactors are combined by multiplying them together. The multiplicative method was judged to be very conservative [3, 7, 11].

The fully-statistical method recognizes that all the worst conditions do not occur at the same time and location. In this method, the individual subfactors are combined in a statistical manner. The fully-statistical method is more accurate and less conservative than the multiplicative method. This method takes into account statistical nature of most of the hot channel subfactors. It is not valid, however, to attempt statistical treatment of the factors that describe uncertainties in performance [5]. Besides, the fully-statistical method may not be applicable when the error for variables is not statistical but systematic [9].

If the errors in some subfactors are statistical, whereas they are not for others, the semi-statistical combination method can be used. In this method a separation is made between the cumulative subfactors (which influence the total profile) and the statistical subfactors (which are randomly distributed along the channels). The total cumulative factor is the product of the individual subfactors whereas the total statistical factor is a statistical sum of the individual subfactors. The semi-statistical method is more accurate and conservative than the fully-statistical method but still less conservative than the multiplicative method.

A semi-statistical method with direct error propagation and a list of parameters that present uncertainties has been proposed by Gimenez *et al.* [5] to evaluate the safety margins for MTR core design. Four categories of the hot channel factors have been considered. These categories are: fuel fabrication, operational measurements, experimental correlations, and modeling. These categories are further broken down into hot channel basic subfactors.

Table 1. Selected hot channel basic subfactors.

Symbol	Basic subfactor
Fuel fabrication tolerances:	
U_l	U^{235} loading
U_h	U^{235} homogeneity
t_m	fuel plate meat thickness
W_m	fuel plate meat width
L	fuel plate active length
W_{ch}	coolant channel width
t_{ch}	coolant channel thickness
Others – modeling:	
Q	core flow rate
Operation measurements:	
T_{in}	core inlet temperature
Q_0	core flow rate
P	reactor power
Experimental correlation:	
h	heat transfer coefficient
ONB_{cr}	ONB correlation
DNB_{cr}	DNB correlation
RD_{cr}	RD correlation

Table 1 presents a list of these categories and the hot channel basic subfactors under each category. Typical list is for MTR reactors, which use plate type fuel, and is adopted for the present study.

Fabrication tolerances are statistical by nature and do not occur at the same time and location. Therefore, it is more realistic to combine them statistically. Uncertainties in the experimental correlations used in the analysis are affecting all the channels in the same way. Therefore, these correlation uncertainties are combined cumulatively. The fluctuations in the operational measurements are combined cumulatively as they affect the entire core. A statistical error in the core flow is included to consider flow variations due to fabrication tolerances in the entrance of the channels.

The proposed method for evaluation of the hot channel factors

The calculation of the numerical values of the hot channel basic subfactors is one of the most important steps in the evaluation of the safety margins for thermalhydraulic core design. The numerical value of the hot channel basic subfactor j as a function of safety parameter i can be calculated by

$$f_{i,j} = \delta_j * \left| d_{i,j} \right| \quad (1)$$

where: $f_{i,j}$ is the numerical value of the hot channel basic subfactor. This value represents the fraction of error in the safety parameter i due to uncertainty in the basic subfactor j; δ_j is the fraction of variation of the hot channel basic subfactor j. In the application of equation (1), values of δ_j are used instead of $1 + \delta_j$, commonly used in the literatures [5, 6, 9, 11]; $d_{i,j}$ is the degree of dependency of the thermalhydraulic safety parameter i on the hot channel basic subfactor j. These parameters, or related quantities, can be expressed in terms of the basic subfactors multiplied by a constant in which no uncertainties are postulated.

Table 2 presents the thermalhydraulic safety parameters, or related quantities, in terms of the selected hot channel basic subfactors. These expressions are used to obtain the numerical values of $d_{i,j}$. Absolute values of $d_{i,j}$ are considered for conservatism.

In Table 2, ΔT_b, ΔT_f, and ΔT_{cl} represent the coolant bulk temperature difference, the film layer temperature difference, and the fuel cladding temperature difference, respectively. ΔT_{ONB} is the ONB temperature difference, T_{sat} is the saturation temperature, and q is the local heat flux.

