STUDY, ANALYSIS, ASSESS AND COMPARE THE NUCLEAR ENGINEERING SYSTEMS OF NUCLEAR POWER PLANT WITH DIFFERENT REACTOR TYPES VVER-1000, NAMELY AES-91, AES-92 AND AES-2006

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2. STUDY ON IMPROVEMENT OF CONVERGENCE FOR PWR SUBCHANNELVOID DISTRIBUTION BENCHMARK; Hoang Minh Giang, Nguyen Phu Khanh, Le Van Hong, Le Dai Dien; Journal of Science and Technology (Accepted to be published); 2014; 14 pages.
3. SIMULATION OF TWO – STAGE HYDRO ACCUMULATORS OF VVER – 1000/V392 IN CASE OF LBLOCA (in Vietnamese); Le Dai Dien, Nguyen Thi Tu Oanh, Nguyen Thi Thanh Thuy, Le Van Hong; The 10th National Nuclear Science and Technology Conference, 15-16 August 2013, Vungtau City, Vietnam**;** 8 pages.
4. CRITICAL HEAT FLUX CALCULATION AND ANNALYSIS OF KS-1 FACILITY BY RELAP5/MODE3.3 (in Vietnamese); Le Thi Thu The 10th National Nuclear Science and Technology Conference, 15-16 August 2013, Vungtau City, Vietnam**;** 8 pages.
5. APPLICATION OF MCNP CODE IN SIMULATION OF VVER-1000 REACTOR CORE (in Vietnamese); Nguyen Huu Tiep, Le Dai Dien, Le Van Hong, Tran Kim Tuan; The 10th National Nuclear Science and Technology Conference, 15-16 August 2013, Vungtau City, Vietnam**;** 9 pages.
6. WHAT IS TECHNOLOGY FOR THE NUCLEAR POWER PLANT NINH THUAN No. 1 PROJECT? (in Vietnamese); Le Van Hong, Tran Chi Thanh; The National Electrical Science and Technology Conference, 6-7 November 2014, Danang City, Vietnam**;** 9 pages.

ABSTRACT: On November 25, 2009, in Hanoi, the National Assembly of 12th term had been approved the resolution about policy for investment of nuclear power project in Ninh Thuan province which include two sites, each site has two units with power around 1000 MWe. For the nuclear power project at Ninh Thuan 1, Vietnam Government signed the Joint-Governmental Agreement with Russian Government for building the nuclear power plant with reactor type VVER. At present time, the Russian Consultant proposed four reactor technologies can be used for Ninh Thuan 1 project, namely: AES-91, AES-92, AES-2006/V491 and AES-2006/V392M. This report presents the main reactor engineering systems of nuclear power plants with VVER-1000/1200. The results from analysis, comparison and assessment between the designs of AES-91, AES-92 and AES-2006 are also presented. The obtained results show that the type AES-2006 is appropriate selection for Vietnam.

I. INTRODUCTION

With 60 years of development and enhancement, nuclear power industry shows not only technical feasibility, economical competitiveness, but also its contribution to reduction of environmental impact caused by green house effect. Therefore, nuclear power industry takes the role in balance of electricity power supply in all the world. However, the nuclear accidents at TMI in 1979, at Chernobyl in 1986 and especially at Fukushima in 2011 already show that effectiveness of nuclear power strongly depends on safety.

On November 25, 2009, in Hanoi, the National Assembly of 12th term approves the resolution about policy for investment of nuclear power project in Ninh Thuan province which include two sites, each site has two units with power around 1000 MWe. In October, 2010, Vietnam Government signed the Joint-Governmental Agreement with Russia Federal Government for building the nuclear power plant at Ninh Thuan 1 (NPP NT1) and in January 2011, the Arrangement with Japanese Government for building the nuclear powers at Ninh Thuan 2 also signed.

Nuclear reactors of VVER type were designed from years of 60’s of last century and were successfully built in Russia and other Eastern countries. In the years of 80’s of previous century the nuclear reactor of type VVER-1000 version V-320 were built in Russia, Ukraine, Bulgaria and Czech Republic [1].

