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Developing a Systematic Education and Training Approach Using Personal Computer Based Simulators for Nuclear Power Programmes

Proceedings of a Technical Meeting Held in Vienna, 15–19 May 2017

IAEA
International Atomic Energy Agency

DEVELOPING A SYSTEMATIC EDUCATION AND TRAINING APPROACH USING PERSONAL COMPUTER BASED SIMULATORS FOR NUCLEAR POWER PROGRAMMES

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IAEA-TECDOC-1836

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PROCEEDINGS OF A TECHNICAL MEETING
HELD IN VIENNA, 15–19 MAY 2017

INTERNATIONAL ATOMIC ENERGY AGENCY
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FOREWORD

The IAEA provides technology teaching and training in support of human capacity building to Member States pursuing, expanding or maintaining their nuclear power programmes. The IAEA has since 1997 advanced extensive training programmes based on its library of personal computer (PC) based basic principle nuclear power plant simulators in support of human resource development in Member States. The education and training courses use basic principle simulators to teach the operation specifics of various advanced reactor technologies. An integrated approach combines lectures with learning by doing on plant operational specifics and fundamentals, including reactor physics, thermohydraulics and safety aspects. Member States have recently recognized and identified the need to exchange information on the use of these tools in education and training curricula toward a more systematic and synchronized approach.

This Technical Meeting discussed the use of PC based basic principle simulators in education and training to enhance understanding of nuclear technologies through learning by doing and to provide a wide spectrum of information on lessons learned, good practices and challenges being faced. A total of 32 experts from 21 Member States, together with several IAEA experts, presented the current status of PC based basic principle simulators and their applications in education and training, and identified relevant areas of improvement and new development. This publication collects the various extended abstracts submitted and presented at the meeting. It also includes summaries of the presentations and the follow-up discussions as well as conclusions and recommendations for further work.

The IAEA acknowledges the contributions of the experts who participated in the Technical Meeting and submitted extended abstracts. In addition, the IAEA would like to thank T. Liu (China), G. Grady (United States of America), C. Szoboles (Hungary), M. Tatsumi (Japan) and S. Rassame (Thailand) for chairing the sessions, and J. Lee (Republic of Korea) for developing Annex II. The IAEA officer responsible for this publication was T. Jevremovic of the Division of Nuclear Power.

CONTENTS

1. INTRODUCTION

1.1. BACKGROUND

The use of the IAEA PC based basic principle simulators (definition provided in Annex I) in education and training is aimed at enhancing understanding of nuclear technologies through learning by doing; this hands on experiential training is highly suitable for operators, maintenance technicians, suppliers, regulators, researchers and engineers. These simulators are highly valuable for students and professors equally because learning only the theory has proven not to be as effective and efficient for skill based human capacity building of the national nuclear power programmes. These simulators can play an important role to help policy makers and their teams to understand the technology in an effective and easy way and thus help make knowledgeable decisions in early stages of choosing a technology for deployment.

The high fidelity full scope simulators available at nuclear power plants provide a training environment that emphasizes the control room setting for the operators to understand the fundamental processes and operational procedures of that particular plant. Such skill based training is most beneficial when the operators enter with existing knowledge based skills. Advances in computer technology have enabled the development of fidelity simulators on a smaller and simpler scale applicable for classroom teaching and training to enhance knowledge based skills. The simpler design of the PC based basic principle simulators, as compared to full scope simulators, allows trainees to more quickly grasp on the fundamentals through learning-by-doing without missing details of complex nuclear technology processes. A combination of lectures on technology physics and technology itself, along with the ability to more thoroughly examine participants' understanding through 'doing', has shown to be a very effective learning method that strengthens understanding of the fundamentals of nuclear technology principles.

The IAEA has gained significant experience in organizing and delivering training courses worldwide using PC based basic principle simulators. This type of training is cost effective and suitable for the Member States building, extending or maintaining their national nuclear power programmes. Since 1997, the Nuclear Power Technology Development Section builds the library of PC based basic principle simulators. These simulators are made available to the Member States to access and use in their development of the national curricula for education and training. A historical trend of the requests for simulators from the Member States is shown in Figure 1. Since 1999, the Nuclear Power Technology Development Section provides a wide variety of education and training courses concerning efficient human capacity building and strengthening of the human resource development within the national nuclear power programmes in the Member States. Table 1 provides a brief summary of the courses provided to over 500 participants from over 40 Member States in the last 18 years.

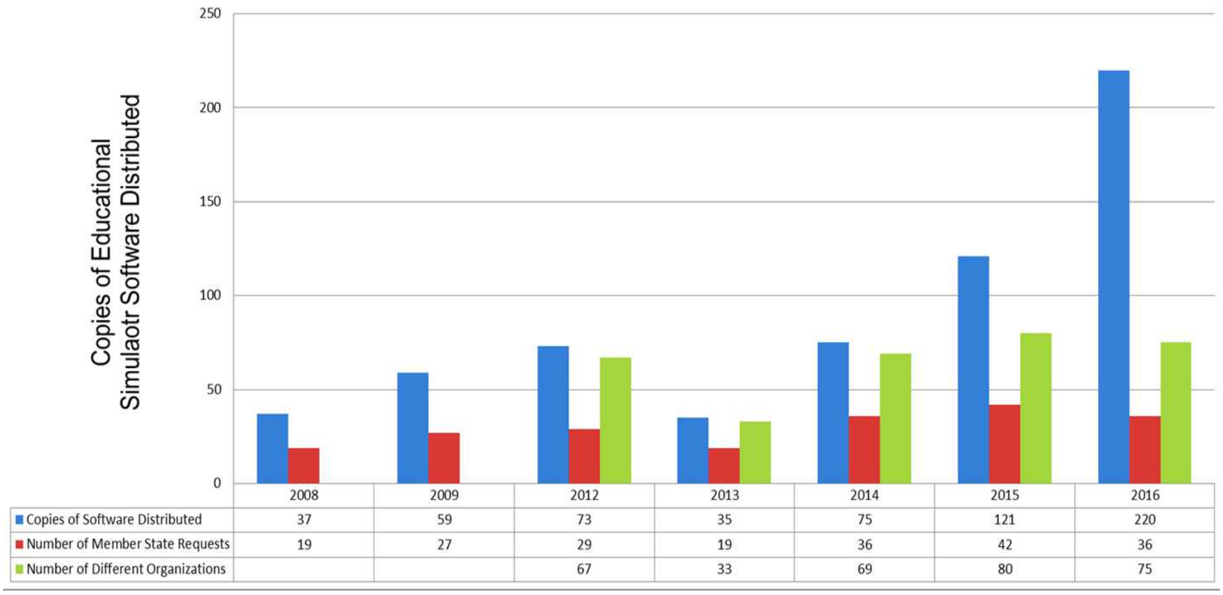

FIG 1. Historical trend of the requests for the IAEA simulators from the Member States.

