ГЛОБАЛЬНАЯ ЯДЕРНАЯ БЕЗОПАСНОСТЬ, 2020 №1(34), С. 62–72

УДК 621.039.586

НЕОПРЕДЕЛЕННОСТЬ В РАСЧЕТАХ ИЗ-ЗА «МГНОВЕННЫХ» АВАРИЙНЫХ СИТУАЦИЙ НА ВВЭР-1000

© 2020 Д.А. Амер*, С.П. Никонов**

**Александрийский Университет, Александрия, Египет,11432*
***Национальный исследовательский ядерный университет «МИФИ», Москва, Россия,115409*

В работе показано возникновение волн давления и их распространение в оборудовании первого контура реакторной установки ВВЭР-1000 при аварийных ситуациях, связанных с мгновенной остановке Главного циркуляционного насоса или двухстороннем истечении при мгновенном двухстороннем разрыве в холодной нитке главного циркуляционного трубопровода. Исследуется влияние времени инициализации аварии (остановки насоса, разрыва трубопровода) на интенсивность процесса -амплитуду, частоту изменения давления. Рассматриваются перепады давления в процессе аварийной ситуации на основных элементах контура. Показано, что максимальные изменения в амплитуде и частоте, как самого давления, так и перепадов давления на элементах контура относятся к начальной стадии аварии. Основное внимание направлено на перепады давления на оборудовании, т.к. именно этот параметр определяет динамические нагрузки на оборудование, которые могут привести к выходу его из строя.

Ключевые слова: ВВЭР-1000, Калининская АЭС, разрыв с двухсторонним истечением, аварии с потерей теплоносителя, ГЦН, мгновение, аварийные ситуации, волны давления, Время полного раскрытия сечения течи.

Поступила в редакцию 09.11.2019
После доработки 13.12.2019
Принята к публикации 25.12.2019

Introduction

According to the guidance [1], a studying of the instantaneous emergency modes are included in the report on the safety justification of the NPP with a WWER reactor, which is presented in the set of documents justifying the application for a license for the construction or operation of the NPP. In works [2-4], a study for: the instantaneous stop of MCP in the first loop of the primary circuit (ten seconds of the real process are considered) and double-end break (DBE) in the cold leg (two seconds of the real process are considered), were done. In case of an accident emergency protection reactor (PR-1) only works on the 2nd signal. The fuel composition and kinetics of the reactor core was considered for the case of the end of the cycle. The produced pressure waves and their propagation in the equipment of the primary circuit of the installation are shown. Thus, in the present study, a different gap of time is considered for both emergency cases. The pressure differences were considered because it is the main consequences after LBLOCA in WWER-1000 reactor. And this change in pressure was observed with a strongest amplitude and frequency of pressure fluctuations on NPP elements during the first period after the emergency, which can lead to significant dynamic loads on the structural elements of these objects. The parameters of a typical reactor plant V-320 (WWER-1000) are used for the calculation, particularly, the 3rd unit of the Kalinin NPP. All initial data for the calculation were obtained from the materials of the international standard problem Kalinin-3 [5]. The calculations were carried out using the computational best estimate code «ATHLET», developed by the society for reactor safety (Gesellschaft für

Anlagen-und Reaktorsicherheit-GRS) [6], Germany and certified in Russia for use in calculations to justify the safety of reactors with water coolant [7].

About the Reactor modeling by code ATHLET

As mention, the used NPP is the 3rd unit of the Kalinin NPP which were modeled using code ATHLET including the 4 loops of the primary coolant circuit and the secondary circuit too. Figure 1 shows core nodalization and sectors in the core. The core was divided into 6 parts with a central part. 4 of the six are directly connected to the coolant loops and the other two parts are connected with them using cross-connection considering the heat transfer between all. Figure 2 shows internal Structure and its nodalization using ATHLET input graphic.

As all information about the program ATHLET can be find in its manual [6], so its description will not be included here.

Quite widely used capabilities of the ATHLET code for linking with various three-dimensional neutron-physical programs in the calculation of the spatial distribution of energy release fields and the spatial distribution of the coolant parameters in the reactor core (up to the sub-cassette), an example are the works [8-12].