A simplification can be introduced to the tabulated expression of the Fabrega correlation [4]. Due to the fact that $L << 6.44\, \rho^{0.29}\, t_{ch}{}^{1.21}\, Q^{0.29}$, the expression for the q_{RD}, in Table 2, can be written in terms of

$$\frac{w_{ch} t Q^{0.71} L}{P \mathrm{U}_l} \left(T_{sat} - T_{in} \right). \quad (2)$$

Table 2 shows also that some safety parameters are not linearly dependent on some basic subfactors. In this case, equation (1) assumes linear simplification, when $f_{i,j}$ values

Table 2. Thermalhydraulic safety parameters, or related quantities, expressed in terms of the selected hot channel basic subfactors.

Safety parameter	Expression	Remarks
ΔT_b	$\frac{U_l P}{t_{ch}^{1.71} Q w_{ch}}$	U_h and t_m are not considered because the liquid temperature is an integral quantity
ΔT_f	$\frac{U_l P U_h t_m}{t_{ch}^{0.368} Q^{0.8} w_m L}$	
ΔT_{cl}	$\frac{U_l P t_m}{w_m L}$	
ΔT_{ONB}	$\left(\frac{U_l t_m U_h P}{w_m L}\right)^{0.35}$	for Foster and Greif correlation [10]
q	$\left(\frac{U_l t_m U_h P}{w_m L}\right)$	for the ONB heat flux calculations
q_{DNB}	$151\left(1+t_{ch}^{0.71}Q\right)\left(1+0.19p\right)* \left\{1+0.00914\left(T_{sat}-\frac{U_l P}{t_{ch}^{1.71}Q w_{ch}}-T_{in}\right)\right\}$	for the Mirshak correlation [8]
q_{RD}	$\frac{w_{ch} t_{ch}^{1.71} Q L}{P U_l \left(L+6.44\rho^{0.29} t_{ch}^{1.21} Q^{0.29}\right)}\left(T_{sat}-T_{in}\right)$	for the Fabrega correlation [4]

are evaluated. This simplification has a little impact on the final results. It results in a negligible error in case of small variations of reactor parameters. In fact, equation (1) can be mathematically deduced by a linearization process. The function (safety parameter) may be expanded, by Taylor's series, about the normal values of the independent parameters (subfactors) and the higher order terms may be ignored for their numerical insignificance. For example, the errors in the evaluation of $f_{\Delta T_f}$ resulting from eliminating the higher orders terms were calculated to be 0.99% and 0.29% for 10% variation in Q and t_{ch}, respectively.

From Table 2, it can be also noticed that the $d_{i,j}$ values, for the MTR, are independent of the reactor under consideration. Therefore, the values of $f_{i,j}$ can be calculated, independently of the reactor under consideration, for a 1% variation in the hot channel basic subfactor. Table 3 presents the calculated $f_{i,j}$ values for 1% variation in the basic subfactors.

Calculations of the hot channel safety parameters

The parameters calculated with uncertainties are called here the hot channel safety parameters while those calculated without considering the uncertainties are called here the normal values. For semi-statistical combination, the expressions for the calculation of the hot channel safety parameters are presented as follows.

Hot channel temperatures in coolant bulk, film layer and fuel cladding

The hot channel temperatures, $T_{i,H}$, in coolant bulk, film layer, and fuel cladding are calculated by

$$(3)\quad \begin{cases} T_{i,H} = T_{i,N} + \Delta T_{i,c} + \Delta T_{i,s} + \Delta T\left(T_{in}\right) \\ \Delta T_{i,c} = \sum_{j=1}^{N1}\sum_{i=1}^{i} f_{i,j}\Delta T_{i,N} \\ \Delta T_{i,s} = \sqrt{\sum_{j=1}^{N2}\left\{\sum_{i=1}^{i} f_{i,j}\Delta T_{i,N}\right\}^2} \\ \Delta T\left(T_{in}\right) = \delta_{T_{in}} * T_{in} \end{cases}$$

where the subscripts c and s are representing the cumulative and statistical subfactors, respectively; $i = 1$ for the coolant bulk temperature; $i = 2$ for the film temperature; $i = 3$ for the fuel cladding temperature; $T_{i,N}$ is the normal value of the temperature in i; $\Delta T_{i,c}$ is the temperature rise in i due to cumulative basic subfactors; $\Delta T_{i,s}$ is the temperature rise in i due to statistical basic subfactors; $\Delta T_{i,N}$ is the normal value of the temperature difference in i; $\Delta T(T_{in})$ is the temperature rise in the T_{in} due to uncertainty in the measurements of the coolant inlet temperature; $N1$ is the number of cumulative hot channel basic subfactors, and $N2$ is the number of statistical hot channel basic subfactors.