In the years of 90’s previous century, the Russia design institutions launch research and development program for nuclear reactor of 3rd generation. The St Petersburg Design Institute developed nuclear power plant AES-91, version V-428. This design had built and put in operation in Tianwan, China [2,3]. The Moscow Design Institute developed nuclear power plant AES-92 and this design was built in Kudankulam, India [4,5].

In the year of 2000, both design institutions in St Petersburg and in Moscow developed the new nuclear power plant AES-2006 with reactor VVER-1200. The first two units AES-2006/V491 are under construction in Leningrad NPP-2, which was designed by St Petersburg Design Institute [6] and other two units AES-2006/V392M was built in Novo-Voronezh NPP-2, which was designed by Moscow Design Institute [7].

For the nuclear power project Ninh Thuan 1, Vietnam needs to consider and assess reactor technology and select one type of reactor from four options proposed by consultant. The four reactor technologies are AES-91, AES-92, AES-2006/V491 and AES-2006/V392M. With the purpose of providing recommendation to National Steering Committee for Ninh Thuan nuclear power project and also of providing advice to utility in reactor technology assessment and selection, the Ministry of Science and Technology requested Vietnam Atomic Energy Institute to be main responsible role to implement an independent national project, code DTDL.2011-G/82: “Study, Analysis, Assess and Compare the Nuclear Engineering Systems of Nuclear Power Plants with different reactor types VVER-1000, namely, AES-91, AES-92 and AES-2006”.

The specific goal of the project is following:

- To identify clearly the main technology features, safety design of three reactor technologies, including AES-91 with model V-428, AES-92 with model V-412 and AES-2006.
- To compare the advantages and disadvantages of three reactor technologies mentioned above and submit to the National Steering Committee for Ninh Thuan nuclear power project about a proposal of an appropriate nuclear reactor type for Vietnam.
- To train the staff member under framework of the project.
- With the goal mentioned above, two main issues of the project are following:
- Study, Analysis, Assess and Compare the Nuclear Engineering Systems of Nuclear Power Plant of different reactor types VVER-1000, namely AES-91, AES-92 and AES-2006;
- Calculation and analysis of reactor physics and core thermal-hydraulics of the reactor

type VVER-1000.

II. RESULTS AND DISCUSSION

With in the period of 33 months, from September 2011 to June 2014, the participants of the project have been implemented their works with the content mentioned above and summed up the results in 3 main reports, printed in 3 volumes:

- Volume 1: Report on Design Analysis of reactor technology type VVER-1000;
- Volume 2: Summarized report on analysis, assessment, comparison of three type of reactor technologies: AES-91, AES-92 and AES-2006;
- Volume 3: Report on calculation and analysis of reactor physics and core thermal-hydraulics for reactor type VVER-1000/V392.

Volume 1 presents analysis design of main nuclear engineering systems of nuclear power plant type VVER-1000/1200, including:

1. Reactor design of VVER-1000/1200;
2. Design of reactor coolant system;
3. Design of safety systems;
4. Design of instrumentation and control systems;
5. Design of steam and power conversion system (Turbine-Generator system);
6. Design of electricity supply systems;
7. Design of nuclear fuel storage and fuel handling systems;
8. Design of radioactive treatment and waste management systems;
9. Design of radiation protection systems.

The study results show that:

Design bases of the nuclear engineering systems of nuclear power plant type AES-91, AES-92 and AES-2006 comply with Russia Regulatory Requirement Documents, Technical Standard and Code applying to design of engineering systems and equipments for nuclear power plants. These design bases also comply with safety requirements from International Atomic Energy Agency – IAEA and other international documents. Besides, the new nuclear reactors VER-1000/1200 are also designed in compliance with European Utility Requirements for LWR NPPs – EUR and compliance with general design criteria of NPPs from US NRC.