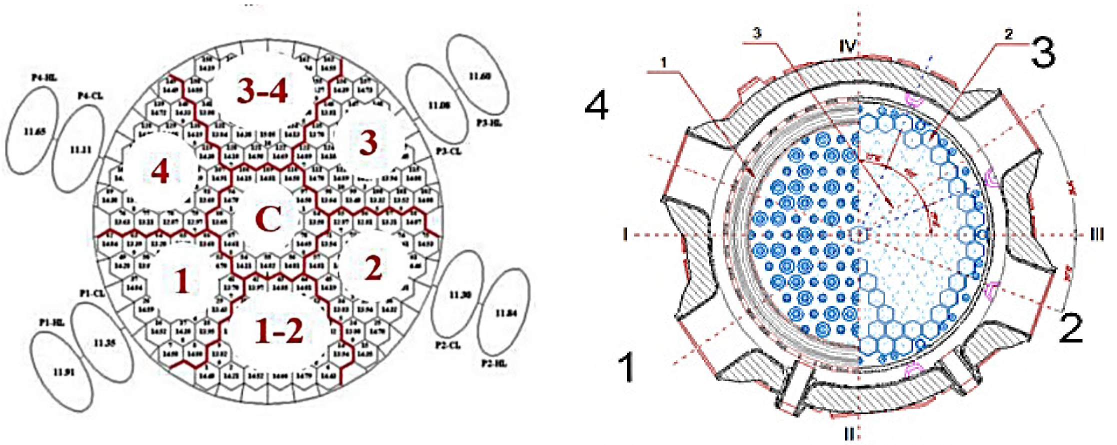

Figure 1 – Core nodalization and sectors in the core

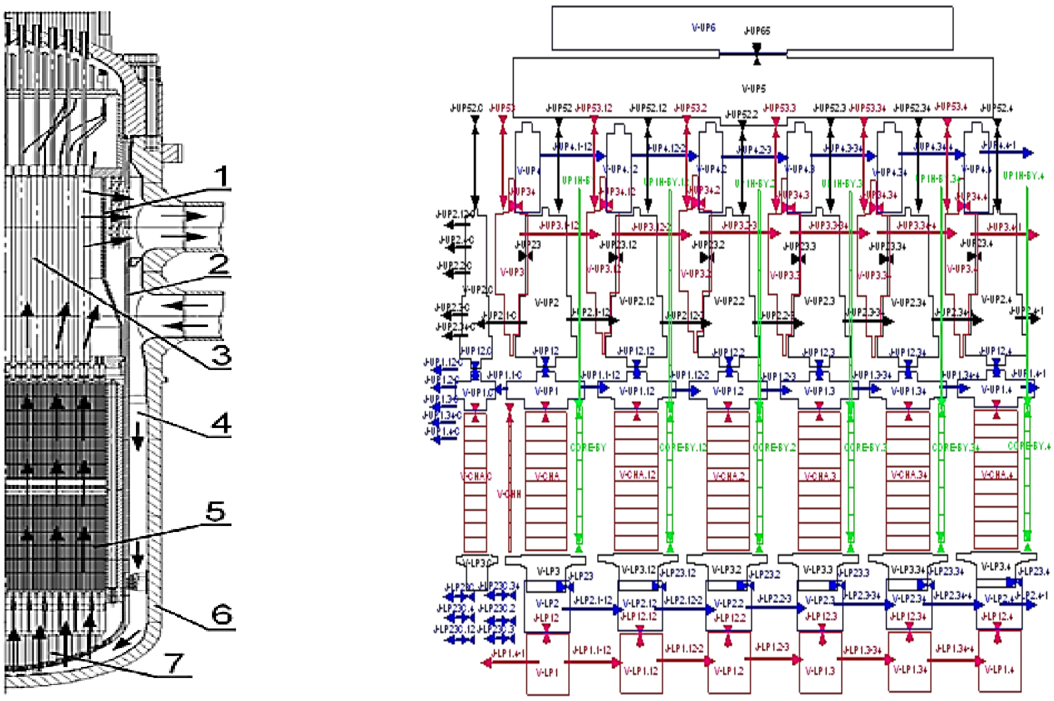

Figure 2 – Internal Structure and its nodalization

The point of the present research

As mentioned in the conclusion of those works, the considered «instantaneous» period of time of initialization of an accident (pump stop or pipeline rupture) is not defined in the guidance. Thus, in the present study, a different gap of accident initialization time (10^{-4}, 10^{-3}, 10^{-2}, 10^{-1} and 1 second) are considered for two emergencies:

1) Double End Large Break LOCA (DELBLOCA) at the reactor entrance in the first loop of the primary circuit (the considered location for break is shown in figure 3),

2) Main Circulation Pump (MCP) in the first cooling loop stops.

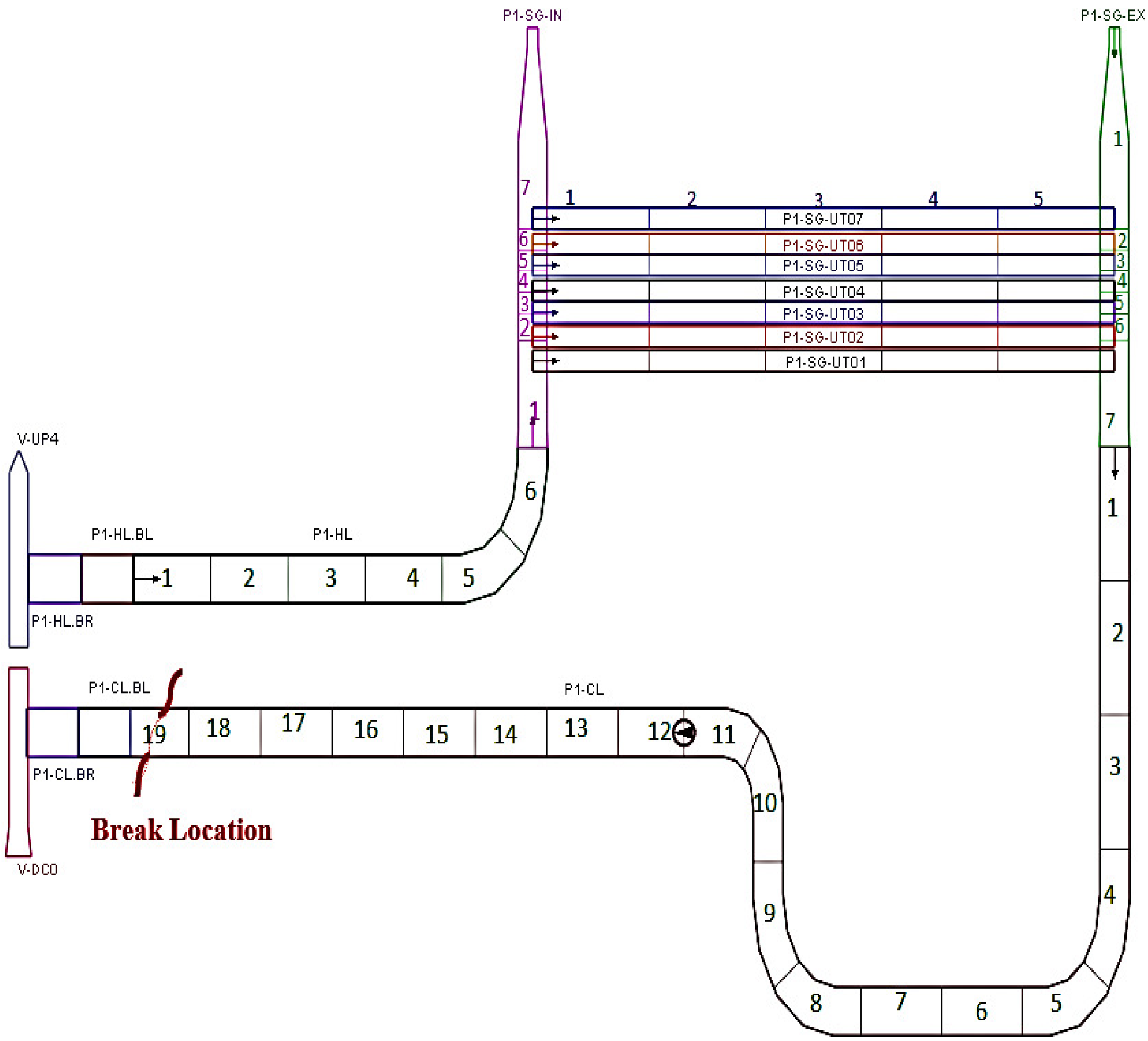

Figure 3 – The considered break location for the first case in the study

Results and discussion

1) Case 1: MCP stops:

Figure 4 shows the pressure waves in the reactor from the side of emergence comparing the 5-time gaps. For time gap ‘10^{-3}’ and ‘10^{-4}’ second, the first peak is sharper than the same in case of time gap ‘10^{-2}’ and ‘10^{-1}’ second. While for time gap ‘1’ second case, the decreasing behavior on average is also noticed, but without the fluctuations which present in the other 4 cases.