In equation (3) the errors due to cumulative and statistical subfactors are added to the normal values of the

Table 3. Fraction of errors in the safety parameters for 1% variation of the hot channel basic subfactors.

Hot channel basic subfactor	$f_{i,j}$ Thermalhydraulic safety parameter, or related quantity					
	ΔT_b	ΔT_f	ΔT_{ONB}	q_{ONB} 1)	q_{DNB} 2)	q_{RD} 3)
U_t	0.01	0.01	0.0035	0.01	0.01	0.01
U_h	0	0	0.0035	0.01	0	0
t_m	0	0.01	0.0035	0.01	0	0
W_m	0	0.01	0.0035	0.01	0	0
L	0	0.01	0.0035	0.001	0	0.01
W_{ch}	0.01	0	0	0	0.01	0.01
t_{ch}	0.0171	0.00368	0	0	0.0171	0.005
T_{in}	0	0	0	0	0.01	0.01
Q_0	0.01	0.008	0	0	0.01	0.0071
P	0.01	0.01	0.0035	0.01	0.01	0.01
h	0	0.01	0	0	0	0
ONB_{cr}	0	0	0.01	0.01	0	0
DNB_{cr}	0	0	0	0	0.01	0
RD_{cr}	0	0	0	0	0	0.01
Q	0.01	0.08	0	0	0.01	0.0071

1) For Foster and Greif correlation [10].
2) For Mirshak correlation [8].
3) For Fabrega correlation [4].

coolant bulk, film layer, and fuel cladding temperatures for conservatism.

From equation (3), the hot channel coolant bulk temperature can be calculated by

$$(4)\quad \begin{cases} T_{b,H} = T_{b,N} + \Delta T_{b,c} + \Delta T_{b,s} + \left(\delta_{T_{in}} T_{in}\right) \\ T_{b,c} = \left\{ f_{\Delta T_b,Q_0} + f_{\Delta T_b,P} \right\} \Delta T_{b,N} \\ T_{b,s} = \sqrt{\left\{ \left(f_{\Delta T_b,U_l} + f_{\Delta T_b,W_{ch}} + f_{\Delta T_b,t_{ch}} + f_{\Delta T_{b,Q}} \right) \Delta T_{b,N} \right\}^2} \end{cases}.$$

The hot channel film layer temperature can be calculated by

$$(5)\quad \begin{cases} T_{f,H} = T_{f,N} + \Delta T_{f,c} + \Delta T_{f,s} + \left(\delta_{T_{in}} T_{in}\right) \\ \Delta T_{f,c} = \left\{ f_{\Delta T_b Q_0} + f_{\Delta T_b,P} \right\} \Delta T_{b,N} \\ \qquad + \left\{ f_{\Delta T_f,h} + f_{\Delta T_f,Q_0} + f_{\Delta T_f,P} \right\} \Delta T_{f,N} \\ \Delta T_{f,s} = \sqrt{\begin{aligned} &\left\{ f_{\Delta T_b,U_l} \Delta T_{b,N} + f_{\Delta T_f,U_l} \Delta T_{f,N} \right\}^2 \\ &+ \left\{ f_{\Delta T_f,t_m} \Delta T_{f,N} \right\}^2 + \left\{ f_{\Delta T_f,W_m} \Delta T_{f,N} \right\}^2 \\ &+ \left\{ f_{\Delta T_f,L} \Delta T_{f,N} \right\}^2 + \left\{ f_{\Delta T_b,W_{ch}} \Delta T_{b,N} \right\}^2 \\ &+ \left\{ f_{\Delta T_b,t_{ch}} \Delta T_{b,N} + f_{\Delta T_f,t_{ch}} \Delta T_{f,N} \right\}^2 \\ &+ \left\{ f_{\Delta T_b,Q} \Delta T_{b,N} + f_{\Delta T_f,Q} \Delta T_{f,N} \right\}^2 \end{aligned}} \end{cases}$$

where the subscripts b and f are representing the bulk coolant and film layer, respectively.

