ACCURACY ASSESSMENTS WITH FAST FOURIER TRANSFORM BASED METHOD (FFTBM)

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Abstract

NPP safety analysis based on the "Best Estimate" approach and best estimate codes represent the plant behavior in a realistic way. The result of best estimate system codes, however, are still affected by uncertainty; a large number of different and complex phenomena are occurring in a plant, and the model and solution methods in the codes remain approximate. System codes offer a great degree of freedom to their users, which, as downside, introduce user dependent results. Also hardware and the compiler that has been used might affect the calculations. Therefore the best estimate predictions of nuclear power plant scenario must be supplemented by proper uncertainty evaluations in order to be meaningful. UMAE (Uncertainty Methodology based on Accuracy Extrapolation) and CIAU (Code with the capability of Internal Assessment of Uncertainty) uncertainty methods derive the uncertainty by comparing experimental results with code calculations. UMAE and CIAU need an objective method, independent from expert judgment, which quantifies the accuracy of a code calculation with respect to an experiment. A methodology suitable to quantify the code accuracy has been developed based on the Fast Fourier Transform method (FFTBM). This method is easy to understand, convenient to use, user independent and it clearly indicates when a simulation needs to be improved. The FFTBM derives from the measurement and the prediction the accuracy in the frequency domain. The acceptability factor for code calculation was determined based on several hundreds of code calculations. Application of the FFTBM is not limited to support for uncertainty evaluation. It also is a convenient method to derive a figure of merit, to quantify the quality of a code prediction. In fact, the FFTBM method has been applied to various international standard problems, standard problem exercises and other experiment – simulation exercises. The purpose of the paper summarize typical applications of the FFTBM in international standard problems (ISP) or standard problem exercise (SPE) organized by CSNI or IAEA.

1. Introduction

The thermalhydraulic systems (TH-SYS) codes, widely used to simulate the behaviour of Nuclear Power Plants (NPPs) during accident scenarios or abnormal conditions, are affected by uncertainty. Despite the complexity reached by these codes and the improvement in the understanding of the physical phenomena, the results of a computer code cannot be expected to accurately model such phenomena that are not yet fully understood by the scientific community. In general, the results of code predictions, specifically when compared with experimental data reveal unavoidable discrepancies. Several are the reasons for these discrepancies: model deficiencies, approximations in the numerical solutions, nodalization and user effects, imperfect knowledge of boundary and initial conditions. Therefore, it is necessary to quantify the uncertainty in the code results and the sensitivity effect of the most effective parameters. For these purposes different methods for the treatment of the uncertainty have been proposed; one of these, developed to the University of Pisa, is the UMAE (Uncertainty Methodology based on Accuracy Extrapolation). The basic idea of UMAE is the use of the accuracy from the comparison between measured and calculated trends of relevant experiments and calculations, respectively. The experiments must come from relevant scaled facilities and the calculation results from qualified codes and nodalizations. This avoids the need to select input uncertainties; also, resulting uncertainty range are coming from the process and do not need subjective evaluations. The development of suitable nodalizations and qualification at the 'steady state' and the 'on-transient' levels are needed. The process of nodalization qualification is fully independent from the process aiming at the derivation of the extrapolated accuracy (different data bases are used). The fulfilment of various conditions (quality of data base, of NPP nodalization, of code performance) allows the finalization of the process that, vice versa, can be interrupted at different stages. In the first situation, accuracy, coming from several comparisons between measured and calculated trends can be "extrapolated" and becomes uncertainty. This is superimposed to the unique best-estimate code run performed by a qualified NPP nodalization. The demonstration that a given physical phenomenon occurs in differently scaled facilities is necessary: this can be achieved through the use of the FFTBM. Owing to the above, the UMAE could not be applied if experiments reproducing the target test scenario are not available.

2. The Fast Fourier Transform Based Method (FFTBM)

2.1 Introduction

Several approaches have been proposed to quantify the accuracy of a given code calculation (see [1] [2]). Even though these methods were able to give some information about the accuracy, they were not considered satisfactory because they involved some empiricism and were lacking of a precise mathematical meaning. Besides, engineering subjective judgment at various levels is deeply inside proposed methods. Generally, the starting point of each method is an error function, by means of which the accuracy is evaluated. Some requirements were fixed which an objective error function should satisfy:

1. at any time of the transient this function should remember the previous history;
2. engineering judgment should be avoided or reduced;
3. the mathematical formulation should be simple;
4. the function should be non-dimensional;

5. it should be independent upon the transient duration;
6. compensating errors should be taken into account (or pointed out);
7. its values should be normalized.