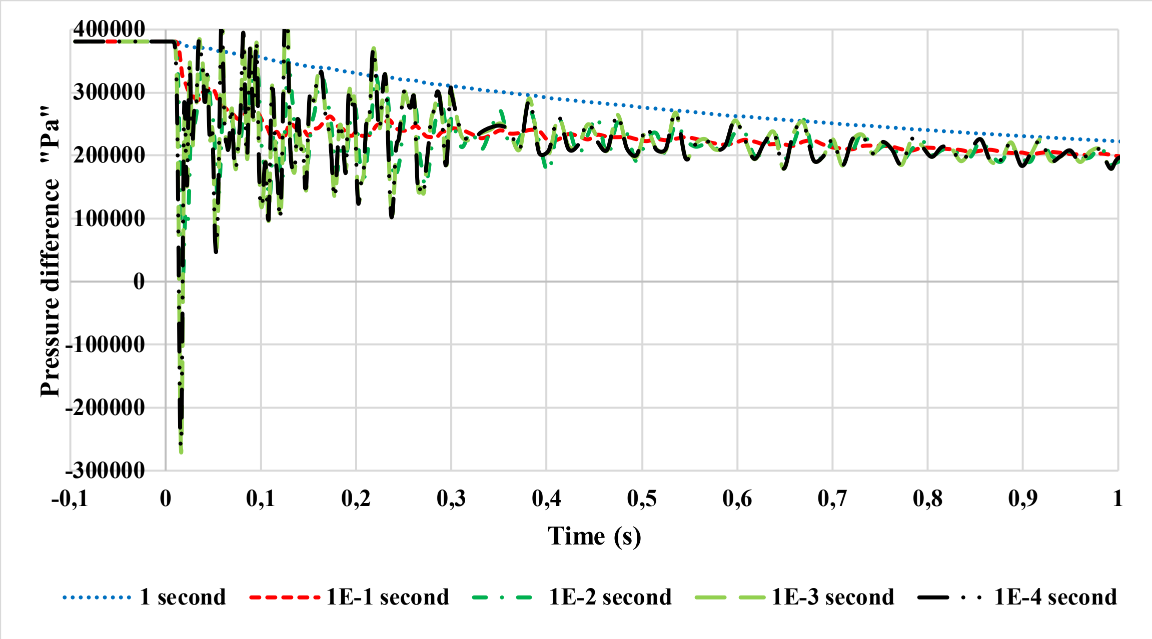

Figure 4 – Changing the pressure difference at the reactor from the side of the emergency loop in the case of MCP stops

Moreover, figure 5 shows the changing of the pressure drop at the core from the side of the emergency loop comparing the 5 considered time gaps. The sharpest peak of pressure drop is recorded in the cases of the time gaps ‘10^{-3}’ And ‘10^{-4}’ second followed by pressure drops due to time gap = 10^{-2} then 10^{-1} seconds. The smoothest pressure drops was recorded due to 1 second time gap.

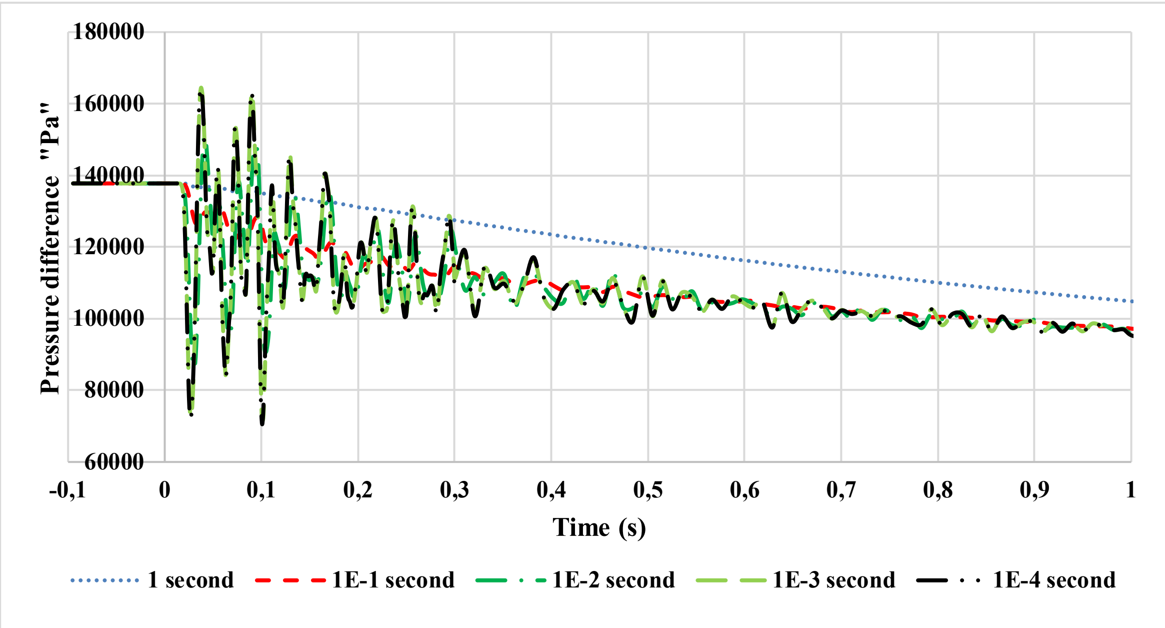

Figure 5 – Changing the pressure difference at the core from the side of the emergency loop in the case of MCP stops

Furthermore, the pressure wave in MCP is shown in figure 6. Similarly, the smoothest drop is observed in the case of time gap = 1 second. Then, a one-down peak is noticed due to a time gap = 10^{-1} second. And finally, a wavy pressure drop with oscillations was recorded due to the time gaps ‘10^{-3}’, ‘10-^{4}, and ‘10^{-2}’ second too.