The normal value of the fuel cladding temperature difference is usually very small. Therefore, its effect on the value of the hot channel fuel cladding temperature can be neglected without affecting the final results. The hot channel fuel cladding temperature, $T_{cl,H}$, can be calculated directly by

$$(6)\qquad T_{cl,H} = T_{cl,N} + \Delta T_{f,c} + \Delta T_{f,s} + \Delta T(T_{in})$$

where $T_{cl,N}$ is the normal value of the fuel cladding temperature.

Hot channel ONB temperature

The hot channel ONB temperatures, $T_{ONB,H}$, is calculated by

$$(7)\qquad \begin{cases} T_{ONB,H} = T_{ONB,N} - \Delta T_{ONB,c} - \Delta T_{ONB,s} \\ \Delta T_{ONB,c} = \sum_{j=1}^{N1} f_{T_{ONB},j} \Delta T_{ONB,N} \\ \Delta T_{ONB,s} = \sqrt{\sum_{j=1}^{N2} \left\{ f_{T_{ONB},j} \Delta T_{ONB,N} \right\}^2} \end{cases}.$$

The errors due to cumulative and statistical subfactors are subtracted from the normal value of the ONB temperature for conservatism.

Hot channel heat flux

The hot channel heat flux that initiates a thermalhydraulic critical phenomenon is calculated by

$$(8)\qquad \begin{cases} M_H = M_N - \Delta M_c - \Delta M_s \\ \Delta M_c = \sum_{j=1}^{N1} f_{M,j} M_N \\ \Delta M_s = \sqrt{\sum_{j=1}^{N2} \left\{ f_{M,j} M_N \right\}^2} \end{cases}$$

where M represents the heat flux that initiates a thermal-hydraulic critical phenomenon; q_{ONB}, q_{DNB}, and q_{RD}.

The errors due to cumulative and statistical subfactors are subtracted from the normal values of the heat fluxes for conservatism.

Equations (3) through (8) can be adjusted for the use in case of multiplicative and fully-statistical combination methods. For the multiplicative method, all the basic subfactors will be evaluated according to the cumulative approach. On the other hand, for the fully-statistical method, all of the basic subfactors will be evaluated according to the statistical approach.

Hot channel safety margins

Once the hot channel heat fluxes had been determined, their relevant ratios can be evaluated. These ratios represent the safety margins of the critical phenomena. These safety margins are calculated as follows.

The hot channel ONB ratio, $ONBR_H$, is calculated by

$$(9)\qquad ONBR_H = \frac{q_{\text{ONB}_H}}{q_{T,\text{ONB}}} = SM_{\text{ONB}}$$

where $q_{T,\text{ONB}}$ is the local heat flux at the point where at further power raise the ONB will first appear and SM_{ONB} is the safety margin of ONB phenomenon.

The hot channel minimum DNB ratio, $DNBR_H$, is calculated by

$$(10)\qquad DNBR_H = \frac{q_{\text{DNB}_{H,\min}}}{q(\text{DNB}_{\min})} = SM_{\text{DNB}}$$

where: $q_{\text{DNB}_{H,\min}}$ is the hot channel DNB heat flux at the point where $DNBR_N$ is a minimum; $q(\text{DNB}_{\min})$ is the local heat flux at the same point; SM_{DNB} is the safety margin of DNB phenomenon.

The hot channel minimum RD ratio, RDR_H, is calculated by

$$(11)\qquad RDR_H = \frac{q_{\text{RD},H}}{q_{\max}} = SM_{\text{RD}}$$

where: $q_{\text{RD},H}$ is the hot channel RD heat flux; $q_{\max}$ is the maximum local heat flux; SM_{RD} is the safety margin of the redistribution phenomenon.

