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FFTBM and Primary Pressure Acceptance Criterion

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ABSTRACT

When thermalhydraulic computer codes are used for simulation in the area of nuclear engineering the question is how to conduct an objective comparison between the code calculation and measured data. To answer this the fast Fourier transform based method (FFTBM) was developed. When the FFTBM method was developed the acceptance criteria for primary pressure and total accuracy were set. In the recent study the FFTBM method was used for accuracy quantification of RD-14M large LOCA test B9401 calculations. The blind accuracy analysis indicated good total accuracy while the primary pressure criterion was not fulfilled. The objective of the study was therefore to investigate the reasons for not fulfilling the primary pressure acceptance criterion and the applicability of the criterion to experimental facilities simulating heavy water reactor. The results of the open quantitative analysis showed that sensitivity analysis for influence parameters provide sufficient information to judge in which calculation the accuracy of primary pressure is acceptable.

1 INTRODUCTION

The fast Fourier transform based method (FFTBM) was the first developed method to conduct objective comparison between the thermalhydraulic code calculation and measured data [1]. Later the stochastic approximation ratio based method (SARBM) [2], [3] in time domain was proposed as supplement to FFTBM to increase the confidence into the results of quantitative analysis. The automated code assessment program (ACAP) was developed [4] to be able to see the progress in the TRACE computer code development. Nevertheless, only the FFTBM provides a procedure to quantify the whole calculation and therefore it is very widely used. The FFTBM shows the measurement-prediction discrepancies (accuracy quantification) in the frequency domain. The acceptance criteria for code calculation were determined based on several tens of complex transients including small break loss-of-coolant accident (LOCA), large break LOCA and long lasting transients in light water reactors [1]. After development the FFTBM method has been applied to various international standard problems, standard problem exercises and other experiment simulations [5], [6], [7]. When correlating the primary pressure accuracy and total accuracy weak relation was found. Recently this was shown also in the accuracy analysis of RD-14M large LOCA test [8] that was conducted by Atomic Energy of Canada Ltd. (AECL).

The RD-14M large LOCA test with reliable set of experimental data was selected for an international standard problem exercise entitled “Intercomparison and validation of computer codes for thermalhydraulics safety analyses”. The activity was performed within the frame of International Atomic Energy Agency’s (IAEA’s) Technical Working Group on Advanced Technologies for Heavy Water Reactors (TWG-HWR). The RD-14M experimental facility located in Canada represents typical CANDU reactor [9]. Although much FFTBM applications were done, the present FFTBM application was the first one to experimental facility simulating heavy water reactor. The blind accuracy analysis indicated good total accuracy while the primary pressure criterion was not fulfilled. The objective of the study was therefore in the open accuracy analysis to investigate the reason for not fulfilling the primary pressure acceptance criterion. The topic was identified as being of importance to the applicability of the primary pressure criterion to experimental facilities simulating heavy water reactor. Additionally, the results of blind and open accuracy analysis were compared.

2 FFTBM OVERVIEW

The detailed description of the FFTBM method can be found in [6]. For calculation of discrepancies the experimental signal $F_{\exp}(t)$ and error function $\Delta F(t)$ are needed. The error function in the time domain is defined as $\Delta F(t) = F_{cal}(t) - F_{\exp}(t)$ where $F_{cal}(t)$ is calculated signal. The code accuracy quantification for a individual calculated variable is based on amplitudes of discrete experimental and error signal obtained by FFT at frequencies f_n, where (n=0,1,...,2^m) and m is the exponent. These spectra of amplitudes are used for calculation of average amplitude (AA) and variable accuracy (VA):

$$\mathrm{AA_i} = \sum_{n=0}^{2^m} \left|\tilde{\Delta F}(f_n)\right| \Big/ \sum_{n=0}^{2^m} \left|\tilde{F}_{\exp}(f_n)\right|; \qquad \mathrm{VA_i} = (\mathrm{AA})_\mathrm{i} \cdot (\mathrm{w_f})_i \cdot N_\mathrm{var} \tag{1}$$