TABLE 1. IAEA TRAINING AND EDUCATION COURSES AND WORKSHOPS: ACTIVE LEARNING WITH PC BASED BASIC PRINCIPLE SIMULATORS

Year	*Title*	*Location*
1999	Workshop on Reactor Simulator Development	Vienna, Austria
2000	Workshop on the Application and Development of Advanced Nuclear Reactor Simulators for Educational Purposes	Trieste, Italy
2001	Workshop on Advanced Nuclear Simulation	Trieste, Italy
2002	Workshop on Advanced Nuclear Power Plant Simulation	Trieste, Italy
2003	Workshop on Nuclear Power Plant Simulators for Education	Trieste, Italy
2004	Workshop on Nuclear Power Plant Simulators for Education	Trieste, Italy
2005	Workshop on Nuclear Power Plant Simulators for Education	Trieste, Italy
2006	Workshop on NPP Simulators for Education	Bucharest, Romania
2007	Workshop on Nuclear Power Plant Simulators for Education	Trieste, Italy
2009	Workshop on NPP Simulators for Education	Trieste, Italy
2011	Workshop on Enhancing Nuclear Engineering through the Use of the IAEA PC based Nuclear Power Plant Simulators	Milano, Italy
2012	Present paper at European Nuclear Power Plant Simulation Forum 2012	Barcelona, Spain
2013	Course on Physics and Technology of Water Cooled Reactors through the Use of PC Based Simulators	Madrid, Spain
2013	Interregional Course on Fundamentals of Pressurized Water Reactors with PC based Simulators	Daejeon, Korea
2014	Understanding the Physics and Technology of Advanced Passively Safe Water Cooled Nuclear Reactors using Basic Principle Simulators	Bangi, Malaysia
2015	Physics and Technology of Water Cooled Reactors through the use of PC based Simulators	Trieste, Italy
2015	Understanding the Physics and Technology of Advanced Passively Safe Water Cooled Nuclear Reactors using Basic Principle Simulators	Santiago, Chile

TABLE 1. IAEA TRAINING AND EDUCATION COURSES AND WORKSHOPS: ACTIVE LEARNING WITH PC BASED BASIC PRINCIPLE SIMULATORS (cont.)

2015	Course on Fundamentals of Pressurized Water Reactors with PC based Simulators	Daejeon, Korea
2015	Course on Fundamentals of Pressurized Water Reactors with PC based Simulators	Amman, Jordan
2015	Physics and Technology of Water Cooled Reactors through the use of PC based Simulators	College Station, Texas
2016	Physics and Technology of PWRs with PC based Simulators	Daejeon, Korea
2016	Understanding the Physics and Technology of PWRs through the use of PC based Simulators	Tunis, Tunisia
2016	Understanding the Physics and Technology of PWRs through the use of PC based Simulators	Ocoyoacac, Mexico
2017	Pilot Training on WCR Technologies and Severe Accidents with PC Simulators	Salt Lake City, USA
2017	IAEA/KAERI Regional Course on WCRs Technologies and Passive Systems: Competence based Approach with PC Based Basic Principle Simulators	Daejeon, Korea
2017	Training Course on Reactor Technologies and Severe Accidents: Learning by Doing with PC Simulators	Salt Lake City, USA
2017	Understanding Technology and Physics of WCRs with PC Simulators	Trieste, Italy
2017	IAEA/VINATOM National Training Course on PWRs Technologies and Passive Safety Systems	Hanoi, Viet Nam

1.2. OBJECTIVES AND ORGANIZATION OF THE TECHNICAL MEETING

The purpose of this meeting was to provide a platform for detailed presentations, technical discussions and exchange of lessons learned on the use of PC based basic principle simulators in education and training with the goal of discussing the approaches to lead to a comprehensive, integrated and systematic learning by doing education strategy for enhancing individual knowledge-based skills. The specific objectives of the meeting were aimed to facilitate the exchange of experiences in using the basic principle simulators in developing and developed countries, foster worldwide collaboration in their further systematic use in human capacity building of the national nuclear power programmes, enhance communication between industry (utilities, companies), regulatory bodies, universities and research organizations and discuss and update scientific and engineering knowledge in this area. More specifically the focus of the meeting was to:

— Promote the exchange of information relevant to the use of PC based basic principle simulators in education and training in different organizations (universities, institutes, companies, nuclear power plants, and government organizations);
— Collect information on the approaches for developing a comprehensive, integrated and systematic learning by doing education strategy using the IAEA’s library of PC based basic principle simulators for different reactor technologies;

- Discuss and identify tasks related to a systematic approach to training (SAT) and various training modules relevant to conventional and advanced nuclear power plant system engineering;
- Discuss the implementation strategy of the systematic educational approach to training using the PC based basic principle simulators; and
- Provide recommendations to the IAEA for future activities in regard to the use of the IAEA PC based basic principle simulators.

The meeting programme included discussion and writing sessions for the participants to develop the summary and highlights of the meeting, and to develop recommendations to the IAEA on future activities in this area. More specifically, the meeting was divided into three topical sessions, three discussion sessions and the summary session. The topical sessions provided opportunities for participants from countries with established national nuclear power programmes and countries embarking on nuclear power programmes to share information on their experiences and identified needs and challenges in education/training approaches using PC based basic principle simulators. The topical sessions provided a forum for information exchange on systematic human capacity building through education and training with basic principle simulators integrated into national nuclear power programmes, reactor technology teaching with basic principle simulators, and software examples. The discussion sessions provided a number of recommendations on the meeting topical sessions. The summary session produced a base for this technical report in compiling on the contributions from all meeting participants.

1.3. OBJECTIVES OF THE TECHNICAL DOCUMENT

This TECDOC compiles the outputs and outcomes of the Technical Meeting on "Developing a Systematic Education and Training Approach Using Personal Computer Based Simulators for Nuclear Power Programmes."

The purpose of this publication is to provide the Member States with the ample review of the current state of the art of the PC based basic principle simulators and their active use in education and training by summarizing in enough details the information presented at the Technical Meeting.

1.4. ORGANIZATION OF THE TECHNICAL DOCUMENT

Section 1 recalls the background and the objectives and the organization of the Technical Meeting, as well as the organization of this TECDOC.