Application

The above method and equations were applied to the case of the Egyptian Second Research Reactor, ETRR-2, for illustration. ETRR-2 is an open pool type research reactor of 22 MW thermal power. The reactor is cooled by forced convection and uses the plate type fuel elements. Table 4 presents the main data of the ETRR-2 reactor.

The normal values of the thermalhydraulic safety parameters for ETRR-2 have been calculated using the computer code TERMIC [6]. One-dimension calculations in a single channel have been performed. It has been assumed that 95% of the total fission energy is deposited in the fuel. One of the objectives of the neutronic design calculations of the ETRR-2 core is to verify that the nuclear power peak factor is kept less than 3 for the range of all operating conditions [2]. This value of the nuclear power peak factor has been considered as an input parameter to the thermalhydraulic calculations.

The list of the hot channel basic subfactors in Table 1 is considered for ETRR-2 calculations. The fractions of variations of these subfactors for ETRR-2 are given in Table 5. The fractions of variations of the subfactors concerning the fuel fabrication tolerances are obtained from the fuel specifications of the ETRR-2 [1]. The errors in the measurements of the reactor power, core flow rate, and coolant inlet temperature have been assumed to be 5%, 10%, and 2%, respectively. The uncertainty in the heat transfer coefficient has been assumed to be 20% as the experimental data for any of the single phase correlations commonly used are generally fit within a band of ±20% [11]. The uncertainties in the ONB, DNB, and RD correlations have been assumed to be 20%, 10%, and 10%, respectively.

Table 4. ETRR-2 design parameters.

Parameter	Value
Reactor power	22 MW
Number fuel elements in core	29
Number of fuel plates per fuel element	19
Active fuel length	0.8 m
Fuel plate thickness	0.0015 m
Fuel clad thickness	0.0004 m
Coolant channel thickness	0.0027 m
Coolant channel width	0.07 m
Heat transfer area	56.4102 m^2
Coolant velocity	4.7 m/s
Core flow rate	1950 m^3/h
Maximum local heat flux[1)]	111.15 W/cm^2
Coolant inlet temperature	41°C
Water level above the core	10 m

[1)] Assuming 95% of power deposition in the fuel and adopting nuclear power peak value of 3.

Table 5. Fraction of variations and calculated numerical values of the hot channel basic subfactors for ETRR-2.

Basic subfactor		Safety parameter or related quantity					
Symbol	δ%	ΔT_b	ΔT_f	ΔT_{ONB} 1)	q_{ONB} 1)	q_{DNB} 2)	q_{RD} 3)
U_t	1	0.01	0.01	0.0035	0.01	0.01	0.01
U_h	8	0.00	0.08	0.028	0.08	0.00	0.00
t_m	4.3	0.00	0.043	0.0150	0.043	0.00	0.00
W_m	0.5	0.00	0.005	0.00175	0.005	0.00	0.00
L	1.3	0.00	0.013	0.0045	0.013	0.00	0.013
W_{ch}	0.15	0.0015	0.00	0.00	0.00	0.0015	0.0015
t_{ch}	3.7	0.063	0.0136	0.00	0.00	0.0632	0.0185
T_{in}	2	0.00	0.00	0.00	0.00	0.02	0.02
Q_0	10	0.1	0.08	0.00	0.00	0.1	0.071
P	5	0.05	0.05	0.0175	0.05	0.05	0.05
h	20	0.00	0.2	0.00	0.00	0.00	0.00
ONB_{cr}	20	0.00	0.00	0.2	0.2	0.00	0.00
DNB_{cr}	10	0.00	0.00	0.00	0.00	0.1	0.00
RD_{cr}	10	0.00	0.00	0.00	0.00	0.00	0.1
Q	10	0.1	0.08	0.00	0.00	0.1	0.071

1) Based on Foster and Greif correlation [10].
2) Based on Mirshak correlation [8].
3) Based on Fabrega correlation [4].

The numerical values of the hot channel basic subfactors as a function of the thermalhydraulic safety parameters are calculated using equation (1) and the results are presented in Table 5.