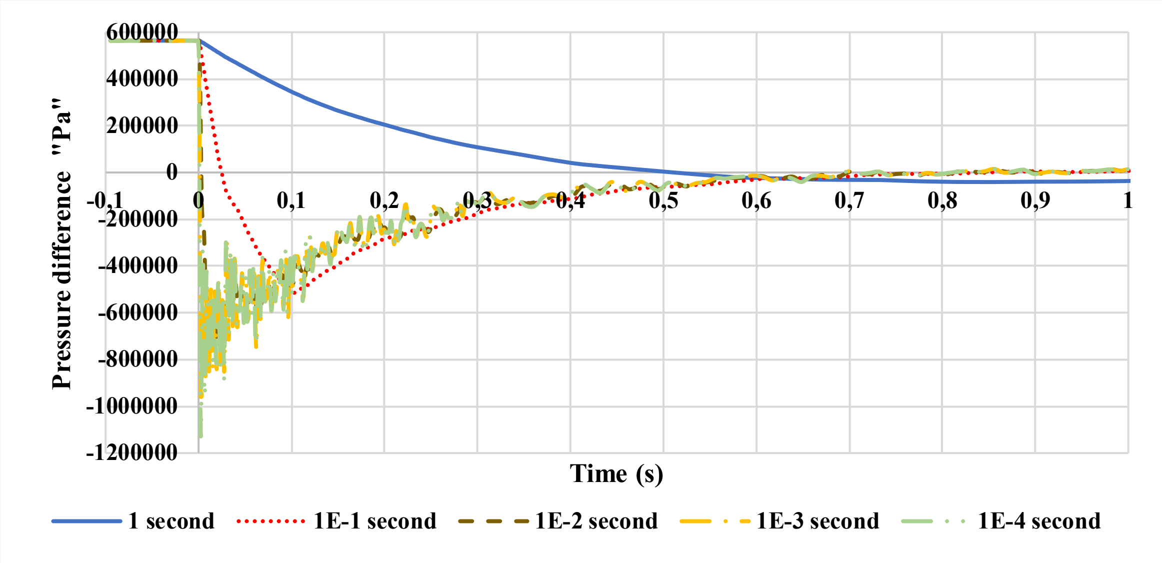

Figure 6 – Changing the pressure difference at the MCP in the emergency loop in the case of MCP stops

The fourth main component here is the steam generator. Figure 7 illustrates the consequences pressure waves in the SG in the emergence loop due to the considered the 5-time gaps. As well, the same response behavior like in the first three components is the recorded here.

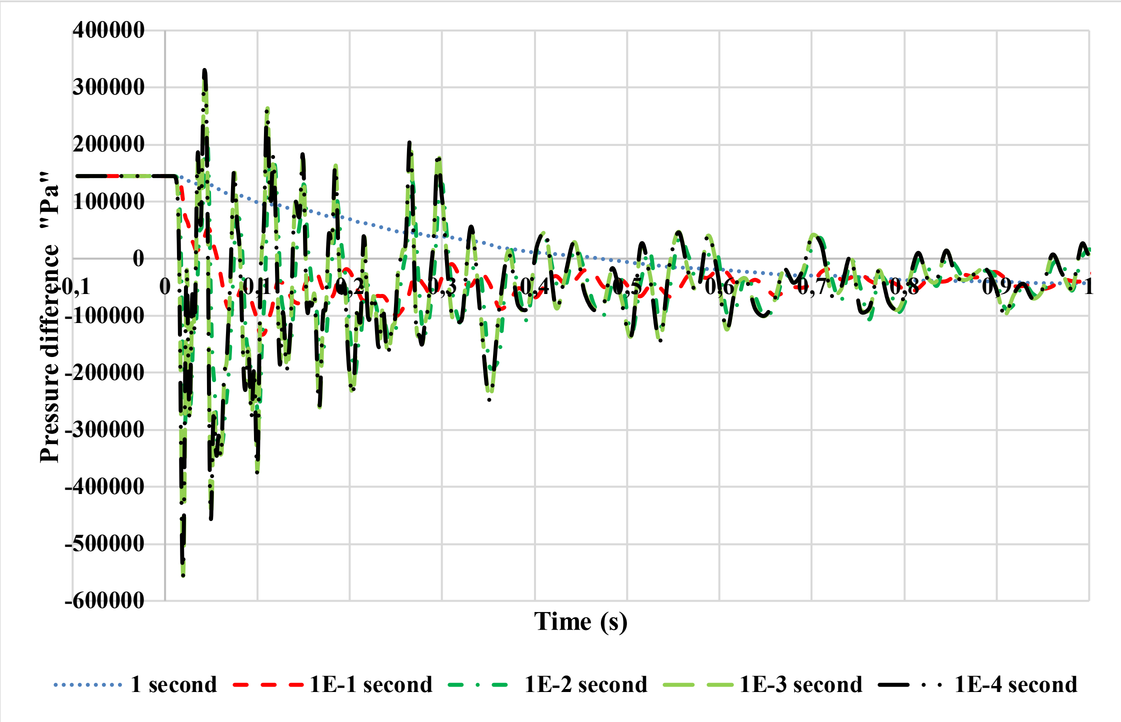

Figure 7 – Change of pressure difference on the SG from the side of the emergency loop in the case of MCP stops

2) Case 2: DELBLOCA

In the case of double end large break LOCA (DELBLOCA), two groups of time gaps are considered:

1) 10^{-1}, 10^{-2}, 10^{-3}, 10^{-4} comparing with 1 second, and

2) 0.3, 0.5, 0.7 and 1 second.

Considering the same time gaps in DELBLOCA case, the results show a completely different behavior for the pressure changing in case of 1 second than the others considered 4-time gaps. This deference can be noticed for pressure drop at reactor, core, MCP and the steam generator which shown in figures 8, 10, 12 and 14 respectively.

The other reason to include more time gaps in case of DELBLOCA is the general conclusion which was included in work [4]: «Comparing the two cases, MCP.1 instant stop and LOCA, the changes in all parameters are sharper and stronger in the case of LOCA than in the case of MCP.1 instant stop».

Starting with the most important component: the reactor, figure 8 shows the pressure waves because of the 5-time gaps which considered in the first case study (MCP stops). But, here due to the completely differed recorded response from 1 second time gap to the others, thus in figure 9 shown the pressure waves due to time gaps = 0.3, 0.5, 0.7 and 1 second. The manner / behavior in which the pressure changed in case of 1-second time gap is more similar to it in the case of 0.3, 0.5 and 0.7 than in the case of 10^{-1}, 10^{-2}, 10^{-3} and 10^{-4}. There is no debate that the closest situation to the reality is 1 second time gap. Nevertheless, the maximum drop-peak is recorded in the case of time gap = 10^{-4} second with a value of ($-9.98\times10^{+6}$).