Section 2 provides a detailed summary of the technical and discussion sessions.

The general conclusions and recommendations from the Technical Meeting are provided in Section 3.

A synopsis of the extended abstracts presented at the meeting is included in the publication for reference.

2. SUMMARY OF MEETING SESSIONS

The meeting consisted of the Opening Session, three Topical (Technical) Sessions, three Discussion Sessions, Summary Session and Closing Session. Twenty three (23) presentations were provided during the three technical sessions and discussions were centered on several topics related to each topical session as follows:

Topical Session 1 Systematic Human Capacity Building: *Education and Training with Basic Principle Simulators Integrated into National Nuclear Power Programmes*

Topical Session 2 Reactor Technology Teaching with Basic Principle Simulators

Topical Session 3 NPP Simulators: *Software Examples*

These topical sessions provided opportunities for participants from countries with established national nuclear power programmes and countries embarking on nuclear power programmes to share information on their experiences and identified needs and challenges in national human capacity building specifically within the educational and training curricula using PC based basic principle simulators.

The content and main conclusions of these Sessions are summarized in the following sections based on the participants' presentations and submitted abstracts.

2.1. TOPPICAL SESSION 1: SYSTEMATIC HUMAN CAPACITY BUILDING: *EDUCATION AND TRAINING WITH BASIC PRINCIPLE SIMULATORS INTEGRATED INTO NATIONAL NUCLEAR POWER PROGRAMMES*

This Session contained 10 presentations covering the experiences, practices, lessons learned and examples of the academic and industrial use of PC based basic principle simulators for education, training and re-training of national nuclear engineering force.

The first presentation, entitled *IAEA Education & Training Courses based on Active Learning with Nuclear Reactor Basic Principle Simulators*, described the IAEA's activities relating to training and education courses on nuclear power plant's fundamentals and reactor technology specifics of the advanced and current water cooled reactor technologies with the use of PC based basic principle simulators. A summary of this presentation populates the Section 1 of this publication.

The second presentation, entitled *Systematic Education and Training Plan Using PC Based Simulators for In House Capacity Development of Thai Regulators in Preparation for Nuclear Power Programmes*, provided a high level overview of the current power development plans for Thailand. Namely, as a regulatory body, the Office of Atoms for Peace (OAP) in Thailand always pursues the ways for ensuring the utmost nuclear and radiological safety of the public and environment. According to the 2015 country's power development plan, total in capacity of 2000 MWe of nuclear power plants is planned to be added during

2015–2036. Therefore there is a high need for systematic education and training programme for in house capacity development of the regulators in preparation for the nuclear power plant programme. Currently, many of the staff entering the regulatory body being recent graduates are without specific knowledge or experience in nuclear power plants. The strategy is to implement a systematic and staged approach to training using PC based simulators as the tools for in house building of personnel skills. The country's systematic education and training plan expected to be realized in 2–3 years' time frame, with the use of PC based basic principle simulators, is planned to be implemented in three stages as follows:

- Stage 1 the necessary training tools will be acquired and a training center will be established at OAP with necessary software, hardware and expertise required to "train the trainers" in using the PC based simulators.
- Stage 2 is referred to the in house training that includes developed in house training programmes and established team of the trained personnel. The plan is that in house experts will then be able to develop part task simulators, concept simulators and special technology training toward selection of those of interest to the country's energy plan.
- Stage 3 defines more advanced training through the development or acquisition of more specialized models. There is a need for structured curricula using the available basic principle simulators as tools to continuously advance the capabilities of the regulators; eventually the team may develop a new tool to be used to train and test the inspectors. Securing a qualified instructor is a challenge but would significantly improve a systematic approach to training.

The third presentation, entitled *Use of Computer Codes and Simulators in Education* provided a review of the history of nuclear power in Lithuania, and discussed about the Lithuanian experience in the use of computer codes and simulators in education. After 1990 when Lithuania declared its independence, the Ignalina nuclear power plant came to jurisdiction of the Republic of Lithuania with all technical scientific support organizations remained in Russian Federation. Therefore there was an immediate need to develop independent nuclear regulatory and technical institutions, and thus the need for human capacity development and maintained training and education programmes. In 2004 and 2009 Ignalina Unit 1 and Unit 2 were shutdown, respectively. However, despite the closure of Ignalina nuclear power plant units, the country still maintains active nuclear facilities including nuclear fuel in unit 2 reactor, and the interim spent fuel storage facility. Plans for the new plant Visaginas NPP (Hitachi ABWR) are on hold. There is collaboration among a variety of technical support organization including Vilnius University which is focused on teaching the fundamental physics, and Kaunas University of Technology, which focuses on teaching and training on modelling of transients, accident thermohydraulic processes and deterministic safety analysis. There is a close cooperation between Kaunas University of Technology and the Lithuanian Energy Institute. These organizations have united doctorate in the area of technological sciences "Energy and Power Engineering." The organizations use a variety of simulation based training tools such as the RELAP5 based Nuclear Plant Analyzer, Ignalina Full Scope

Simulator and GRAPE (Graphical RELAP and SCADAP Codes). One of the challenges is the recruitment of potential nuclear engineers and training on effective use of these complex tools.

The forth presentation, entitled *Practice and Consideration of Training Capability with Simulators after 30 Years of Nuclear Simulator Development Experience in China* described the nuclear power landscape in China including the wide variety of nuclear reactor technologies deployed and the role of China Nuclear Power Operation Technology Corporation Ltd (CNPO). To meet the demands of the fast-growing nuclear power industry, China has implemented a complete training system series in accordance with IAEA practices to ensure a sufficient supply of nuclear power employees. Regarding training methods and means, China mainly adopts classroom training, simulator based training, on-the-job training, laboratory, mock–up & workshop training, computer- based training and so on. The knowledge gained using this strategy helped in establishing the China's own HPR1000 design. Over the past three decades, China has made great progress in its nuclear power construction. At the end of 2016, China had 35 business units with a total installed capacity of 33.28 million kW, and 21 units under construction with a total installed capacity of 24.25 million kW. In the next five years following 2016, 6 to 8 newly constructed nuclear power units will be added per year, reaching a total installed capacity of 58 million kW by 2020. The presentation further described a variety of simulation applications targeted at different uses and different users. The applications start with simulation for public awareness and acceptance of nuclear power, and progress in complexity to classroom simulation applications, maintenance simulation and full scope operator training simulators. Future developments will also include the integration of more engineering codes and immersive technologies such as virtual reality. CNPO is developing a Collective Operation Training System using virtual reality to help train on the coordination of tasks between the main control room and auxiliary field operators.