The simplest formulation about the accuracy of a given code calculation, with reference to the experimental measured trend, is obtained by the difference function

$$\Delta g(t) = g_{calc}(t) - g_{\exp}(t) \qquad (1)$$

The information contained in this time dependent function, continuously varying, should be condensed to give a limited number of values which could be taken as indexes for quantifying accuracy. This is allowed because the complete set of instantaneous values of ΔF(t) is not necessary to draw an overall judgment about accuracy.

Integral approaches satisfy this requirement, since they produce a single value on the basis of the instantaneous trend of a given function of time. On the other hand, searching for functions expressing all the information through a single value, some interesting details could be lost. Therefore, it would be preferable to define methodologies leading to more than one value in order to characterize the code calculation accuracy.

2.2 Fast Fourier Transform approach

Time representation of a physical parameter that describes a particular phenomenon is the traditional way to represent a signal. However the time domain representation may be insufficient to gain insight as to what constitutes a signal. For example a signal can be affected by the presence of noise or disturbances at particular frequencies that are hidden in the time domain. In this context, the complete behavior of a signal can be understood changing the representation domain, in particular translating a given signal function of the time in the frequency domain that works with the frequency spectrum, that is, with the signal expressed as a function of frequency. The method whereby we may obtain the variation of a quantity as a spectral function is the Fourier Transform (FT). The FT is a powerful tool for signal processing that allows the decomposition of a signal as the sum of a possibly infinite number of sinusoids of different frequencies. The graphical display of a transformed signal is obtained through the two spectral coordinates: amplitude and frequency. In Figure 1 is illustrated an example of the Fourier transform of a simple time function. The FT of the example function is the two sinusoids that summed together produce the shape of the original time function

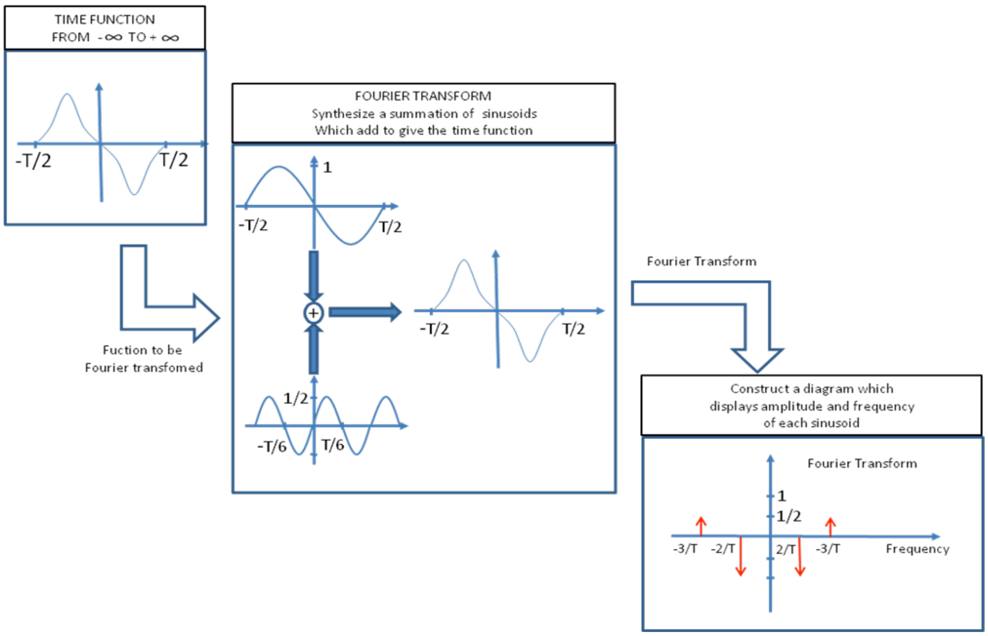

Figure 1 Sample Fourier Transform representation.

The construction of the frequency spectrum of a signal is obtained by means of integral formulation, namely:

$$\tilde{g}(f)=\int_{-\infty}^{+\infty} g(t)e^{-j2\pi f t}dt \tag{2}$$

If the integral exist for every real value of the parameter f, it defines a function $\tilde{g}(f)$ known as Fourier transform of the function $g(t)$. The back transformation from the frequency domain to the time domain is defined by the inverse Fourier transform (see equation (3))

$$g(t)=\int_{-\infty}^{+\infty} \tilde{g}(f)e^{j2\pi f t}df \tag{3}$$

It is assumed that the time function to which the Fourier transform is applied verify the analytical conditions required by its application theory; i.e., it is assumed that they are continuous (or generally continuous) in the considered time intervals with their first derivatives, and absolutely integrable in the interval (-∞, +∞).This last requirement can be easily satisfied in our case, if the addressed functions assume values different from zero only in the interval (0, T). Therefore:

$$\tilde{g}(f)=\int_{0}^{T} g(t)e^{-j2\pi f t}dt \tag{4}$$

Generally, in computational work, we do not treat a continuous function $g(t)$, but rather $g(t_k)$ given by a discrete set of t_k's. (For now, we assume that a physical process of interest is described in the time domain.) In most common situations, the value of $g(t)$ is recorded at evenly spaced intervals. In this context, we have to estimate the Fourier transform of a function from a finite number of its sampled points. Suppose that we have a set of measurements performed at equal time intervals of Δt. Then the sequence of sampled values is given by:

$$\{g_0(t_0), g_1(t_1), ..., g_k(t_k)\}, \quad t_k = k\Delta t, \quad k = 0,1,2,...,N-1 \tag{5}$$

Suppose that we have N consecutive sampled values. With N numbers of input, we can produce at most N independent numbers of output. So, instead of trying to estimate the Fourier transform $\tilde{g}(f)$ in the whole range of frequency f, we seek estimates only at the discrete values $f = f_n$ with $n = 0,1,2,...,N-1$. By analogy with the Fourier transform for a continuous function $\varphi(t)$, we may define the Fourier transform for a discrete set of $g_k = g(t_k)$ ($k = 0,1,2,...,N-1$) as below:

$$\tilde{g}(f_n) = \int_0^{T_d} g(t) e^{-i2\pi f_n t} dt \approx \frac{1}{N}\sum_{k=0}^{N-1} g_k e^{-i2\pi f_n t_k} \Delta t = \Delta t \bullet \frac{1}{N}\sum_{k=0}^{N-1} g_k e^{-i2\pi f_n t_k} \tag{6}$$

In other words to obtain the frequency spectrum of the sampled function we compute the integral through a discrete sum. The equation (6) between the discrete Fourier transform of a set of numbers and their continuous Fourier transform when they are viewed as samples of continuous function sampled at an interval Δt can be written as:

$$\tilde{g}(f_n) = \Delta t \bullet \tilde{g}_n \tag{7}$$

The discrete Fourier transform can be computed with an algorithm called the Fast Fourier Transform (FFT), which is algorithm that rapidly computes the discrete FT. To apply it, functions must be identified by a number of values that are a power with base equal to 2 and sampling theorem must be fulfilled. The fulfillment of the sampling theorem is required to avoid distortion of sampled signals due to aliasing occurrence. This theorem, first enunciated by Nyquist in 1928 [3] and then proved by Shannon in 1949 [4], establishes that any band limited signal can be uniquely determined by its samples as long as the sample rate is at least twice that of the highest frequency found in the signal. The highest frequency of the signal is usually referred to as the Nyquist frequency and twice this, which is the frequency that must be exceeded by the sampling rate, is commonly called the Nyquist rate. Thus, if the number of points defining the function in the time domain $N = 2^{m+1}$ then according to the sampling theorem the sampling frequency is given by the equation (7).

$$\frac{1}{\Delta t} = f_s = 2 f_{max} = \frac{N}{T_d} = \frac{2^{m+1}}{T_d} \tag{8}$$

Where, T_d is the transient time duration of the sampled signal and f_{max} is the highest (maximum) frequency component of the signal. The sampling theorem does not hold beyond f_{max}. From the relation in (8) is seen that the number of points selection is strictly connected to sampling frequency. The FFT algorithm determines the number of points, equally spaced, which is a power with base 2 (N range from 2^9 to 2^{12}). Generally, an interpolation is necessary to satisfy this requirement. Taking in account that the available subroutine packages evaluate the FFT normalized to the time duration T_d, from the equations (4) and (8), it can be easily seen that $\left|\tilde{g}(0)\right|$ represent the mean value of the function $g(t)$ in the interval $(0, T_d)$ while $\left|\tilde{g}(f_n)\right|$ represent the amplitude of the n-th term of the Fourier polynomial expansion $g(t)$. To apply the methodology described above, after selecting the signals to be analyzed, it is necessary to choose the following parameters: number of points, sampling frequency and cut frequency.