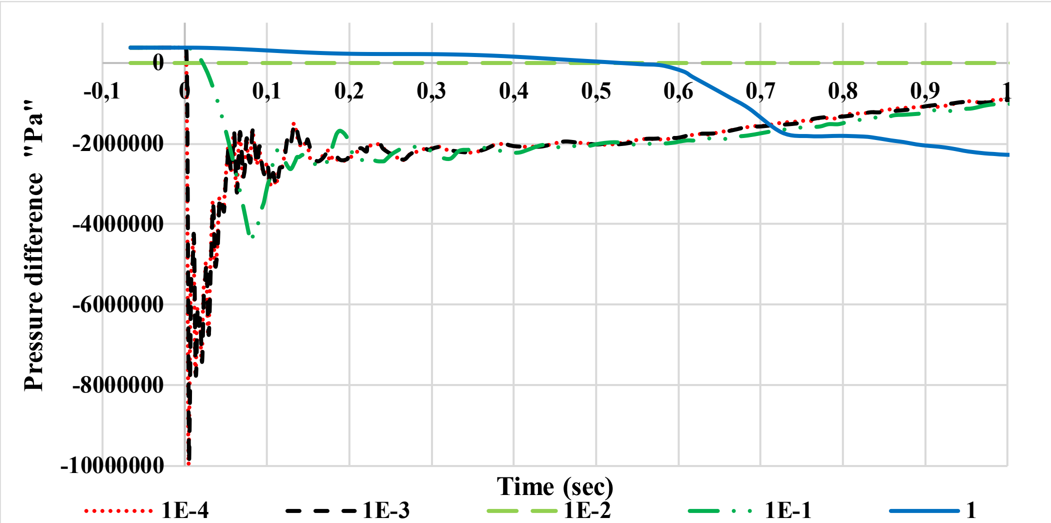

Figure 8 – Changing the pressure difference at the reactor from the side of the emergency loop (first group time gaps) in the case of DELBLOCA

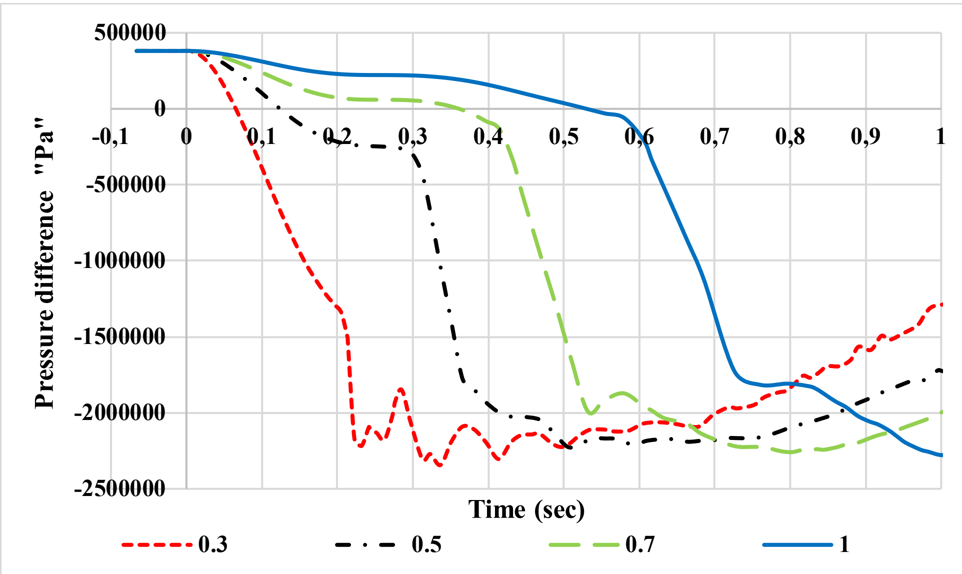

Figure 9 – Changing the pressure difference at the reactor from the side of the emergency loop (second group time gaps) in the case of DELBLOCA

The second main component is the reactor core. Also, the pressure waves due to the first-time gaps group (10^{-1}, 10^{-2}, 10^{-3}, 10^{-4} and 1 second) are shown in figure 10, the for the second time gaps group (0.3, 0.5 ,0.7 and 1 second) are shown in figure 11.

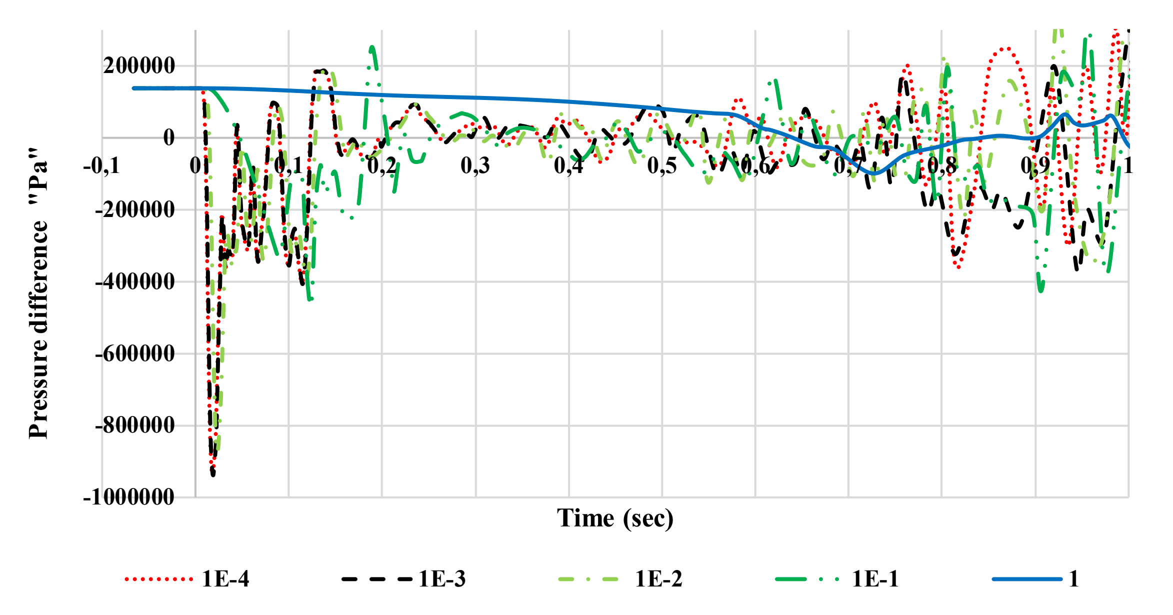

Figure 10: Change of pressure difference on the core from the side of the emergency loop (first group time gaps) in the case of DELBLOCA

Moreover, like mentioned before even the closest case to reality is the case of time gap = 1 second, but again, here the maximum drop-peak is recorded for time gap $=10^{-4}$ second with a value = $-9.34\times10^{+5}$ Pa.