The design of nuclear engineering systems of NPPs type AES-91, AES-92 and AES-2006 is inherited experience from previous operation records and also is improved significantly in comparison with the design of nuclear engineering systems of NPPs of reactor VVER-1000/V320 [2,4,8,9].

The designs of nuclear engineering systems of NPPs type AES-91, AES-92 and AES-2006 are mainly similar with each other, but the design of AES-2006 was improved, upgraded, especially in severe accident mitigation and management systems [10]. It satisfyes the new requirements from Russia Regulatory Body, IAEA, International Nuclear Safety Advisory Group (INSAG) and other stakeholders. Therfore, the AES-2006 nucear powe plant with reactor type VVER-12000 achieves new features [1,10]:

- Enhancement of economy and engineering effectiveness;
- Advanced safety features with high confidence;

- Optimization of construction cost and operation cost.

Volume 2 introduces the engineering systems of NPPs type AES-91, AES-92 and AES-2006 and proposes a method for comparison and assessment of reactor technology. The procedure of comparison and assessment focus on structure, system and components (SSCs) important to safety, including two aspects:

- The SSCs takes the functions of normal operation such as reactor and reactor coolant system;

- The SSCs take the function of safety such as engineering safety systems dealing with design base accidents (DBA) and severe accidents (SAs).

The analysis, comparison and assessment were applied to four considerable technologies, that are AES-91, AES-92 AES-2006 designed by St.Peterburg Institute and AES-2006 designed by Moscow Institute. The main characteristics of unit with reactor VVER-1000/V428, VVER-1000/V412, VVER-1200/V491 and VVER-1000/V292M are shown in Table 1.

Table 1: Main characteristics of unit with reactor VVER-1000/V428, VVER-1000/V412, VVER-1200/V491 and VVER-1000/V292M [2,4,6,7].

No.	Parameter	**AES-91** St. Ptbg	**AES-92** Moscow	**AES-2006** St. Ptbg	**AES-2006** Moscow
1	**Reactor type**	**VVER-1000/V-428**	**VVER-1000/V-412**	**VVER-1200/V-491**	**VVER-1200/V-392M**
1.1	Reactor thermal power, MWth	3,000	3,000	3,200	3,200
1.2	Unit electric power, MWe	1,060	1,060	1,198	1,198
1.3	Power unit gross efficiency, %	35.3	35.3	37.4	37.4
1.4	Reactor lifetime, years	40	50	60	60
1.5	Number of loops, loop	4	4	4	4
1.6	Coolant flow rate through the reactor, m^3/h	86,000	86,000	88,000	88,000
1.7	Coolant temperature at reactor inlet, ºC	291.0	291.0	298.6	298.6
1.8	Coolant temperature at reactor outlet, ºC	321.0	321.0	329.7	329.7
1.9	Coolant pressure at core outlet, MPa	15.7	15.7	16.2	16.2
2	**Steam generator type**	**PGV-1000M**	**PGV-1000M**	**PGV-1000MKP**	**PGV-1000MKP**
2.1	Steam production, t/h	1,470	1,470	1,600	1,600
2.2	Steam pressure, MPa	6.27	6.27	7.0	7.0
2.3	Temperature of feetwater, ºC	220	220	225	225
3	**Main circulation pump type**	**GTsNA-1391**	**GTsNA-1391**	**GTsNA-1391**	**GTsNA-1391**

4	**Turbine type**	**K-1000-60/3000**	**K-1000-60/3000**	**K-1200-6,8/50**	**K-1200-6,8/50**
5	**Generator type**	**TZV-1000-2UZ**	**TZV-1000-2UZ**	**TZV-1200-2UZ**	**TZV-1200-2UZ**

The study results show that:

For normal operation systems: the design of main structure, systems and components of AES-2006 was improved, upgraded significanly in comparison with SSCs in AES-91, AES-92 and especially in NPPs with standard reactor VVER-1000/V320.

Reactor vessel was enlarged in height length and diameter and was made by better material with increasing the thickness of the inner layer. Therefore, the service time of the reactor vessel was increased from 30-40 years to 60 years [2,4,11].