2.3 How to use the FFT to quantify the code accuracy

The method developed for the code accuracy quantification of an individual calculation is based on the amplitude of the FFT of the experimental signal and of the difference between this one and the calculated trend. In particular the method introduces the definition of two *figures of merits,* which gives a synthesis of the information inside the error function (1). Indeed any of features that have these figures is to have memory of the discrepancy between the experimental and the analytical time trend of a parameter.

$$AA = \frac{\sum_{n=0}^{2^m} \left|\Delta\tilde{F}(f_n)\right|}{\sum_{n=0}^{2^m} \left|\tilde{F}_{exp}(f_n)\right|} \qquad WF = \frac{\sum_{n=0}^{2^m} \left|\Delta\tilde{F}(f_n)\right| \cdot f_n}{\sum_{n=0}^{2^m} \left|\Delta\tilde{F}(f_n)\right|} \tag{9}$$

The average amplitude AA represents a sort of average fractional error of the addressed calculation, while the weighted frequency gives an idea of the frequencies which give the greatest contribution to the inaccuracy. The two obtained values can be used to evaluate the accuracy of the code calculation by representing the discrepancies with respect to the experimental data through a point in the AA-WF domain. Of course the most interesting information is given by AA, which represents the relative magnitude of these discrepancies; WF adds a further information allowing to better identify the character of accuracy. As an example, oscillations of the calculated values around an average trend can be readily identified by the method. Moreover, this information can be used, in principle, in the quantification of the accuracy. In fact, depending on the transient and on the variable considered, low frequency errors can be more important that high frequency ones, or vice versa (in thermal–hydraulic transient, better accuracy is generally represented by low AA values at high WF values) [5] [6].

Trying to give an overall picture of the accuracy of a given calculation, average indexes of performance are obtained by defining average performance indices: the total weighted $(AA)_{tot}$ (10) and the total WF_{tot} (see equation (10))

$$(AA)_{tot} = \sum_{i=1}^{N_{var}} AA \cdot (w_f)_i \ ; \ (WF)_{tot} = \sum_{i=1}^{N_{var}} (WF)_i (w_f)_i \qquad (10)$$

With

$$\sum_{i=1}^{N_{var}} (w_f)_i = 1 \qquad (11)$$

Where N_{var} is the number of analyzed parameters and $(w_f)_i$ are weighting factors that take into account the different importance of each parameter from the viewpoint of safety analyses.
Following the quantitative evaluation of accuracy, the Quantitative Assessment (QA) can be managed by means of the application of the FFT method. Obviously, the most suitable factor for the definition of an acceptability criterion is the average amplitude AA. With reference to the accuracy of a given calculation, we can define the following acceptability criterion:

$$(AA)_{tot} < K \qquad (10)$$

Where, K is an acceptability factor that is valid for the whole transient. As lower is the AAtot value, as better is the accuracy of the analyzed calculation. With reference to experience gathered from previous applications of this methodology, K = 0.4 has been chosen as reference threshold value identifying acceptable accuracy of a code calculation.

3. Application of the FFTBM

Three example applications of the FFTBM for assessing the total accuracy of the code results are proposed. The first one is an analytical exercise on a (Main Steam Line Break) MSLB transient in PKL-III facility (Test G3.1) [7]. The second one is related to the benchmark on large break LOCA transient in PSB VVER facility (Test 5A) [8]. The last one is the ATLAS ISP-50 (see [12]).

3.1 Application to Test G3.1

The test G3.1, which is the third test of an experimental program consisting of eight tests, carried out in PKL-III test facility has been selected by the program review group and the management board for performing an analytical activity among the project participants. This test is a fast cool-down transient, namely a main steam line break. The design of the experiment involves two phases: the first is based on the 0.1A break in main steam line as initiating event and the second one consists in the ECCS (Emergency Core Cooling System) injections by means of the HPIS (High Pressure Injection System) connected with the cold legs #1 and #4 [7].

For the quantitative analysis of the accuracy of the results, which are submitted by participants (GRS, KAERI, PSI, UNIPI, UPV, and UPC) to the benchmark, 23 parameters are selected. They are selected as the minimum number relevant to describe the transient, considering both the peculiarities of the transient and the availability of the experimental data. Those parameters are then combined to give an overall picture of the accuracy of a given calculation. The total average amplitude of the transient is the result of the sum of all the average amplitudes with their "weights".

The "weight" of each contribution is dependent by the experimental accuracy, the relevance of the addressed parameter, and a component of normalization with reference to the average amplitude evaluated for the primary side pressure. The reference results of the method are usually focused on three values: the averages amplitudes of the primary pressure and of the global (or total) response, consistently with the typical application of the method plus the coolant temperature at the affected SG outlet due to the peculiarity of the test. The procedure for code assessment, as described in ref. [7], considers, in case of LOCA (Loss of Coolant Accident) transients, two threshold limits: $AA_{pp} \leq 0.1$ for the average amplitude of the primary pressure and $AA_{tot} \leq 0.4$ for the total average amplitude. The results of the total average amplitude are depicted in Figure 2.