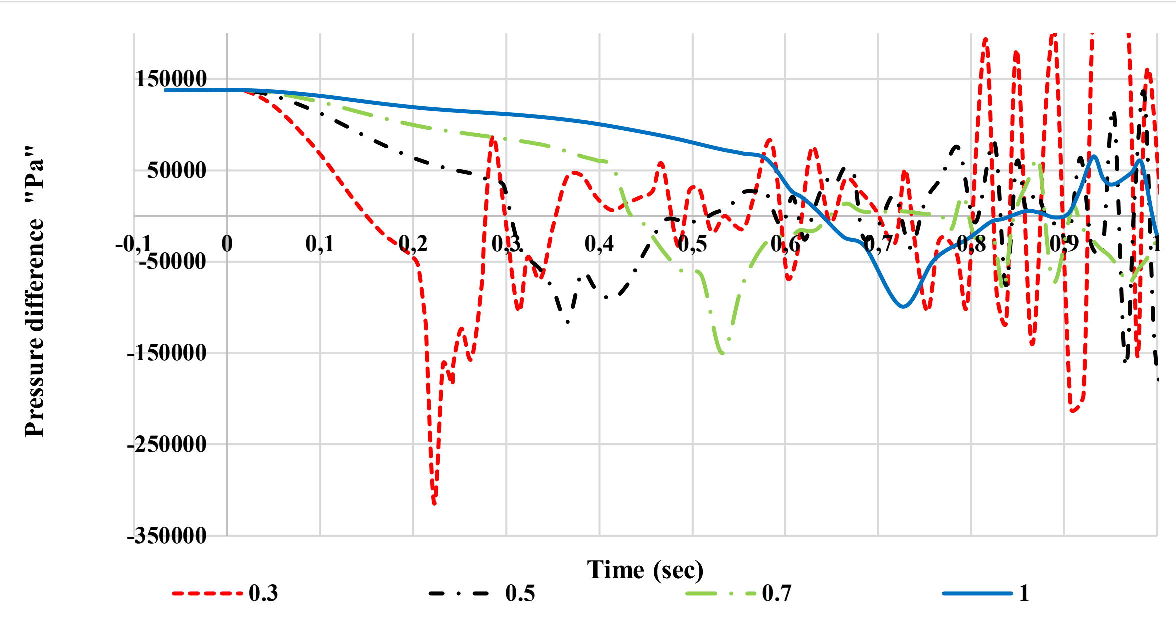

Figure 11 – Change of pressure difference on the core from the side of the emergency loop (second group time gaps) in the case of DELBLOCA

The third main component is the main circulation pump (MCP) which in the emergency loop. Figure 12 illustrates the comparison between the pressure waves due to the first group of time gap, while in figure 13 shown the pressure waves due to the second group of time gaps as it was mentioned for reactor and core.

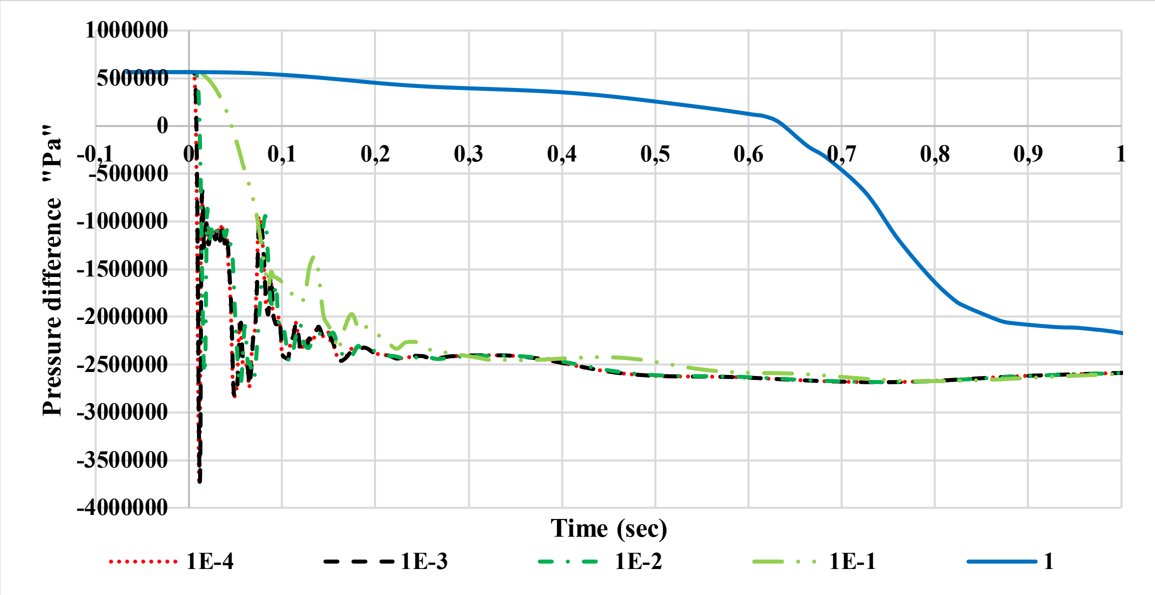

Figure 12 – Changing the pressure difference at the MCP in the emergency (first group time gaps) in the case of DELBLOCA

The same likes for the reactor and core, here too for the MCP, the maximum drop-peak is presence in the case of time gap = 10^{-4} and 10^{-3} seconds. Moreover, the completely different pressure wave in the case of time gap = 1 second than the other first group time gaps, which is more likely to be compared with the second group time gaps as shown in figure 13.

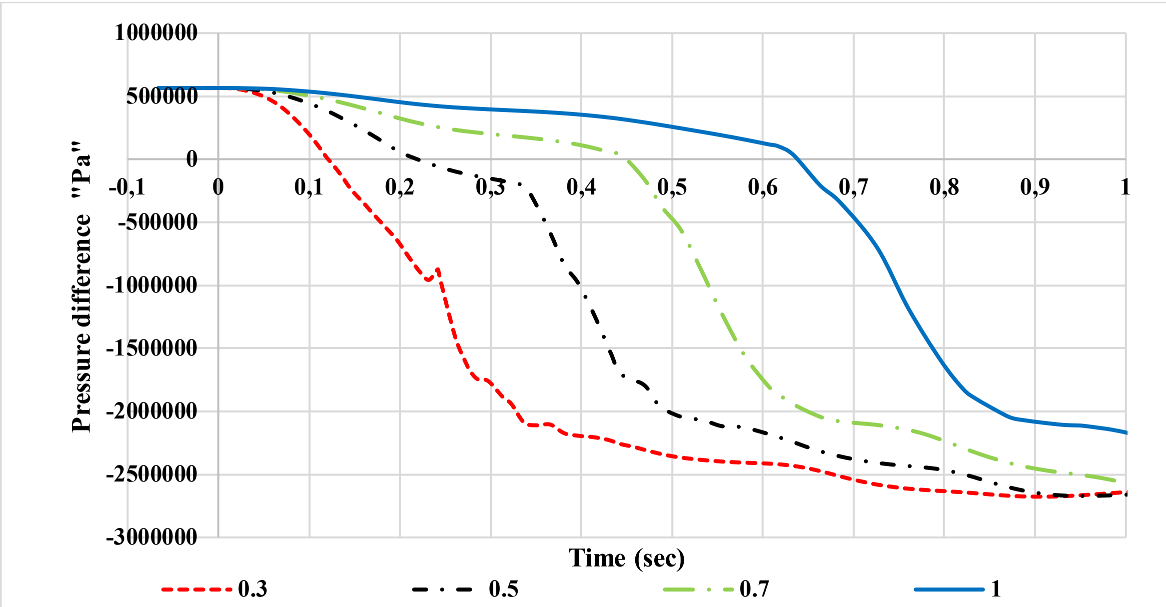

Figure 13 – Changing the pressure difference at the MCP in the emergency (second group time gaps) in the case of DELBLOCA

The last main component is the steam generator which is in the emergency loop. The maximum pressure difference in the steam generator is recorded due to time gap = 10^{-3} with value = $6.81\times10^{+6}$, while -as expected- at time gap = 1 second the pressure different has a completely different manner than the others comparable time gaps in the same figure.