where N_{var} is the number of the variables analysed, and $(\mathrm{AA})_\mathrm{i}$, and $(w_\mathrm{f})_\mathrm{i}$ are average amplitude and weighting factor for i-th analysed variable (i=1,..., N_var), respectively. Minimal variable accuracy $\mathrm{VA_{min}}$ is defined as maximal $\mathrm{VA_i}$ and maximal $\mathrm{VA_{max}}$ is defined as minimal $\mathrm{VA_i}$. The AA factor can be considered a sort of average fractional error and closer is AA value to zero the more accurate is the result. The overall picture of the accuracy for the given code calculation is obtained by defining total average amplitude (total accuracy):

$$\mathrm{AA_{tot}} = \sum_{i=1}^{N_\mathrm{var}} (\mathrm{AA})_i \cdot \left(w_f\right)_i \quad \text{with} \quad \sum_{i=1}^{N_\mathrm{var}} \left(w_f\right)_i = 1; \tag{2}$$

For the total accuracy the following criteria were set: $\mathrm{AA_{tot}} \leq 0.3$ characterize very good code predictions, $0.3 < \mathrm{AA_{tot}} \leq 0.5$ characterize good code predictions, $0.5 < \mathrm{AA_{tot}} \leq 0.7$ characterize poor code predictions, and $\mathrm{AA_{tot}} > 0.7$ characterize very poor code predictions. For primary pressure the criterion is $\mathrm{AA_{pr}} \leq 0.1$. For acceptability of the calculation $\mathrm{AA_{tot}} < \mathrm{K}$ is required. The acceptability factor K valid for the whole transient was set to 0.4. In addition, the K=1 was set for any part of transient; therefore the accuracy evaluation should be performed for different parts of transient. The number of discrepancies (ND) indicates the number of variables with variable accuracy $\mathrm{VA_i}$ above the acceptability limit K=0.4.

3 DESCRIPTION OF FACILITY, TEST AND PARTICIPANTS

3.1 Description of RD-14M experimental facility

The RD-14M experimental facility is a pressurized-water loop with essential features similar to the primary heat transport loop of a typical CANDU reactor. Five reactor channel/feeder geometries were selected, representing three middle channels, one top channel, and one bottom channel of a typical CANDU reactor. In the test section are located fuel element simulators (electrically heated). The steam generators (boilers) are scaled approximately 1:1 with typical CANDU steam generators, in terms of tube diameter, mass flux, and heat flux. Primary fluid circulation is provided by two centrifugal pumps. Primary circuit pressure is maintained by a loop pressurizer that contains an electrical heater. The facility is equipped also with an Emergency Core Coolant (ECC) system that provides effective cooling to the fuel element simulators under postulated LOCA accidents conditions. Detailed description is given in [9].

3.2 Description of test B9401

The test B9401 performed on RD-14M experimental facility was a 30 mm diameter inlet-header break test with a high pressure pumped emergency coolant injection available. About two seconds after break initiation, the power was decreased to represent decay power levels and the primary loop pump speeds were exponentially decreased to simulate a pump trip. The ECC isolation valves were opened at 20.6 s and the surge tank was manually isolated at 22.8 s. The test was terminated after an extended period at decay power levels.

3.3 Description of participants

The calculations were performed by six participants from six countries using different codes. Only in the case of Argentina and Romania the same code and code version was used. The information on country, institution and code used is given in Table 1.