The achieved results bring to the following considerations: the accuracy rises above 0.2 if the overall transient is considered (Figure 3). Accuracies values above 0.4 are calculated for KAERI and UPV-2 results. This is mainly connected with the operation of the valve during the second phase of the transient. Excellent quantitative accuracy of the results is achieved by GRS (0.073) and UNIPI-1 (0.062) in calculating the coolant temperature at the SG outlet of the affected loop during the first phase of the transient. Higher values are observed in the other cases. The total quantitative accuracy is below 0.2 considering the Phase I (see Figure (2)) of the transient for 5 out of 8 participants. It remains below 0.2 for 3 out of 8 participants if the overall transient is considered (see Figure (3) and Table (1)).

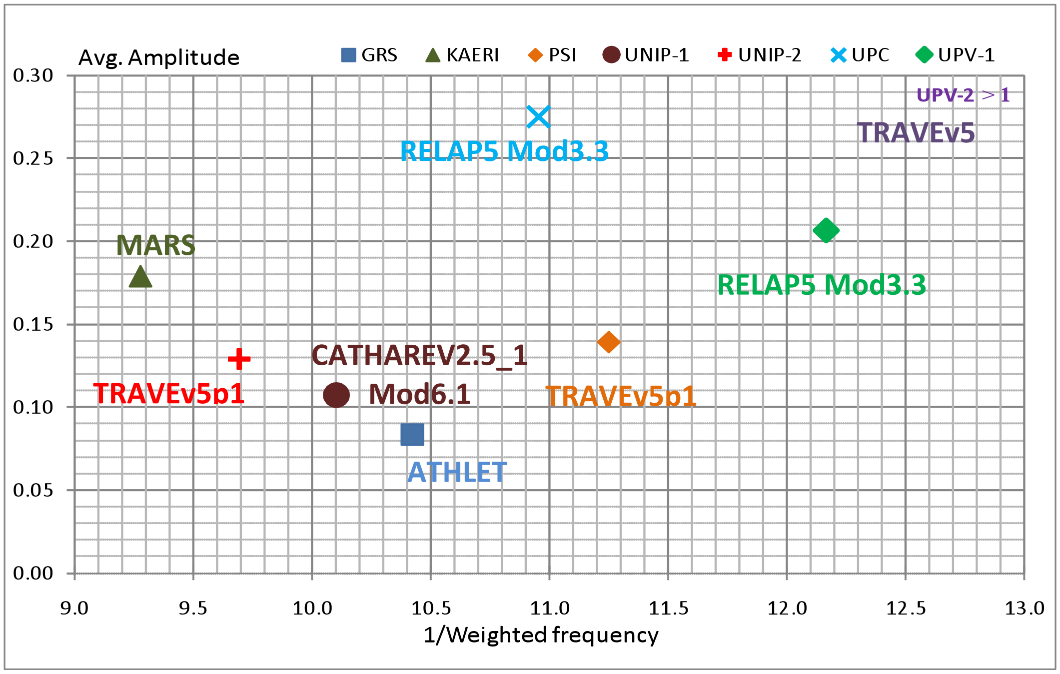

Figure 2 Quantitative accuracy evaluation of the results: From 0 up to 1030s

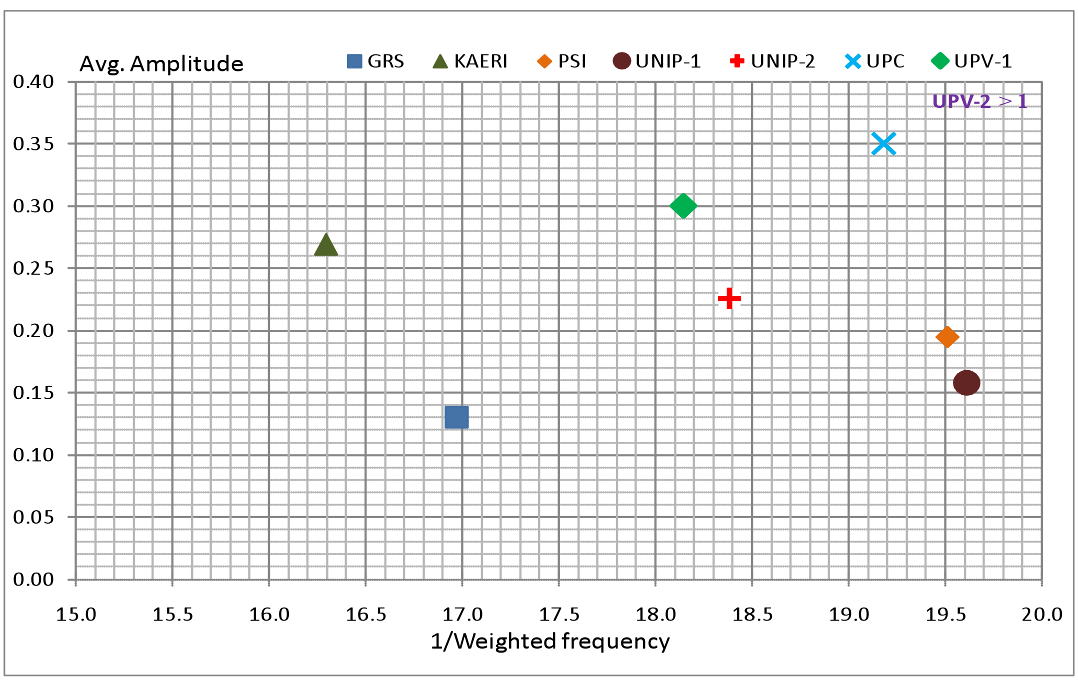

Figure 3 Quantitative accuracy evaluation of the results: Overall transient

Table 1 summary of results obtained by application of FFT-BM – overall transient.

#	PARAMETER		GRNSPG UNIPI C2				GRNSPG UNIPI TRACEv5			
			Time of interval							
	Description	ID	(0-1030s)		(0-4410s)		(0-1030s)		(0-4410s)	
			AA	AA	AA	WF	AA	WF	AA	WF
1	UP pressure	*P RDB OP*	0.025	0.087	0.266	0.035	0.011	0.097	0.317	0.035
2	PRZ pressure	*P DH MB 50*	0.023	0.093	0.272	0.034	0.013	0.127	0.322	0.033
3	SG-1 pressure	*P DE1 SEK MB 50*	0.032	0.070	0.038	0.051	0.048	0.045	0.053	0.033
4	SG-4 pressure	*P DE4 SEK*	0.065	0.096	0.062	0.053	0.032	0.113	0.033	0.062
5	LP coolant (liquid) temp.	*TF UP OBEN*	0.039	0.089	0.043	0.058	0.065	0.105	0.147	0.056
6	UP coolant (liquid) temp.	*TF OP ME11/1*	0.041	0.063	0.041	0.035	0.063	0.101	0.142	0.057