The core volume was enlarged to hold more fuel and then to extend the fuel cycle. By using new fuel assembly type with new improvement of high enrichment and high burnup and also new improvement of more control and protection system absorbing rods (CPS ARs) arranged, the AES-2006 gets higher safety level and economy effectiveness in comparison with AES-91, AES-92 [12].

In comparison with those in AES-91& AES-92, the steam generator of AES-2006 was enlarged, so that its water volume increases and it will be more confident if deal with LOCAs. The arrangement of heat exchange tubes is also changed from alternate pattern to parallel pattern. This will allow to increase coolant flow in the tubes, to reduce deposition and to increase strength of the tubes also to increase heat exchange capability. In the design, pressure and temperature of steam increase. All of the issues mentioned above make increasing power of the steam generator and its safety level is also improved [1,2,4].

The reactor coolant pumps used in AES-91, AES-92 and AES-2006 are the same type of GtsNa-1391. Many experience from operation of the reactor coolant pump with different types such as GtsN-195and GtsN-195M in standard NPPs was inherited in design of pump type GtsNA-1391. The new improvements used in design of pump GtsNA-1391 focus on enhacemnt of confidence, convenience in operation, mainternance in comparison with pump type GTsN-195M [1,2,4].

Although investment cost of AES-2006 is higher than AES-91 & AES-92, but the NPP type AES-2006 with new improvements torward enhancement of safety and of economy effectiveness, it will be attractive selection for Vietnam and also will be suitable to the trend of future NPPs in the world.

For safety function systems: according to the requirements of resolution N^{o}41 adopted by National Assembly on safety, the AES-2006 meets requirements better than AES-91 & AES-92. In the design of AES-2006, the severe accident mitigation and management systems can deal with almost scenarios effectively. The results from quatitative PSA calculation are shown in Table 2. The core damage frequency (CDF) and large release frequency (LRF) of AES-2006 are 10 time lower in comparison with AES-91 & AES-92 [13,14,15].

Table 2: Results from PSA calculations of defferent reactor types [14,19].

No.	Parameter	**AES-91** St. Ptbg	**AES-92** Moscow	**AES-2006** St. Ptbg	**AES-2006** Moscow
1	Reactor type	**VVER-1000/V-428**	**VVER-1000/V-412**	**VVER-1200/V-491**	**VVER-1200/V-392M**

2	Core damage frequency (CDF), 1/a	**3.39×10^{-6}**	**2.38×10^{-7}**	**5.80×10^{-7}**	**4.68×10^{-7}**
3	Large release frequency (LRF), 1/a	6.30×10^{-8}	2.20×10^{-7}	2.00×10^{-8}	2.27×10^{-8}

The CDF anh LRF two designs, namely AES-2006 with VVER-1200/V491 and AES-2006 with VVER-1200/V392M are very low and they are close each to other. The difference from two these designs is the different approach to realize safety systems and severe accident mitigation and management systems [13,14,15].

From safety point of view, the AES-2006 is appropriate selection for Vietnam.

Volume 3 presents the study results from reactor physics and thermal-hydraulics of reactor VVER-1000/V392, including:

1. Overview of fuel design and nuclear design of reactor VVER-1000/V392;
2. Calculation several reactor physics parameters of the VVER-1000/V392;
3. Prepare data for thermal-hydraulics simulation;
4. Data calculation of main components used for RELAP5 input;
5. Calculation and analysis of steady state of reactor VVER-1000/V392;
6. Calculation and anaylysis of several transient and accident scenarios of reactor VVER-1000/V392.

In analysis of scenario of LOCAs, the behavoir of peak cladding temperature is mots important due to related to safety acceptance criteria. Figure 1 shows the peak cladding temperature in hot channel versus time in different location of break: guillotine break in cold ledg of loop 1, in cold leg of loop 2 and in hot leg of loop 3.