Table 1: Participants in the IAEA benchmark

ID	Country	Institution	Code used
arg	Argentina	National Atomic Energy Commission (CNEA)	FIREBIRD-III MOD1-77
can	Canada	Atomic Energy of Canada Limited (AECL)	CATHENA 3.5d Rev.0
ind	India	Bhabha Atomic Research Center (BARC)	RELAP5/MOD3.2
it	Italy	University of Pisa	RELAP5/MOD3.2.2g
ko	Korea	Korea Institute of Nuclear Safety (KINS)	RELAP5/CANDU
ro	Romania	Cernavoda NPP Unit 1 (CNPP)	FIREBIRD-III MOD1-77

4 RESULTS

The blind and open accuracy analyses were performed. In the blind accuracy analysis the information about the experimental facility and test was not available. The improved FFTBM software was used [10] in both analyses with the capability to show the variables with discrepancies therefore qualitative analysis was performed by visual observation of variables. The study using improved FFTBM [11] showed that the proposed accuracy measures quantitatively represent the information from qualitative analysis thus giving a more complete picture of the code accuracy. This is important when the reader is not provided with the accompanied qualitative analysis.

Before the blind analysis was made available for comments, the representative from Italy reviewed it. After receiving the draft intercomparison report with the results of qualitative analysis and the participant's comments on blind accuracy calculation a new quantitative analysis, called open, was performed which did not significantly change the main conclusions based on original (blind) quantitative analysis. However, some issues from blind analysis were resolved.

4.1 Blind accuracy analysis

The results of accuracy analysis for the whole transient duration 400 s with 23 selected variables are shown in Table 2. The novel feature of this analysis is that void fractions were used in the analysis. Namely, short discussions were held with the representative from Italy regarding phenomenological windows, variables and void fraction weights selection. The results showed that all participants fulfilled the acceptance criterion (see Section 2) for the calculation while the primary pressure criterion was not fulfilled (6P-D1). The results also showed that all codes were capable to satisfactorily predict the transient. In Table 3 are shown new accuracy measures for blind quantitative analysis. The best calculation has only three discrepancies (ND). For most calculations the maximal and minimal variable accuracies were integral of ECC flows and boiler 1 inlet fluid temperature, respectively. The core heatup was predicted satisfactorily for all except ‘ro’ calculation.

In general, the analysis clearly showed the differences between calculations. It seems that user (user effects) has more influence on the results than the code selected (see ‘arg’ and ‘ro’ results). The best calculation was judged very good by FFTBM. The main concern by reviewer was the primary pressure that not fulfilled the criterion, which is universal for all water reactors. To resolve this issue detailed analysis was performed.

Table 2: Results of blind quantitative analysis

	Participants ID	arg	can	ind	it	ko	ro
ID	Variables (device code)	Average amplitudes (AA) for time interval (0-400 s)					
1	Δp on the pump 1 (5Q-D1)	0.198	0.202	0.319	0.191	0.226	0.159
2	Δp on the pump 2 (12Q-D1)	0.416	0.451	0.589	0.498	0.524	0.489
3	Pressure in header 7 (6P-D1)	0.127	0.117	0.152	0.129	0.135	0.121
4	Pump 1 discharge flow (1F)	1.145	0.970	0.944	1.414	1.582	2.225
5	Pump 2 discharge flow (2F)	1.002	2.420	0.983	1.387	2.143	3.112
6	ECC flow to header 5 (231F-D1)	0.938	0.984	1.342	1.064	0.880	1.056
7	ECC flow to header 8 (234F-D1)	0.679	0.737	0.973	0.693	0.748	0.827
8	Integral of ECC flows (1H)	0.025	0.030	0.053	0.030	0.038	0.146
9	Boiler 1 inlet void fraction (11VF-DT1)	0.637	0.615	0.686	0.619	0.724	0.807
10	Boiler 2 inlet void fraction (12VF-DT3)	0.956	0.948	1.229	1.128	1.098	1.115
11	Pump 1 outlet void fraction (21VF-DTZ)	0.899	0.871	1.062	0.930	0.869	0.933
12	Pump 2 outlet void fraction (4VF-DTZ)	0.977	0.493	1.051	0.497	0.561	0.495
13	Boiler 1 inlet fluid temperature (60T-D1)	0.338	0.242	0.481	0.253	0.304	0.287
14	Boiler 2 inlet fluid temperature (61T-D1)	0.212	0.148	0.325	0.205	0.147	0.124
15	Boiler 1 outlet fluid temperature (60T-D2)	0.181	0.127	0.286	0.159	0.212	0.144
16	Boiler 2 outlet fluid temperature (61T-D2)	0.206	0.143	0.204	0.136	0.179	0.285
17	Top pin sheath temperature (208T-D12)	0.265	0.191	0.209	0.266	0.307	0.666
18	Bottom pin sheath temperature (203T-D12)	0.293	0.346	0.257	0.268	0.181	0.239
19	Void fraction – HS13 inlet (31VF)	0.837	0.929	0.949	1.013	1.129	0.802
20	Void fraction – HS13 outlet (32VF)	0.907	0.991	0.951	1.034	1.074	0.956
21	Δp between HS13 and header 5 (45Q-D1)	0.949	0.942	1.062	1.036	1.212	1.001
22	Pressure in surge tank (26P-D1)	0.103	0.097	0.194	0.140	0.147	0.116
23	Boiler 1 drum pressure (1P)	0.092	0.096	0.090	0.588	0.084	0.643
	total	0.295	0.277	0.357	0.312	0.313	0.392