7	UH coolant (liquid) temp.	*TF DK ME 19*	0.031	0.143	0.232	0.055	0.089	0.124	0.436	0.054
8	PRZ coolant (liquid) temp. (at 1.716m)	*TF DH ME 3*	0.018	0.102	0.087	0.031	0.006	0.106	0.119	0.056
9	SG 1 outlet coolant (liquid) temp.	*TF KS1 DE-AUS*	0.062	0.083	0.094	0.055	0.143	0.09	0.171	0.053
10	SG 3 outlet coolant (liquid) temp.	*TF KS2 DE-AUS*	0.022	0.110	0.052	0.053	0.034	0.121	0.107	0.053
11	SG 1 outlet mass flow	*F DE1 AUS WR –VR –VLR*	0.048	0.069	0.053	0.054	0.030	0.084	0.033	0.066
12	SG 2 outlet mass flow	*F DE4 AUS WR– VR –VLR*	0.047	0.058	0.055	0.045	0.028	0.066	0.033	0.048
13	Steam line 1 BRK nozzle	*F LBA 10 CF 001*	0.248	0.204	0.204	0.114	0.331	0.092	0.322	0.073
14	Integral BRK flow rate	--	0.064	0.102	0.055	0.046	0.036	0.08	0.036	0.032
15	DC RPV inlet 1 / outlet 1	*DP RDB EIN/AUS1*	0.542	0.152	0.426	0.077	0.552	0.114	0.482	0.058
16	DP inlet-outlet SG 1 (BL)	*DP DE1 E/A*	1.560	0.107	1.136	0.038	2.214	0.155	1.736	0.078
17	DP inlet-outlet SG 4 (IL)	*DP DE4 E/A*	1.070	0.141	1.188	0.085	1.666	0.164	1.610	0.084
18	DP across BRK device	*DP FD-LECK DE10*	0.799	0.190	0.786	0.111	0.407	0.135	0.421	0.081
19	PRZ collapsed level	*H JEF 10 CL 001*	0.098	0.103	0.092	0.077	0.081	0.136	0.096	0.078
20	SG-1 riser collapsed level	*H DE1 SEK STGRM/GES*	0.162	0.112	0.175	0.090	0.187	0.096	0.201	0.079
21	SG-1 DC collapsed level	*H JEA 10 CL 851*	0.300	0.096	0.308	0.073	0.242	0.101	0.249	0.081
22	SG-2 riser collapsed level	*H DE2 SEK STGRM/GES*	0.038	0.050	0.062	0.051	0.046	0.083	0.104	0.049
23	Hottest cladding temp.	*TW K10/6*	0.097	0.103	0.082	0.042	0.045	0.068	0.114	0.06
	TOTAL AVERAGE ACCURACY	*Total (23 parameters)*	**0.107**	***0.099***	**0.158**	**0.051**	**0.129**	**0.103**	**0.226**	***0.054***