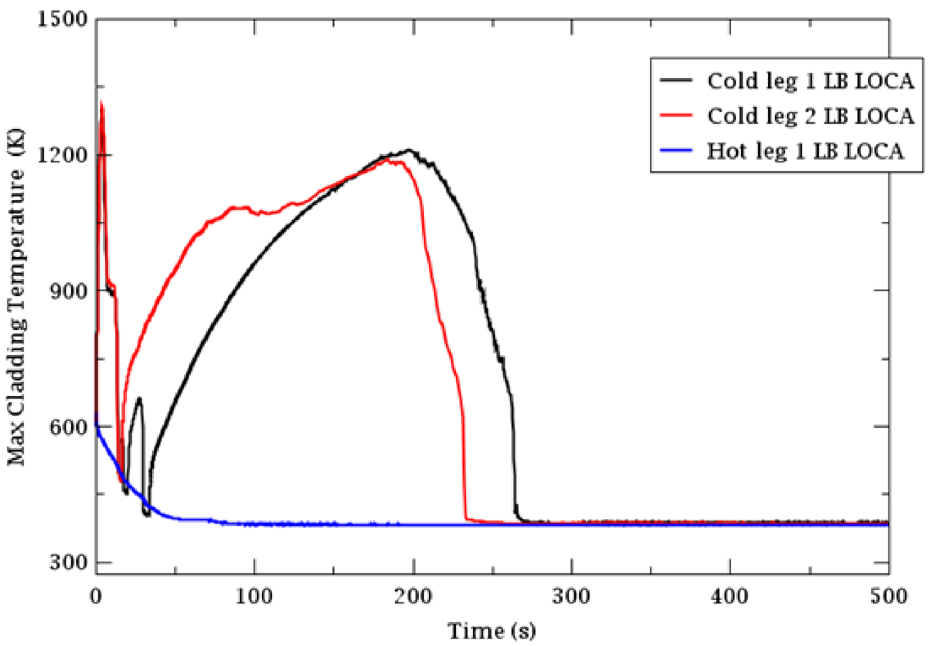

Figure 1: Peak cladding temperature vs time calculated by RELAP5

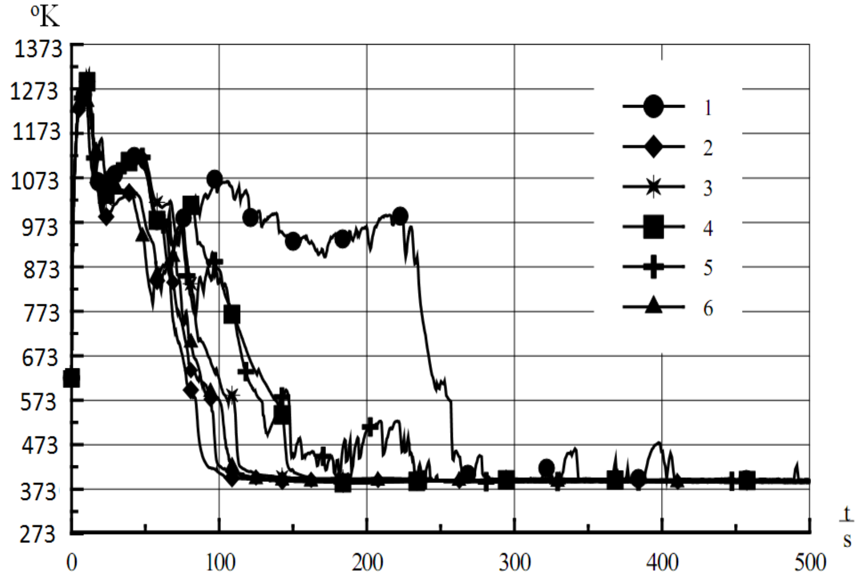

Figure 2: Peak cladding temperature calculated in SAR [9,16]

Figure 2 presents behavior of peak cladding temperature in hot channel in six sensitivity study calculated by SAR including different break locations: guillotine break of Main Circulation Pipe Line in cold legs (2x 850 mm), double end break at surge line of pressurize and guillotine break of Main Circulation Pipe Line in hot legs.