Table 3: New accuracy measures for blind accuracy analysis

	Time interval 0- 400 s					
Participant ID	AA_{tot}	VA_{max}	variable with VA_{max}	VA_{min}	variable with VA_{min}	ND
arg	0.30	0.03	1H	0.86	60T-D1	6
can	0.28	0.03	1H	0.81	2F	3
ind	0.36	0.06	1H	1.23	60T-D1	7
it	0.31	0.03	1H	0.65	60T-D1	9
ko	0.31	0.04	1H	0.78	60T-D1	7
ro	0.39	0.06	5Q-D1	1.20	208T-D12	8

4.2 Primary pressure analysis

Because the experimental data were recorded every 0.1 s, for the FFTBM analysis maximum (f_{max}) and cut frequency (f_{cut}) of 5 Hz were selected. When the reasons for not fulfilling the primary pressure criterion were investigated, it was discovered that recorded experimental pressure signal exhibit small oscillations, which were not clearly visible from the comparison plot for the whole transient duration. The calculated data were sampled each second and the trends were much smoother as it is shown in Figure 1. Therefore the experimental data were reduced by taking sample at each second. Instead of 3984 points 407 points were used for FFTBM analysis. In the past this problem was not encountered because the maximum number of data points in the original FFTBM was limited to 1000 points and it was needed to reduce the data first. When the original experimental signal was compared by reduced experimental signal the AA was about 0.07 (comparison of the same signals should give zero) using f_{cut}=5 Hz. This means that experimental data should be reduced or f_{cut} decreased to avoid the higher frequencies contribution which in this case has no physical meaning as the trend of oscillating (original) and smooth (reduced) pressure signal is the same. Therefore in the open analysis the f_{cut} was set to 0.5 Hz to eliminate higher frequency contribution. Another option is to use reduced experimental signal giving practically the same results as it will be shown later. In this way part of the information from experimental signal is lost (small oscillations) and therefore the accuracy increases. Nevertheless, this is the only way to objectively perform quantitative analysis and in such a way also analyses by original FFTBM are performed.