3.2 Application to Test 5A

The Test 5a , identified as "CL-2x100-01", is the fifth and last experiment of the OECD/NEA PSB-VVER project Test Matrix. It consists in the simulation of a Large Break Loss Of Coolant Accident. The main objectives of this test are ([9], [10] and [11]): to obtain experimental data not covered by the VVER validation matrix; to investigate the TH response of the VVER-1000 primary system to guillotine break of cold leg; to obtain experimental data for validation of thermal-hydraulic codes applied to LB-LOCA analysis of VVER-1000; to evaluate the capability of the PSB-VVER facility to simulate the LB-LOCA in VVER-1000.

The experiment starts with the ruptures of the membranes in Cold Leg (CL) #3 and the closure of the valve located between the two break devices, simulating the occurrence of the Double Ended Guillotine Break (DEGB) in the facility. The experiment "CL-2x100-01" simulates the LB-LOCA transient in VVER-1000 NPP. The complete description of the test is available in the EDR, issued by EREC, see [10]

In this application example of the FFTBM six codes calculation results were analyzed considering for the quantification of the accuracy 18 parameters. In Table 2 is reported only RELAP5-3D©, which show a very good prediction of the experiment. Actually they have a total average accuracy lower than 0.4.

Table 2 Results obtained by application of FFTBM: overall transient.

#	PARAMETER		UNIPI Posttest R5-3D	
	Description	**ID**	**(0-1476s)**	
			AA	**WF**
1	**UP pressure**	***YC01P16***	**0.069**	**0.145**
2	PRZ pressure	*YP01P01*	0.039	0.209
3	SG-3 pressure	*YB03P01*	0.105	0.060
4	ACC-1 pressure	*TH01P01*	0.059	0.058
5	LP coolant (liquid) temp	*YC01T06*	0.110	0.139
6	UP coolant (liquid) temp	*YC01T04b*	0.409	0.132
7	Total ECCS mass flow rate (HPIS+LPIS)	--	0.055	0.353
8	PMI (without ACCs)	**Mass1*	0.667	0.249
9	DP across the core (elev. 1.915 – 5.440m)	*YC01DP07-10*	1.534	0.341
10	DP across UP & UH (elev. 5.440 – 12.525m)	*YC01DP11-15*	1.855	0.315
11	DP across loop seal -4	*YA04DP04+05*	1.823	0.348
12	PRZ level	*YP01L02*	0.165	0.211
13	ACC#1 level	*TH01L01*	0.015	0.173
14	SG#3 level	*YB03L01*	0.555	0.105
15	Max Clad T bottom (0.35- 0.71 m)	*YC01T113*	0.173	0.153
16	Max Clad T 2/3 level (2.12 - 2.47 m)	*YC01T55*	0.766	0.080
17	Max Clad T top (2.82 - 3.18 m)	*YC01T39*	0.784	0.087
18	FRBS power	*YC01N01*	0.116	0.358
TOTAL AVERAGE ACCURACY			**0.377**	**0.153**

3.3 ATLAS ISP-50

The ATLAS program started in 1997 under a nuclear R&D mid- and long-term project funded by the Korean government. Since a complete installation of the ATLAS in 2005, several commissioning tests have been performed successfully. Subsequently, the first preliminary integral effect test for a Small Break LOCA (SBLOCA) with a break size equivalent to a 3-inch cold leg break was performed in 2006.

The ISP exercise using the ATLAS facility was proposed and discussed at the 10th Plenary Meeting of the NEA Committee on the Safety of Nuclear Installations (CSNI) Working Group on Analysis and Management of Accidents (WGAMA) in September 2007. At the 11th WGAMA meeting in October 2008, KAERI submitted a specified ISP proposal and a related CAPS (CSNI Activity Proposal Sheet) as well based on a DVI line break scenario for PRG approval, after final endorsement by WGAMA members. Subsequently, the ISP exercise with the ATLAS facility focusing on a DVI line break scenario was finally approved by the CSNI meeting in December 2008 and was numbered by ISP-50.

The ATLAS ISP-50 aims at:

- Better understanding of thermal-hydraulic phenomena in the upper annulus down-comer region during the DVI injection period.
- Generation of integral effect database for code development and validation.
- Investigation of the possible limitation of the existing best-estimate safety analysis codes

Among the DVI line break scenarios, 50% of the cross section of a DVI nozzle would be of interest because this break size is on the edge of the criterion provided by the EPRI requirement where a core uncovery should be prevented by a best-estimate methodology. In particular, the thermal-hydraulic phenomena occurring in the upper annulus down-comer region between the DVI nozzle and the cold leg nozzles are expected to be complicated due to the countercurrent flow of the upward break flow and the downward safety injection flow. Therefore, the relevant models need to be incorporated into the safety analysis codes in order to predict these thermal hydraulic phenomena correctly.