The hot channel safety parameters of ETRR-2 have been calculated using different combination methods. For semi-statistical combination, equations (3) through (11) have been used for the calculations of the hot channel safety parameters. The criteria used for combining the individual subfactors are as presented in the previous analysis. Considering other combination methods, equations (3) through (11) have been adjusted to the multiplicative and fully-statistical combination. Table 6 summarizes the results. The normal values of the thermalhydraulic safety parameters for ETRR-2 reactor are also presented in Table 6.

Table 6 shows that larger safety margins are obtained in case of fully-statistical combination compared with the semi-statistical and multiplicative methods. The latter results in smallest safety margins. The multiplicative method predicts that the ONB will appear at the ETRR-2 core at a power level of 29.7 MW, while the power level at which the ONB will appear is 38.5 MW and 32.78 MW in cases of fully-statistical and semi-statistical combination, respectively. The safety margin of the DNB phenomena is 2.69, 2.96, and 4.22 for multiplicative, semi-statistical, and fully-statistical methods, respectively. The margins of the RD are 1.96, 2.08, and 2.58 for multiplicative, semi-statistical, and fully-statistical combination methods, respectively.

Conclusions

A method for the evaluation of the hot channel factors for thermalhydraulic analysis in MTR reactors has been proposed. In the proposed method, the error in the thermalhydraulic safety parameter due to the hot channel

Table 6. Hot channel thermalhydraulic safety parameters with different combination methods for ETRR-2.

Combination method	Safety parameter							
	$T_{cl\text{-}m}$ 1) (°C)	T_{ONB} (°C)	q_{ONB} (W/cm²)	q_{DNB} (W/cm²)	q_{RD} (W/cm²)	*ONBR*	*DNBR*	*RDR*
Normal values	92.2	146.0	243	536	339	2.26	4.84	3.04
Semi-statistical	113.2	139.7	160	327	232	1.49	2.96	2.08
Multiplicative	118.9	139.2	143	292	197	1.35	2.69	1.96
Fully-statistical	103.4	140.9	184	467	258	1.75	4.22	2.58

1) Fuel cladding maximum temperature.

subfactor is evaluated in terms of the fraction of variation of the subfactor multiplied by the degree of dependency of the safety parameter on the subfactor.

The values of the degree of dependency can be obtained from the expressions which is relating the thermalhydraulic safety parameter to the subfactors. The proposed method is simple in concept, easy to be used, and results in very small errors.

The values of the hot channel factors are independent of the reactor under consideration for 1% variation of the subfactor. Therefore, the numerical values of the fraction of errors for 1% variation can be generalized for the use in the thermalhydraulic analysis of MTR.

The equations for the calculations of the hot channel safety parameters that are presented particularly for the semi-statistical combination method can be easily adjusted to consider other combination methods.

Nomenclature

δ – fraction of variation of the hot channel factor;
ρ – water density;
d – degree of dependency of safety parameter on hot channel factor;
DNB – departure from nucleate boiling;
DNBR – departure from nucleate boiling ratio;
f – numerical value of the hot channel factor;
h – heat transfer coefficient;
L – fuel active length;
$N1$ – number of cumulative subfactors;
$N2$ – number of statistical subfactors;
ONB – onset of nucleate boiling;
ONBR – onset of nucleate boiling ratio;
P – power;
p – pressure;
Q – core flow rate;
q – heat flux;
q_{DNB} – departure from nucleate boiling heat flux;
q_{ONB} – onset of nucleate boiling heat flux;
q_{RD} – flow redistribution heat flux;
RD – flow redistribution;
RDR – flow redistribution ratio;
SM – safety margin;
T – temperature;
t_{ch} – coolant channel thickness;
t_m – fuel plate meat thickness;
U_l – uranium loading;
U_h – uranium homogeneity;
W_m – fuel plate meat width;
W_{ch} – coolant channel width;

Subscripts

b – coolant bulk;
c – cumulative subfactors;
ch – coolant channel;
cl – fuel cladding;
cr – correlation;
f – film layer;
H – hot channel values;
in – inlet conditions;
N – normal values (without uncertainties);
s – statistical subfactors;
sat – saturation conditions.

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