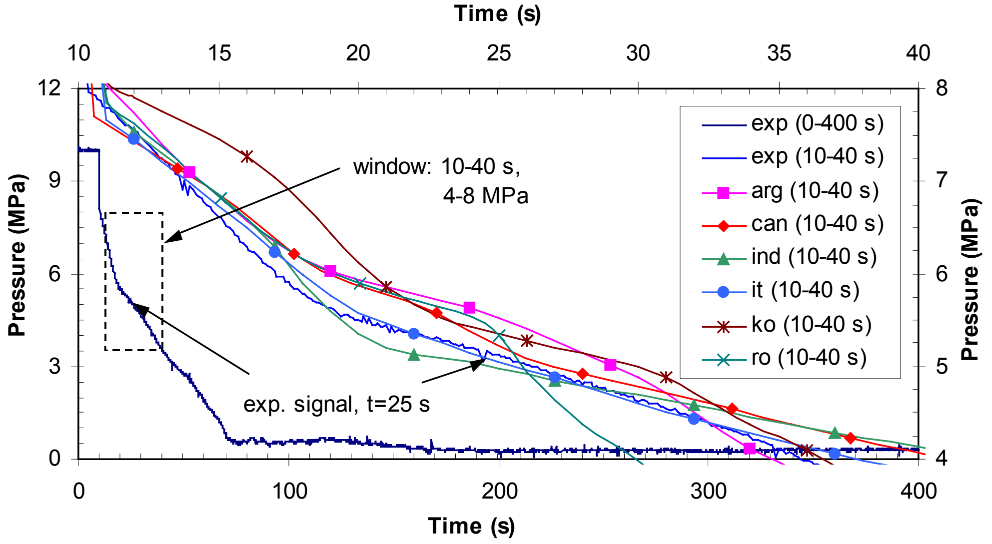

Figure 1: Comparison between experimental and calculated pressures in header 7

4.3 Open accuracy analysis

Because of the reasons above the f_{max} and f_{cut} in the FFTBM analysis were set to 0.5 Hz. As already mentioned the comments of participants on blind accuracy analysis were taken into account in the open analysis. The new list for calculating total code accuracy consists of 24 variables. Instead of pressure in header 7 (6P-D1) the pressure in header 6 was selected (4P-D1) as suggested by representative from Italy. The variable pressure difference between heat structure (HS) 13 and header 5 was eliminated due to not valid measurements reported for two-phase conditions. For the same reason the variables primary pump flowrate 1F and 2F were replaced by variables differential pressure between header 8 and 5 (35Q-D1) and between header 6 and 7 (36Q-D1). Because in the intercomparison report [12] it is stated that ECC flowrates to each header are important the variables EEC flow to header 6 (232-F1) and header 7 (233F-1) were added. The results for AA and total accuracy for the whole transient are shown in Table 4. In general the accuracy increases because of lower selected f_{cut}. However, the general conclusions remain the same with exception that primary pressure criterion is fulfilled for most participants.