The fifth presentation, entitled *Use of Computational Simulators within the Training Program for Examiners of the Licensing Process to Reactor Operators and Senior Operators of Nuclear Facilities* provided details on the Mexican regulatory structure and the Mexican licensing process, which is based upon US licensing approach described in 10 CFR 55. The presentation further described the process for training the examiners who will license for the nuclear power plant operators. The initial stage of the training process includes the use of computational code simulators such as the MELCOR simulator for one week, followed by two months of training on the full scope control room simulator at the Laguna Verde nuclear power plant. During the full scope simulator training, the examiners learn how to write and administer effective simulator examinations to properly evaluate the performance of plant operators. The regulators could benefit from additional simulation tools.

The sixth presentation, entitled *Academic and Industrial Use of PC Based Nuclear Plant Simulators* described two use cases for PC based simulators. The first is the Generic PWR (GPWR) PC based full scope simulator used by numerous universities in their nuclear engineering programs and by technical colleges to support fundamentals training for nuclear workers. The second use case was the Advance Gas Reactor Basic Principles Simulator developed and used by EDF–Energy to provide both overview of plant operating characteristics and control strategies as well as a bridge between classroom training and eventual plant specific full scope simulator training. Future develops of the GPWR will focus on web delivery platform integrated with an integrated scenario based interface.

The seventh presentation, entitled *PC Based Reactor Simulator Lab for Education and Training Purposes at Malaysian Nuclear Agency* described a variety of simulation tools used by the Malaysian Nuclear Agency including an upgraded TRIGA reactor simulator, and PC based simulators such as PCTRAN for AP1000, and IAEA NPP simulators for PWR, BWR, CANDU and ACR700 plants. The simulators are being integrated into university programs and are currently used mainly for an introduction into nuclear plants versus evaluation of student knowledge at this stage. Future plans include establishing an Interned Reactor Laboratory to conduct regional training and eventually the purchase of a full scope nuclear power simulator.

The eighth presentation, entitled *Simplified In–Core–Fuel Management Software for Education and Training* described a simulation tool developed at the Hacettepe University to aid in the understanding of fuel characteristics across the lifecycle of fuel in the reactor. The simulation includes the effects of enrichment, burnable poisons and fuel loading map patterns among other capabilities. The tool can use both one dimensional and two dimensional nodal neutronics solver and uses genetic algorithms. The value is in fuel cycle analysis versus transient and is beneficial in use to create input parameters for other simulator applications. Future plans include the potential addition of a time dependent neutronics module.

The ninth presentation, entitled *Need to Introduce a Systematic Education and Training Approach Using Personal Computer in Nuclear Engineering Education Program at the ENSMR* provided description of the current status of University [Higher National School of Mines–Rabat] level programmes for nuclear physics, reactor physics, nuclear instrumentation and nuclear industry industrial applications. The challenges facing the university are collaboration with government and industry to attract more students into the programme for future workforce needs. To solve this a systematic approach adopted includes (1) defining a strategy, (2) information exchange between academia, research and end users, (3) acquisition of simulation tools for academia and potentially advanced models for specialist training. While the focus is on Generation III reactors the desire is to also compare to Generation II models to gain wider knowledge.

The tenth extended abstract although not presented at the meeting is included in this publication. The *Human Resource Education Process for Nuclear Energy Area* in Armenia provides an extensive summary of a study required to define the programmes for development of the human resource infrastructure needed for a human resource education process for nuclear energy area in Armenia.

The presentation slides are available on-line:
https://www.iaea.org/NuclearPower/Meetings/2017/2017-05-15-05-17-NPTDS.html.

2.2. TOPICAL SESSION 2: REACTOR TECHNOLOGY TEACHING WITH BASIC PRINCIPLE SIMULATORS

Five presentations were presented in Topical Session 2 covering different aspects of implementation and use of simulators in teaching the reactor technology fundamentals.

The first presentation, entitled *Technatom's Implementation of Personal Computer Based Solutions for Nuclear Power Training Programmes* introduced the evolution of simulators used in the nuclear industry since the early age of nuclear power programmes. He clarified the needs for simplified scoped (generic) simulators applied for both, supporting initial training of licensed operators and introduction of basic nuclear power plant principles for other nuclear professionals including students in the nuclear field. Learning stations functionalities using the generic simulators developed by Tecnatom are described; specifically the process diagrams, trends, 3D primary circuit visualization tool, training exercises tool are outlined. The implementation of learning stations in the training includes two modes, namely, a demo mode and the operation mode. Major training advantages of using the learning stations in the nuclear power plant Spanish training programme are described. Furthermore, the training of soft skills such as communications, decision making, cognitive skills and etc. are being introduced in the nuclear training programme in Spain. Tecnatom is developing the severe accident module integrated within the nuclear power plant Alamaraz simulator. Additionally it was stated that the nuclear industry is demanding new training approaches to enhance the trainee learning capability with training cost reduction. In this regards, improved training tools and methodologies used in the training are expected and required.

The second presentation, entitled *The Use of Software Simulators and Full Scope Simulators for the Teaching of Reactor Physics* provided and extensive introduction to the current status and future plans of the nuclear power programme in Argentina including the overview of the nuclear teaching institutions in Argentina. Three major tasks of teaching programmes in UNC–CNEA are focused at safe operation of RA–0 research reactor, performing on the research about the application of TIC's to education, and development of Instrumentation for Research Reactors. The types of leaners, nuclear subjects taught and teaching techniques in the institute are described in the details. The description of reactor physics practical class is outlined in terms of learning place, materials used and learning contents in the class. The advantage and disadvantages of using the learning place at RA–0 Research Reactor, Embalse Nuclear Power Plant Full Scope Simulator, and Atucha II Nuclear Power Plant Full Scope Simulator are discussed. The video containing the analysis of the teacher relating the observed in the simulation with the respective theoretical contents is planned to be developed.

The third presentation entitled *Web–Based Nuclear Simulators and their Use in Education and Training* provided the historical information of CARST establishment as well as how courses and teaching styles developed at CARST. The CARST offers a variety of nuclear technology and radiation courses to the undergrad and graduate level students. Several major nuclear stakeholders in South Africa such as Department of Energy, Ithemba Laboratory for base accelerator sciences, Nuclear Energy Cooperation of South Africa, and Koeberg nuclear power plant are introduced. The Koeberg nuclear power plant is described in terms of plant specification and economic impact to the country. Additionally, the governmental plan for new nuclear power plant building is outlined. Lastly, the simulators for teaching and training at CARST such as using of MCNPx to simulate different scenarios in nuclear reactors and accelerators are summarized.