In the present ISP-50 exercise, the predictions of a 50% DVI line break accident of the APR1400 with different best-estimate computer codes (TRACE, CATHARE, RELAP, TRAC, ATHELET, CATHENA and MARS are compared with each other and above all with the results of a carefully specified experimental study. This exercise would contribute to assessing the code’s modelling capabilities and to identifying any deficiencies of the best-estimate system codes of the participants against the obtained integral effect data on the DVI line break accident.

In Table 3 the results of the application of the FFTBM for the comparison exp/calc obtained by University of Pisa in the blind calculation performed with RELAP5/MOD3.3. The results of the FFTBM applied for different time intervals show an excellent agreement between the experimental data. In particular has to be noted that the AA result for the primary pressure is about 0.05 in each of the identified phases. Among the variables selected for the FFTBM, the primary pressure has a relevant role because it gives an estimation of the energy stored into the system and for this the error foreseen is the lowest: 10%.

Table 3: Results obtained by application of FFTBM: at different intervals.

	PARAMETER	Time of interval					
		0 ~ 24 s		0 ~ 300 s		0 ~ 2500 s	
		AA	WF	AA	WF	AA	WF
1	Core power	0.0019	0.3515	0.0038	0.2660	0.0077	0.2313
2	Pressurizer pressure	0.0525	0.2182	0.0561	0.0902	0.0491	0.0581
3	SG1 steam dome pressure	0.0227	0.3476	0.1184	0.1175	0.1661	0.1014
4	SIT-01 pressure	excl.	excl.	excl.	excl.	0.1175	0.0820
5	Core inlet temperature	0.0043	0.1502	0.0230	0.0748	0.0461	0.0927
6	Core exit temperature	0.0166	0.1996	0.0178	0.0659	0.0347	0.0678
7	Clad temp. at region 2	0.0097	0.1315	0.0307	0.1275	0.0444	0.1044
8	Clad temp. at region 7	0.0169	0.2528	0.0219	0.0954	0.0401	0.0910
9	Clad temp. at region 12	0.0132	0.0782	0.0295	0.1512	0.0459	0.1195
10	Hot leg 1 flow rate	0.6276	0.1134	1.1152	0.1155	1.5100	0.1932
11	Hot leg 2 flow rate	1.5921	0.1353	1.3118	0.1098	1.8627	0.1842
12	Active SIT-01 flow rate	excl.	excl.	excl.	excl.	1.2627	0.1953
13	Total break flow rate	0.4812	0.2811	0.6268	0.1909	0.6058	0.1897
14	Accumulated break mass	0.0363	0.1766	0.0343	0.1026	0.0491	0.1082
15	Downcomer level	0.0175	0.2235	0.1963	0.1153	0.5744	0.0865
16	Active core region level	0.1162	0.1952	0.3517	0.0646	0.5623	0.1130
17	Pressurizer level	0.0652	0.1678	0.0689	0.1296	0.0900	0.1073
18	Collapsed water level IL1A	0.2033	0.1599	0.3489	0.0880	0.3976	0.0845
19	Collapsed water level IL1B	0.1223	0.2219	0.9718	0.1191	1.2831	0.0879
20	Collapsed water level IL2A	0.1955	0.1947	1.4828	0.1306	1.8920	0.1101
21	Collapsed water level IL1B	0.2105	0.1270	1.2923	0.1184	0.7564	0.0879
	Total (AA_{tot}, WF_{tot})	0.0883	0.1890	0.2352	0.1077	0.2968	0.1009

4. Conclusions

The present paper describes the theory and three example applications of the FFTBM tool in the framework of the code assessment. This tool is based on a solid mathematical theory and is very easy to use and very clear in the understanding of the output results. Inside the UMAE methodology developed at University of Pisa for the quantification of the uncertainty in the application of the codes to the safety of the NPP, the FFTBM is adopted for the quantification of the accuracy between experimental data coming from the integral or separate test facilities and code calculation results.

The results of three examples calculations have been presented: PKL III test G3.1, PSB-VVER test 5a and ATLAS ISP-50. Several participants with different system thermal hydraulic codes have been involved in the projects related to the three experiments. The application of the FFTBM shows excellent results well inside the limits established for the acceptability of the results.

An useful aspect of the application of the FFTBM for different phases identified in the transients is a valid support for the analysis in the understand which part of the transient the accuracy is better or not and as consequence focus the attention in some aspects in the improvement process of the results.

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