Table 4: Results of open quantitative analysis

	Participants ID	arg	can	ind	it	ko	ro
ID	Variables (device code)	Average amplitudes (AA) for time interval (0-400 s)					
1	delta P on the pump 1 (5Q-D1)	0.169	0.176	0.301	0.163	0.207	0.117
2	delta P on the pump 2 (12Q-D1)	0.337	0.391	0.570	0.454	0.481	0.446
3	Pressure in header 6 (4P-D1)	0.074	0.089	0.106	0.084	0.081	0.051
4	Δp between header 8 and 5 (35Q-D1)	0.357	0.499	0.739	0.556	0.623	0.411
5	Δp between header 6 and 7 (36Q-D1)	0.341	0.330	0.560	0.296	0.399	0.517
6	ECC flow to header 5 (231F-D1)	0.894	0.976	1.476	1.102	0.822	1.071
7	ECC flow to header 6 (232F-D1)	1.006	0.720	1.180	0.966	0.952	1.091
8	ECC flow to header 7 (233F-D1)	1.221	0.949	1.788	0.955	0.912	1.148
9	ECC flow to header 8 (234F-D1)	0.572	0.644	0.940	0.582	0.665	0.744
10	Integral of ECC flows (1H)	0.024	0.029	0.056	0.029	0.036	0.137
11	Boiler 1 inlet void fraction (11VF-DT1)	0.558	0.530	0.624	0.533	0.678	0.794
12	Boiler 2 inlet void fraction (12VF-DT3)	0.931	0.901	1.333	1.184	1.101	1.153
13	Pump 1 outlet void fraction (21VF-DTZ)	0.881	0.826	1.084	0.912	0.827	0.925
14	Pump 2 outlet void fraction (4VF-DTZ)	0.961	0.263	1.088	0.275	0.369	0.272
15	Boiler 1 inlet fluid temperature (60T-D1)	0.303	0.203	0.469	0.216	0.275	0.255
16	Boiler 2 inlet fluid temperature (61T-D1)	0.221	0.156	0.343	0.216	0.159	0.132
17	Boiler 1 outlet fluid temperature (60T-D2)	0.164	0.130	0.282	0.166	0.222	0.144
18	Boiler 2 outlet fluid temperature (61T-D2)	0.199	0.149	0.199	0.138	0.188	0.260
19	Top pin sheath temperature (208T-D12)	0.244	0.190	0.213	0.278	0.291	0.710
20	Bottom pin sheath temperature (203T-D12)	0.298	0.366	0.256	0.259	0.173	0.240
21	Void fraction – HS13 inlet (31VF)	0.731	0.879	0.899	1.017	1.166	0.662
22	Void fraction – HS13 outlet (32VF)	0.862	0.993	0.927	1.038	1.153	0.932
23	Pressure in surge tank (26P-D1)	0.042	0.038	0.130	0.078	0.086	0.057
24	Boiler 1 drum pressure (1P)	0.045	0.048	0.041	0.525	0.035	0.553
	total	0.264	0.229	0.361	0.273	0.260	0.318

Finally, Table 5 shows the results of total accuracy as a function of f_{max}, f_{cut} and the number of data. As it is expected the reduced and original experimental data with f_{max}=0.5 Hz and f_{cut}=0.5 Hz and original experimental data with f_{max}=5 Hz and f_{cut}=0.5 Hz gave almost identical results.

Table 5: Total accuracy as a function of f_{max}, f_{cut} and the number of data points

Interval 0-400 s	Original exp. data f_{max}=0.5, f_{cut}=0.5	Original exp. data f_{max}=5, f_{cut}=0.5	Original exp. data f_{max}=5, f_{cut}=5	Reduced exp. data f_{max}=0.5, f_{cut}=0.5
Participants ID	AA_{tot}	AA_{tot}	AA_{tot}	AA_{tot}
arg	0.264	0.263	0.289	0.259
can	0.229	0.225	0.249	0.223
ind	0.361	0.365	0.367	0.361
it	0.273	0.271	0.294	0.268
ko	0.260	0.259	0.280	0.255
ro	0.318	0.316	0.340	0.314

4.4 Results discussion

When FFTBM analysis is performed there are many values, which could be checked. Namely, the AA is a function of f_{cut}, the number of given and interpolated data points (equivalent to f_{max}) and the duration of time window. Normally this dependence is rather small. Therefore the AA representing accuracy is calculated at selected f_{cut} for selected number of interpolated points for the whole transient duration. In the open accuracy analysis all these dependencies were deeply studied for primary pressure accuracy. It was found that all experimental signals oscillated around the trend curve. Where amplitudes of oscillations are very small they may be due to measurement system and therefore it is physically correct to eliminate them. It is intrinsic to and one of powerful features of the FFTBM to detect such oscillations. Generally the contribution of small amplitude oscillations is small. However, in the present study they caused the primary pressure criterion not to be fulfilled. In the analyses using original FFTBM algorithm this problem would not be encountered because the data are normally reduced (thus loosing some information) below 1000 data points. This study shows that more data points are available better comparison could be done by FFTBM. However if the number of experimental and calculated data points is different, analysis with approximately the same number of data points may provide the most reasonable results. Also there is no need to reduce the data if appropriate cut frequency is selected to filter the high frequency components in the amplitude spectrum.