The fourth presentation entitled *Use of PC Based Basic Principle Simulators for Teaching and Training in Thailand* presented the current Thailand's nuclear energy plan and the history of nuclear educational programme in Thailand since 1970s. The available programmes of nuclear engineering education at the level of bachelor, master and doctoral degree at Chulalongkorn University in Thailand are described. The current use of PC based basic principle simulators in the class of teaching can be classified into three types. The first type is the use of IAEA Simulations (old version) as the introductory tools for learning the fundamental operational principles of nuclear power plants in the basic nuclear engineering course. The second type is the use of IAEA Simulations (current version) for the advanced course. The third type is the use of IAEA Simulations (current version) for the training of engineers and scientists at a utility company in Thailand. For three types of courses, the course syllabi, teaching styles, class assignments, advantages and disadvantage of simulator types used, and students' feedbacks are accordingly explained. The next challenges of PC based simulation in Thailand and the suggestions to the IAEA or simulators developer are outlined.

The fifth presentation entitled *The Integration of Point Kinetics Method with Standard Thermal Calculation for Transient HTGR Simulator* gave the information on status and near future plan of the HTGR development in Indonesia. The methodology in developing of several simulators at BATAN is systematically explained in both parts of reactor calculation and nuclear steam supply system using the coupled method of point kinetics and thermal hydraulics. The HTTR Monitoring System, RSG–GAS Simulator, PWR Simulator and TRIGA MARK simulator are the current products of simulators development in Indonesia. Verification of the developed PWR and HTTR simulators are performed by benchmarking against the commercial (state of the art) computer codes or designed standard parameters. Furthermore, the simplest simulator for understanding the physics and technology of PWR developed at BATAN are used as introductory tools to enhance the public acceptance by distribution of the software through some social media channels. Finally, the roadmap and current progress of HTGR simulator development are outlined.

The presentation slides are available on-line:
https://www.iaea.org/NuclearPower/Meetings/2017/2017-05-15-05-17-NPTDS.html.

2.3. TOPICAL SESSION 3: NPP SIMULATORS: *SOFTWARE EXAMPLES*

Topical Session 3 contained nine presentations describing the various software systems of the PC based basic principle simulators and their use for personnel training and education in the university settings. The presentations provided a comprehensive review of the most modern simulator software currently used for training and education in the area of current and advanced water cooled reactors.

The first presentation entitled *25 Years of Experience in the Use of Self Developed PC Based Basic Principle Simulators* described overview of Hungarian nuclear industry and pointed at the current and future needs for education and training in nuclear programmes at the university. In the last close to three decades, five different simulators have been developed at the Institute of Nuclear Techniques of Budapest University of Technology and Economics (NTI BME): PC^2–primary circuit basic principle simulator (DOS, 1987–88), REMEG reactor trip analyzer (DOS, 1989–96), STEGENA–steam generator analyzer ('part task simulator') (DOS, 1991–93), SSIM–secondary circuit basic principle simulator (MS Windows, 1993–95), and PC^2 for Windowsprimary circuit basic principle simulator with a more complex calculation model (MS Windows, 1997–99). Through this 25 year experience of development and use of the five PC based basic principle simulators for WWER440, the lessons learned point at the importance of fundamental understanding of the nuclear systems with simple but effective means of self learning using simulators which is one of the reasons that the original simulator is most frequently used. The best practice in modernization of the original simulator for Windows platform was explained to take the following three directions: modularity, standardization and portability. Importance of exercises was heavily emphasized.

The second presentation entitled *The Use of Personal Computer Based Simulators for Nuclear Power Programmes* gave a brief history of the current situation of nuclear power plant in Armenia (two units, WWER440) which experienced a long shutdown due to reunion of Soviet Union and restart with repair and safety enhancement. He introduced the two series of simulators currently used for training of the nuclear power plant personnel. One is a "multiple functional simulator" which consists of several workstations to cover normal and abnormal conditions for training of MCR personnel. The other is a "maintenance simulator" which gives self–learning course of maintenance procedures with 3D graphics.

The third presentation entitled *Easy PWR: INSTN's Learning Tools Suite for Learners in PWR Power Operation and Neutronics Applied to Core Control* briefly introduced the organization and mission of INSTN in which two simulators are used for simulating normal and accidental plant's conditions. However, shortcomings of the simulators in training of specific situations motivated a development of a different type of simulator. Easy PWR is a platform for such purpose which equips some "tools" to help the students navigating to learn specific scenarios such as for example the Xe oscillations and startup sequences. The platform provides modules for user interfaces such as input/output and physical simulations such as neutronics and thermal hydraulics which are shared among the tools. The calculation modules are validated against the results by design calculation codes. A future direction to establish a “micro-simulator” is outlined; the goal of this simulator is to explain fundamentals of more complex physical phenomena.

The fourth presentation entitled *Overview of Software Development for Analysis and Design of Nuclear Power Reactors in Mexico* described a development project called AZTLAN in Mexico. Like NURESIM in EU and CASL in the USA, this system follows an approach of multi-physics simulation. AZTLAN, which represents a big challenge for Mexico, is a project lead by ININ jointly with various universities. It is not a project to develop a simulator but a suite of simulation codes. In the project several organizations are involved and four expert groups are conformed. In this system of codes, the neutronics codes are based on the multi-group transport/diffusion methods developed in the Cartesian and hexagonal coordinate systems. A thermal hydraulics code like RELAP is also single–handedly developed. Visualization is realized by the use of Salome software. Some mathematical models for severe accidents are also taken into account. The expected outcome of the project is the establishment of a multidisciplinary simulation platform, documentation and validated models so that it can be used for education without any charge.

The fifth presentation entitled *Development and Application of WWER1000 PC Based Simulators for Education and Training in NRNU MEphI* provided a comprehensive explanation of the WWER1000 simulator and analyzer which were developed by MEPhI. This simulator is also included within the IAEA PC based simulator suite, and it was used for IAEA Training Courses. For example, the last two courses took place in Jordan Atomic Energy Commission (JAEC), Amman, Jordan, 22–26 November 2015 and in Arab Atomic Energy Agency (AAEA), Tunis, Tunisia, 11–15 July 2016. The WWER1000 PC based simulator is distributed free of charge among IAEA Member States institutions. The simulator includes modelling of the reactor core, primary/secondary system control and protection systems, all with a good fidelity for the purpose of education and training. The simulator can model an initial core and a reloaded core in normal and abnormal conditions. The WWER1000 PC based simulator gives an understanding of the reactor construction and operational characteristics. Visualization functions are useful for students to understand the calculation results and physical phenomena. The protocol viewer is also provided to ease in the analysis of the calculation results. Comparisons among protocols are helpful to understand differences visually. Training tasks are well developed for effective learning. In many workshops, the simulator was effectively utilized for the education purpose. An analyzer, called MFA RD, which is an upgraded version of the simulator, is used not only in educational laboratory but also in the international and regional workshops to cover wider range of educational needs. The course using the analyzer is well designed and organized. The update of the simulator is planned to support the multitouch capability in Windows10.