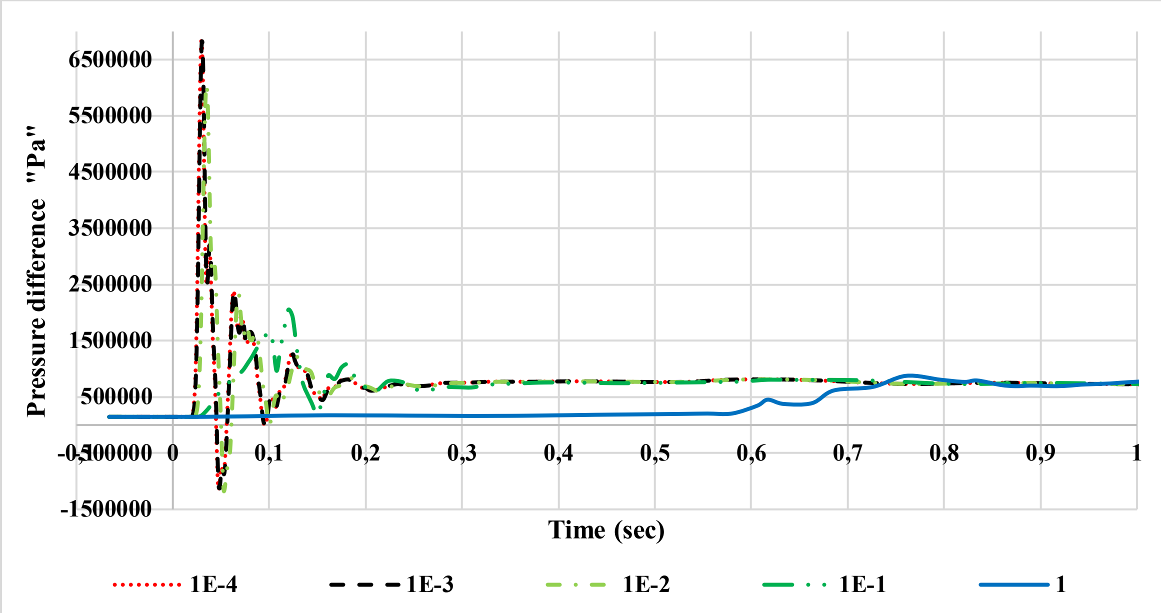

Figure 14 – Changing the pressure difference at the SG from the side of the emergency loop (first group time gaps) in the case of DELBLOCA

Figure 15 shows the wave of the pressure different in SG due to the second group time gaps. The maximum value is presented in the case of time gap = 0.3 second with peak value = 1.53E+6.

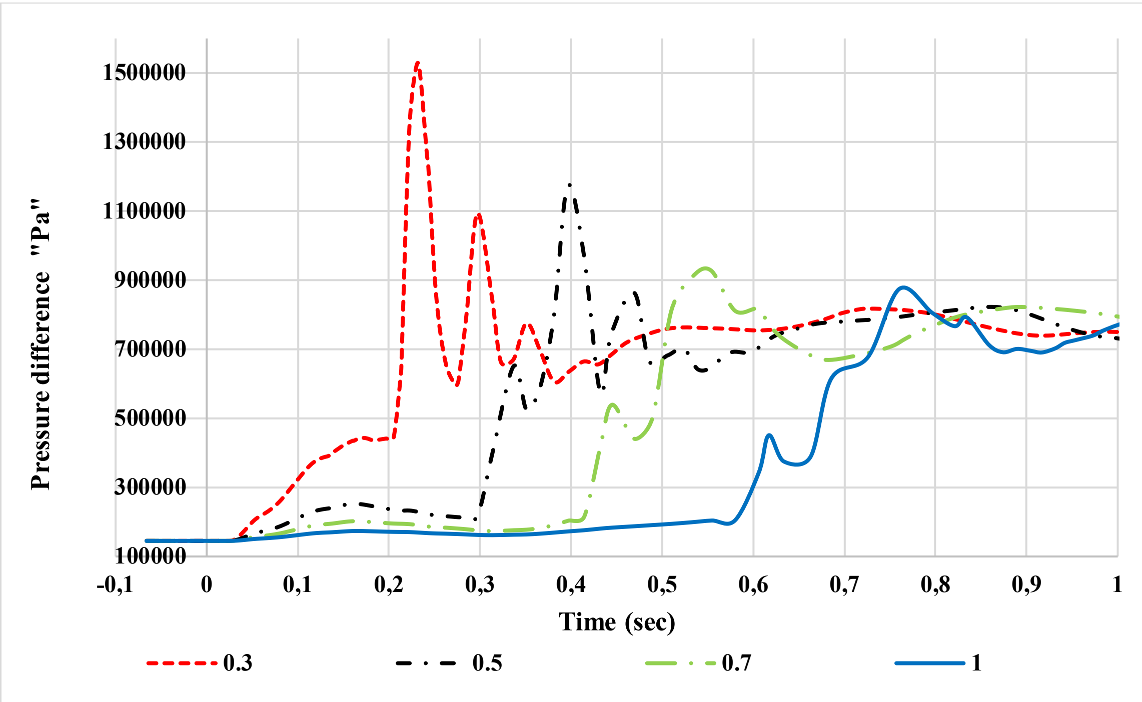

Figure 15 – Changing the pressure difference at the SG from the side of the emergency loop (second group time gaps) in the case of DELBLOCA

Conclusion

By change time gap, a different pressure behavior is presented. Also, word (Instantaneous) should be more defined during the study for nuclear reactor safety reports. Tables 1 and 2 include the maximum values for pressure for the main components (reactor, core, steam generator and MCP) which recorded and illustrate at which time gap were recorded.