5 CONCLUSIONS

This was the first FFTBM application to the facility simulating CANDU reactor. Some concern was raised by the primary pressure criterion, which was not fulfilled in blind accuracy analysis. In the open quantitative analysis the problem of pressure accuracy was mostly resolved and it can be concluded that primary pressure criterion is applicable also to facilities simulating heavy water reactors.

The conclusions based on accuracy analysis agree well with conclusions from the intercomparison report. When the total accuracy results obtained from the present study are compared with international FFTBM database related to light water reactor experimental scenarios and connected calculations it can be concluded that the accuracy of the best calculations of the RD-14M LB LOCA is consistent with the best practice in LWR technology.

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REFERENCES

[1] F. D'Auria, M. Leonardi, R. Pochard, “Methodology for the evaluation of thermalhydraulic codes accuracy”, Proc. Int. Conf. on New trends in Nuclear System Thermohydraulics, Pisa, Italy, May 30 – June 2, University of Pisa, 1994, pp. 467-477.

[2] A. Prošek, “Quantitative Accuracy Assessment of Thermalhydraulic Code Predictions with SARBM”, Proc. Int. Conf. Nuclear Energy in Central Europe 2001, Portorož, Slovenia, September 10-13, Nuclear Society of Slovenia, 2002, pp. 1-8.

[3] A. Prošek, B. Mavko, “The accuracy quantification of thermal-hydraulic code”, *Journal of Mechanical Engineering*, **49(4)**, 2003, pp. 218-229.

[4] R.F. Kunz, G.F. Kasamala, J.H. Mahaffy, C.J. Murray, “On the automated assessment of nuclear reactor systems code accuracy”, *Nuclear Engineering and Design*, **211**, 2002, pp. 245-272.

[5] B. Mavko, A. Prošek, F. D’Auria, “Determination of code accuracy in predicting small-break LOCA experiment”, *Nuclear Technology*, **120**, 1997, pp. 1-19.

[6] A. Prošek, F. D'Auria, B. Mavko, “Review of quantitative accuracy assessments with fast Fourier transform based method (FFTBM)”, *Nuclear Engineering and Design*, **217(1-2)**, 2002, pp. 179-206.

[7] A. Prošek, “Lessons learned from accuracy assessment of IAEA-SPE-4 experiment predictions”, Proc. International Conference Nuclear Energy for New Europe 2002, Kranjska Gora, Slovenia, September 9-12, Nuclear Society of Slovenia, 2002, pp. 205.1-205.8.

[8] A. Prošek, B. Mavko, F. D’Auria, “Quantitative analysis of RD-14M large LOCA test B9401 calculations”, IJS working report IJS-DP-8819, January 2004, Ljubljana.

[9] D.J. Richards, F. D’Auria, G. Bedrossian, Y.J. Cho, S.K. Gupta, R. Istrate, “Intercomparison and validation of computer codes for thermal-hydraulic safety analysis of heavy water reactors”, Int. Conf. NURETH-10, Seoul, Korea, October 5-9, 2003.

[10] A. Prošek, B. Mavko, “A tool for quantitative assessment of code calculations with an improved fast Fourier transform based method”, *Electrotechnical Review*, **70(5)**, 2003, pp. 291–296, 2003 (http://ev.fri.uni-lj.si/5-2003/prosek.pdf).

[11] A. Prošek, “Accuracy assessment of IAEA-SPE-4 predictions with improved FFTBM”, *Trans. American Nuclear Society*, **87**, 2002, pp. 199-201.

[12] D.J. Richards, “Intercomparison and validation of computer codes for thermal-hydraulic safety analysis of heavy water reactors – comparison report”, AECL report, Rev. 0 and IAEA TECDOC, “Intercomparison and validation of computer codes for thermalhydraulic safety analysis of heavy water reactors”, draft, Rev.6-2.