The sixth presentation entitled *PC Based Simulators of NPP with WWER1200 Reactor: Operation and Safety Analysis Oriented Training and Education in VINATOM* provided an overview of the country’s nuclear power programme that has been initiated in 2007, but stopped in 2016. One of the nuclear power plant types Viet Nam was about to install was the WWER1200. In 2010, a programme was launched to develop nuclear power infrastructure. In the framework of IAEA TC Project VIE2010 on Developing Nuclear Power Infrastructure Phase II, the Generic WWER1200 simulator has been supplied for Viet Nam in December 2015. The simulator covers the full range of plant operations and is operated in real time mode so that user can understand the response of the systems which correctly represents the real systems. However, for the education the IAEA PC based basic principle simulators are found to be more suitable. Using the simulator they spent a long time to understand the technical features, including the auxiliary and safety systems of the WWER1200 design. Besides the normal operation modes, such as startup and shutdown, they also studied some of the malfunctions. The presentation included some of the examples they examined.

The seventh presentation entitled *University of Utah Recent Lessons Learned in PC Based Simulator Training with Examples* described the extensive use of simulators in education and training at the University of Utah Nuclear Engineering Program. The specific simulators in use for education and training are the two IAEA simulators, PCTRAN Research Pool Reactor and PCTRAN Two Loop PWR simulators and in house designed simulator called the University of Utah TRIGA Reactor (UUTR) simulator. Students are asked to experiment and master the simulators working alone or in groups, and then tasked with teaching other students about their assigned simulators. This enhances the learning process by providing the students with learning by doing atmosphere. New recently conducted Pilot Training Course on reactor technologies and severe accidents was shortly introduced, with participants having background of practically no experience at all. Some of the accidents analyzed with the students are reactor trip, rod bank failures, LOCA, Load rejection, Loss of Coolant Pump, etc. All these are shown using PCTRAN PWR simulator. Sever accidents such as TMI are reproduced and analyzed with students in order to give them better understanding of the nature of the accidents. Students have very positive feedback on the application of simulators in their education and training.

The eight presentation entitled *Development of a Graphical RELAP based Analysis Platform for Education (GRAPE) and educational materials for fundamental understanding of nuclear power plant behaviors* described the Multi-Physics Simulator, a product of the NEL Ltd efforts. Macro–Physics Simulator is a plant simulator by GSE. Micro–Physics Simulator is based on the Studsvik's Simulate–3K code, and thermal hydraulics is modelled with the Cobra code. First, students run Macro simulator to have the boundary conditions, which are then transferred to core transient analysis with Micro–physics simulator. Micro–Physics Simulator Lite is donated to the IAEA (see Annex II for its brief description). The GRAPE simulator supports the scenario based analysis and visualization platform providing a learning of the plant behavior. The need for severe accident analysis has been growing after Fukushima Daiichi accident in 2011. Scalable Vector Graphics, format of Adobe Illustrator, is used for displaying the information. The plant models already developed are PWR and BWR for certain systems; more models are under development, such as for example for the CANDU designs. The new software is applied by various universities, utility and research institutions in Japan. They have a one week educational course on PWR behavior and accidents analysis.

The ninth presentation entitled *VUJE Nuclear Power Plant Personnel Training Centre* outlined the current situation in nuclear industry in Slovakia and described the specifics and the use of a Buhunice V–2 full scope simulator. The basis of the training is the educational system for the areas of nuclear industry, conventional power plants, and electric grid and for other users. The Training Centre develops and designs hardware and software for education and training including simulator development. It carries out examinations for granting licensees for the execution of functions in nuclear power plants and organizes specialized and international courses. Full scope simulator, a copy of 3rd unit of Bohunice nuclear power plant control room, has been recently upgraded and new features have been added to provide better, more accurate, reliable and realistic training experience. A new specific standalone simulation platform is under development to be used in classroom training for various target groups.

The presentation slides are available on-line:
https://www.iaea.org/NuclearPower/Meetings/2017/2017-05-15-05-17-NPTDS.html.

3. CONCLUSIONS AND RECOMMENDATIONS

3.1. CONCLUSIONS

The participants have confirmed that the meeting has provided a unique opportunity to enhance information exchange among the industry, universities, operators and institutes in the Member States on the use of PC based basic principle simulators in education and training of the national nuclear programme human resources. All participants agreed that the objectives of the meeting as defined in the Terms of Reference were fully met.

The meeting participants outlined the importance of international scientific collaboration on further development and benchmark of, and continuous information exchange on the use of PC based basic principle simulators in education and training. The associated challenges in developing, upgrading and testing the simulators, and their inclusion into the existing education curricula are recognized. An important effort is needed in the world community to focus at the development of simulators inclusive of severe accidents modelling of their progressions and consequences. Such simulators will gain an international attention, and will become a valuable tool to aid to education and training of professionals, but also be useful in educating the general public.

It was recognized that this Technical Meeting was a successful follow up to previous IAEA activities and continuous improvements in delivering educational courses to Member States on technologies of WCRs. It was concluded that this Technical Meeting provided a forum for exchange of activities and practices in Member States on education and training using PC based basic principle simulators that resulted in a production of this technical document inclusive of well supported recommendations received from the participants for the near-term implementations.