Table 1 – In Pump Stop Case

Maximum value for Pressure drops in	Value (pressure different in Pa)	At time gap (in Second)
Reactor	$4.81179\times10^{+05}$	10^{-4}
Core	$1.64560\times10^{+05}$	10^{-4}
Pump	$5.63989\times10^{+05}$	Recorded for all time gaps
Steam Generator	$3.30584\times10^{+05}$	10^{-4}

Table 2 – In DEBLOCA Case

Maximum value for Pressure drops in	Value (pressure different in Pa)	At time gap (in Second)
Reactor	$3.81\times10^{+05}$	Recorded for all time gaps
Core	$4.11\times10^{+05}$	10^{-4}
Pump	$5.645\times10^{+05}$	Recorded for all time gaps
Steam Generator	$6.83\times10^{+06}$	10^{-4}

This means that, the choose of the time step in each case depends on which component will be considered.

For example, in the Pump Stop Case:

If it is important to check the effect on the Reactor, the worthiest situation will be shown if the considered time gap = 10^{-4} second, because in this time-gap, the maximum pressure drop was observed, and so-on.

The essence of the work: not the influence of the calculation step on the process, but the influence of the «instantaneity» of the accident initialization process was Investigated. The calculation step is set automatically in the calculation program, based on the stability and convergence criteria of the solution during the process simulation. The guidance documents refer to an «instantaneous» pump stop or «instantaneous» break, but do not specify the duration of this «instant».

The paper investigates the influence of uncertainty of the duration of the «instant» of the process of stopping the pump or breaking the pipeline on the intensity of the first few seconds of the accident. It is shown that the highest intensity of the process (the amplitude of pressure fluctuations) corresponds to the shortest time of the duration of the «moment».

For future work, it is recommended to do the same analysis of similar breaks in the other cold legs (other three loops), in the hot legs of 4-loops ‘near the reactor’, the study of such a break at the junction of the output ‘cold’ collector SG with cold leg for every loop.

REFERENCES

[1] PNAE G-1-036-95 (NP-006-98). Requirements to the Content of the Report on the Justification of the Safety of as with a WWER Type Reactor (with Change No. 1 of 20.12.2005).

[2] Dina Ali Amer, Nikonov S.P. Pressure Waves in The Primary Circuit of The WWER - 1000 Reactor at Instant Stop of the MCP, Volga-2018, International conference for young scientists, specialists, and post-graduates on Nuclear Reactor Physics, September 2018.

[3] Dina Ali Amer, Nikonov S.P., LOCA and Pressure Waves in The First Loop of The WWER-1000 Reactor, 28th Symposium of AER on WWER Reactor Physics and Reactor Safety, Olomouc, Czechia, October 8-12, 2018.

[4] Dina Ali Amer, Nikonov S.P., Emergency Situations and Pressure Waves In WWER-1000, The Sixth International Conference of Radiation Sciences and Applications, Ibis Dahab, Egypt, 22-26 October, 2018.

[5] V. A. Tereshonok, S.P. Nikonov, M. P. Lizorkin, K. Velkov, A. Pautz, K. Ivanov, International Benchmark for Coupled Codes and Uncertainty Analysis in Modelling: Switching-off of One of the Four Operating Main Circulation Pumps at Nominal Power at NPP Kalinin unit, 18th Symposium of AER on WWER Reactor Physics and Reactor Safety, Hungary, Eger, Oct. 6-10, 2008.

[6] H. Austregesilo, H. Deitenbeck, A. Langenfeld, J. Scheuer, P. Schöffel, ATHLET 3.1A, programmer's Manual, March 2017.

[7] Rostexnadzor, FBU «NTC YARB», Attestacionnyi Pasport Programmnogo Sredstva №350 17.04.2014, Russian.

[8] I. Panka, Gy. Hegyi, Cs. Maráczy, A. Keresztúri, Uncertainties of the Kiko3D- ATHLET Calculations Using the Kalinin-3 Benchmark (Phase II) Data, 25th Symposium of AER on WWER Reactor Physics and Reactor Safety, Hungary, Balatongyörök, Oct.13-16, 2015.

[9] S.Nikonov, A. Pautz, K.Velkov, Detailed Modeling of KALININ-3 NPP WWER-1000 Reactor Pressure Vessel by the Coupled System Code ATHLET/BIPR-VVER, International Conference on Mathematics and Computational Methods Applied to Nuclear Science and Engineering (M&C 2011), ISBN 978-85-63688-00-2, Rio de Janeiro, RJ, Brazil, May 8-12, 2011.

[10] S.P. Nikonov, P. Pham, V.I. Romanenko, G.V. Tikhomirov, Coupled Neutronics Thermohydraulic Calculation of HPLWR Fuel Cell Using Codes MCU/ATHLET, 27th Symposium of AER on WWER Reactor Physics and Reactor Safety, Munich, Germany Oct. 2017.

[11] D Amer and S Nikonov Pressure Waves in the Primary Circuit of the WWER-1000 Reactor at Instant Stop of the MCP. 2018 J. Phys.: Conf. Ser. 1133 012049.

[12] Grundmann U, Lucas D, Rohde U (1995) Coupling of the Thermohydraulic Code ATHLET with the Neutron Kinetic Core Model DYN3D. In: Proc. of Int. Conf. on Mathematics and Computations, Physics and Environmental Analysis, Portland (USA), vol. 1, pp. 257–263.

Uncertainty in Calculation Due to «Instantaneous» Emergency Situations in WWER-1000

D.A. Amer[*1], S.P. Nikonov[2]**

[*]Alexandria University, El-Guish Road, 22, Alexandria, Egypt, 11432
[**]Institute of Nuclear Physics and Technology (INP&T), National Research Nuclear University «MEPhI», Kashirskoye shosse, 31, Moscow, Russia 115409
[1]ORCID iD: 0000-0003-0365-2533
WoS Researcher ID: AAC-7247-2019
e-mail: Dina.amer@alexu.edu.eg
[2]ORCID iD: 0000-0003-4890-6920
e-mail: SPNikonov@mephi.ru

Abstract – The paper shows the occurrence of pressure waves and their propagation in the equipment of the first circuit of the WWER-1000 reactor plant in emergency situations associated with an instantaneous stop of the Main circulation pump or a two-way flow with an instantaneous two-way break in the cold thread of the main circulation pipeline. The influence of the time of initialization of the accident (pump stop, pipeline rupture) on the intensity of the process-amplitude, frequency of pressure changes is investigated. Pressure drops during an emergency on the main elements of the circuit are considered. It is shown that the maximum changes in the amplitude and frequency of both the pressure and the pressure drops on the circuit elements belong to the initial stage of the accident. The main attention is focused on the pressure drops on the equipment, because this parameter determines the dynamic loads on the equipment, which can lead to its failure.

Keyword: ATHLET, WWER-1000, Kalinin NPP, DBE, LOCA, MCP, moment, emergency situations, pressure waves, time gap.