The calculation results in Figure 1 and Figure 2 show that the results calculated by RELAP5 and by SAR are similar in term of maximum of peak cladding temperature lower than 1200 ^{o}C and after 300 second of accident these peak temperature decease to 100^{o}C.

The study results show that utilization of computer code MCNP5 for claculation of reactor physics and especially utilization of computer code RELAP5 for thermal-hydraulics analysis can get the results suitable with reactor physics characteristcs metioned in the design of reactor VVER-1000/V392 and also suitable with results from analysis some scenarios mentioned in Safety Analysis Report [8,16,17,18].

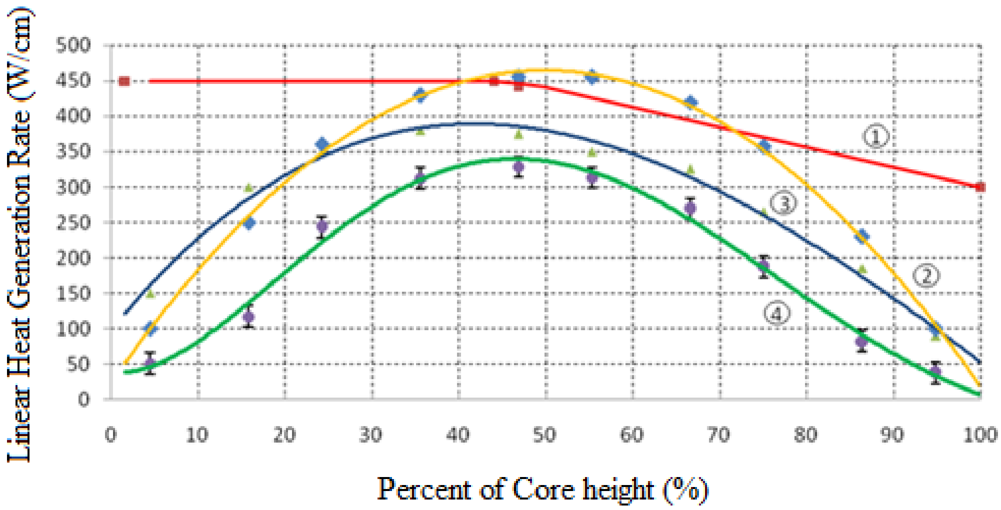

Figure 3: Distribution of Linear Heat Generation Rate (LHGR) vs percent of core height at beginning of first cycle: (1) LHGR given by Regulator; (2) LHGR is recommed to be used in safety analysis; (3) LHGR given in (SAR); (4) LHGR calculated MCNP5 code in present study.

Figure 3 shows that Linear Heat Generation Rate calculations along core height between present study and SAR is similar in the sharp. The different values may be come from model evaluation of each codes.

Study results from thermal-hydraulics simulation also expose that the utilization of computer code RELAP5 as independent tool in order to assess the Safety Analysis Report of reactor type VVER designed by Russia is practical and feasible application.

III. CONCLUSION

The results from analysis, comparison and assessment between the designs of AES-91, AES-92 and AES-2006 show that in order to satisfy the requirements of highest safety level and advanced technology level of the resolution N^o41 adopted by National Assembly of 12^{th} term, the NPP type AES-2006 is appropriate selection for Vietnam.

These results have been used by Vietnam Atomic Energy Institute for recommendation to the National Steering Committee for Ninh Thuan nuclear power project and advice Electricity of Vietnam in reactor technology assessment and selection.

The results of study on reactor physics and thermal-hydraulics for the reactor VVER-1000/V392 were presented in format of two papers being to printed in Journal of Science and Technology (Volume 52, N^o 2B, 2014) and three reports at the 10^{th} National Conference on Nuclear Science and Technology, Baria-Vungtau, August 2013. The resuls were also contribution to finish successfully the Master Degree study for two staffs and contribution to Ph.D study for one other staff.

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