3.2. SUMMARY OF RECOMMENDATIONS

During the Technical Meeting the following summary of recommendations for joint collaborations, IAEA's activities and/or international cooperation were developed with the goal to continue promoting the use of PC based basic principle simulators in education and training toward national human resource development:

A. Classification of the IAEA PC Based Basic Principle Simulators

The participants concluded that there is a wide variety of simulators that are called Basic Principles Simulators (BPS). However, the obvious the differences among them such as for example in respect to the scope and extent of the plant systems being modelled, sophistication of the modelling algorithms, validation of the simulator's models, the ability to change parameters (educational perspective vs operational perspective), and the user interface tools (level of visualization and ease to grasp on the images), create a challenge in how selecting the simulator that fits the best an individual or training group needs. The meeting participants agreed to the following recommendations:

— To better classify all available IAEA simulators into descriptive categories regarding their fidelity, scope, specifics, domain of use and level of visualization, for example. The IAEA originally created a report that could serve as a starting point for further classification of the BPS capabilities. IAEA –TECDOC-995 (1998) needs to be revised and updated because the technology has advanced and the library of the IAEA simulators has expanded. The result of the classification activities can also be used to create a GAP analysis, defining future simulator needs and to help newcomers to choose an appropriate simulator.
— It is recommended that a TECDOC similar to IAEA –TECDOC-995, specifically for educational purposes, is developed.
— In order to clarify applicability of PC based basic principle simulators offered by IAEA, a 'Simulator ID Card' is suggested to be developed (this recommendation has resulted in developing the brief ID cards, as provided in Annex II of this document).
— Create an overview/brief description of the simulators on the web site including the ID cards in order to help newcomers select the simulator that will fit the best their needs.

B. Range of Applicability of the IAEA PC Based Basic Principle Simulators

The meeting participants noticed that there is a need to review the applicability of the current IAEA BPS collection in terms of their intended use and accuracy in modelling specific trends in the nuclear power plant. In that respect, the meeting participants recommended that:

— The applicability of the IAEA PC based basic principle simulators is verified to a certain degree by a group of experts;
— The IAEA simulator developers should be asked to describe the intended full use of the simulators, the methods used to assess the accuracy against the intended use and define the limits of the simulations.

These recommendations may call for a Consultancy Meeting to result in a summary report as a guide for their future use in education and training courses and as a guide to newcomer countries in implementing such tools within their developing the national nuclear power engineering programmes.

C. Training Programmes with the Use of PC Based Basic Principle Simulators

The meeting participants concluded that several different challenges point to the need for a more structured curriculum when using the PC based basic principle simulators; they summarized the challenges as follows:

— Students or trainees coming to simulation courses/labs have various levels of experience and knowledge, making it a challenge on individual training basis. During such training courses, the time must be spent with new users to explain the concepts of the simulator and how to best use it. More experienced students can move to more advanced training scenarios.

- BPS can be used to train a variety of personnel from university students to regulators and industry employees. Each group has different learning objective and desired exercises with the BPSs. For example, the students need a broader based understanding of areas such as control mechanism, feedback on reactivity, and reactivity effects on power, and tend to enjoy the exercises with simulators, whereas regulatory staff personnel may want to understand the genesis and the background of the simulator calculations, and learn more about the fundamentals and equations governing the phenomena.
- The documentation provided for many of the BPS systems focuses mainly on the simulator design and its use, rather on providing needed education and relevant training scenarios.
- The IAEA conduct repeated Train the Trainer courses to Member States; the courses are designed either at the national or regional and interregional levels.

The meeting participants therefore agreed on the following recommendations:

- To suggest a structured curriculum content that progresses the learner from introduction to the simulator toward the advance use of various simulators. The curriculum should take into account also needs for different types of learners: academia, regulatory workforce, industrial workforce.
- To video record the Train the Trainer sessions and made them available to the recipients to be repeatedly used for refreshing the learning topics and for an ad hoc training.
- Some of the IAEA created supporting documentation currently presented in PDF form be converted to video based tutorials and share them with Member States.
- The IAEA to consider developing three levels of training courses in order to help emerging national nuclear power programmes in their human resource development: (a) the Elementary Course to be mainly for newcomers with no nuclear background, (b) the Beginner Course to be applicable to general level courses, mainly for participants having knowledge equivalent to the university bachelor level in engineering and science, and (c) the Advanced Course to target the audience having a substantial background knowledge related to nuclear engineering, mostly equivalent to the university Master level. The approach in designing the contents of these courses should be based on the SAT process if and when possible.

D. IAEA PC Based Simulator Obsolescence

The meeting participants noted that due to continuous changes and developments of the computer operating systems, some of the IAEA PC based simulators became obsolete and thus difficult to use. The participants summarized recommendations in order to overcome these difficulties as follows to:

- Continue successfully using the current IAEA library of PC based simulators, to either contact the original code developers to obtain the upgraded versions, or to re-platform the obsolete codes so the simulators run on a modern computing platforms;
- Foster feedbacks from existing users and share them with the community of developers and users.

This activity may call for a workshop engaging the developers and the users of the PC based basic principle simulators, specifically those that are using the IAEA library of simulators. The workshop shall then result in a comprehensive overview of the current status of the simulators, computer platforms needed, future prospective of their (continuous) upgrading and avenues for information exchange and international collaboration.

E. Severe Accidents Simulators

The advancement of computing power enables more advanced engineering codes to be run on PCs and thus become available for broader use. For more advanced or in–depth understanding of the nuclear power plant phenomena, there is a desire to have simulators based on more sophisticated engineering codes such as but not limited to: RELAP, SCADAP, APROS, MAAP, COBRA or similar. These would probably need to be independent of PC based basic principle simulators and aimed at higher level users.

In addition, the meeting participants discussed the value of developing the severe accident simulators. This is independent of including severe accident codes such as EPRI's Modular Accident Analysis Program (MAAP) or the US NRC's MELCOR code in full scope simulators. While the Technical Meeting participants see the value in engineering codes based simulators, it is not as high priority.

The recommendation of the Technical Meeting is to make a consideration on having (receiving) a well designed severe accident simulator as the addition to the existing collection of the IAEA PC based basic principle simulators.

F. Development of a Nuclear Science and Engineering Enrolment Programmes

A common theme discussed during the meeting was the stagnant or declining enrollment into the nuclear science and engineering education programmes in many Member States. Attracting students to study nuclear engineering, physics and the like may require adapting current training tools to accommodate the learning styles of the next generation nuclear workforce. Simulation has the capability of bridging the gap between traditional classroom training and the interactive, experiential and visual learning styles that are proven to be effective with the millennial generation.

The meeting participants recommended adapting the existing simulators to more visually appealing using 3D technology, virtual reality and serious gaming constructs to appeal to a broader audience of potential workers. Such tools could be further adapted to secondary school students as an introduction to careers in the nuclear industry. It is also recommended that IAEA should acquire simple web based simulators in order to attract secondary school students into the nuclear field.

G. Improvement of the IAEA PC Based Basic Principle Simulators

The meeting concluded that it is apparent that several current IAEA basic simulators still have a room for improvements such as enhancing of interactive capabilities with the students or trainees by addition of sound clips or video clips and inclusion of help functions and data exporting capability in the simulators programs. The meeting participants recommended that:

- The IAEA gather the suggestions to improve its current basic simulators and deliver those ideas to the simulator developers for the next update of the simulator programs;
- The IAEA develops the guidelines for the improvement of the existing versions of simulators.

This activity may call for a workshop and/or another Technical Meeting to engage the simulator developers and the users with the goal to draft the guideline for a general approach to the required improvements of the existing versions of the IAEA simulators.

H. Improving the Accessibility of IAEA Simulators

The meeting participants recommended that the current administrative procedures in requiring the IAEA simulators should be simplified in order to increase interest and provide significantly broader access to the IAEA library of PC based basic principle simulators.

I. PC Based Simulator International Working Group

The meeting participants discussed that the users of PC based simulators and the IAEA may be missing the opportunity to advance the use of simulators due to nonexistent informal international Working Group. An informal Working Group could promote the sharing of best practices, developed training materials and curricula, and recommend needed advances in PC based simulation among the Member States. It was suggested to have a Consultancy Meeting in order to investigate the feasibility/usefulness of setting up an informal international Working Group to achieve the above stated goals.

PAPERS PRESENTED AT THE MEETING

SESSION I

SYSTEMATIC HUMAN CAPACITY BUILDING: *EDUCATION AND TRAINING WITH BASIC PRINCIPLE SIMULATORS INTEGRATED INTO NATIONAL NUCLEAR POWER PROGRAMMES*

SYSTEMATIC EDUCATION AND TRAINING PLAN USING PC BASED SIMULATORS FOR IN HOUSE CAPACITY DEVELOPMENT OF THAI REGULATORS IN PREPARATION FOR NUCLEAR POWER PROGRAMS

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Abstract

This paper describes how the Office of Atoms for Peace (OAP) has planned to established a systematic education and training plan using PC Based simulators for in house capacity development of Thai regulators in preparation for nuclear power programs. The plan is aiming to prepare Thai regulators to effectively handle complicate and demanding tasks by applying various methods such as “train the trainers,” “learning by doing,” “customization,” etc. through the use of PC Based simulators. The plan has been divided into three stages leading to the desire outcomes of producing competent regulators. The plan is currently pending approval. If approved, it will be realized in two to five years.

1. SYNOPOSIS OF PAPER

As a regulatory body, the Office of Atoms for Peace (OAP), Thailand has always sought for ways to ensure the utmost nuclear and radiological safety of the public where one of our top priorities is to enhance nuclear education of our personnel for effective and efficient performance in their respective roles. Currently, Thailand has only one TRIGA Mark III (TRR–1/M1) in operation, but two license applications–one for a new research reactor and one for BNCT facility–are expected in the near future. In the 2015 Power Development Plan, NPPs of 2000 MWe in total capacity are to be added during 2015–2036 to ensure power system reliability. This, in turns, would place higher pressure on the staff and compel OAP to initiate programs to prepare them for such imminent and demanding tasks [1]. With this in mind, PC based Simulators are thought to be great tools in providing systematic education and training for in house capacity development of the regulators in preparation for the NPP programs. The Systematic Education and Training Plan Using PC based simulators will be realized in three stages, as follows:

Stage 1: Acquiring necessary tools and expertise

In this stage, the OAP will tap on resources and international experts to establish a PC based Simulator Center at OAP with necessary software, hardware and expertise to “train the trainers” in using PC based basic principle simulators in teaching and training on various reactor technologies:

a. Systematic learning by doing approach to training and education;
b. Scope of normal, transient and accident simulations with the PC based basic principle simulators: examples, equations, graphical user interfaces;
c. Examples on trainees acquiring practical skills in plant operation under various conditions when trained with the PC based basic principle simulators, and strategies on assessing a person’s

knowledge based skills (this is particularly important in incorporating tests of various operating, transient, and accident conditions as a part of the operator license renewal/approval process)

Stage 2: In house Training

Competent trainers are acquired and in house training programs established. In house experts are capable of developing part task simulators, concept simulators, and special purpose simulators to validate/verify phenomena in question as an option to assist licensing process and technology selection for near-term deployments.

Stage 3: Customized Model

Special purposed models can be developed for concept testing based on basic principles and proven methods to aid assessment of extremely rare circumstances in plant operation of a specific plant of interest.

2. (KEY) RESULTS

The plan is still in an initial stage awaiting approval, but its importance is clearly recognized. If approved, it is expected to be fully realized in two to five years.

3. CONCLUSIONS

The Office of Atoms for Peace (OAP) has deemed that the establishment of systematic education and training plan using PC Based simulators for in house capacity development of Thai regulators is an important endeavour to effectively prepare for the national nuclear power programs. With objectives and stages of the plan clearly defined, the plan will be executed accordingly once it is approved.

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USE OF COMPUTER CODES AND SIMULATORS IN EDUCATION IN LITHUANIA

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Abstract

In 1990, after Lithuania declared its independence, the Ignalina NPP came to jurisdiction of the Republic of Lithuania, however, all technical scientific support organizations remained in the Russian Federation. Therefore the need to develop the independent institutions of nuclear regulatory and technical support was raised. During the 19912009 (till the final close of Ignalina NPP) the necessary infrastructure for nuclear regulation and technical scientific support was created. The Technical and scientific Support Organizations (TSOs), which providing the technical and scientific basis for decisions and activities regarding nuclear and radiation safety, acquired the experience through the different trainings and participation in different international projects. Different computer simulators and codes are playing very significant role in the training process of nuclear energy specialists. The paper discusses about the Lithuanian experience in the use of computer codes and simulators in education.

1. INTRODUCTION

In 1990, after Lithuania declared its independence, Ignalina NPP came to jurisdiction of the Republic of Lithuania. Ignalina nuclear power plant is the only nuclear installation in Lithuania. It consists of two units of RBMK-1500, commissioned in 1983 and 1987. Lithuania inherited Ignalina NPP from the Soviet Union together with the responsibility to ensure safe operation of the plant, but all technical scientific support organizations remained in the Russian Federation. Therefore there was a need to develop the independent institutions of nuclear regulatory and technical support. The State Nuclear Power Safety Inspectorate (VATESI) was established by Government resolution in October 1991. Since 1991 till the closure of Ignalina NPP (the operation of Unit 1 was terminated in 2004 in accordance with the Protocol for Admission of the Republic of Lithuania to the European Union, while the Unit 2 was shut down on 31 December 2009) VATESI has regulated Ignalina NPP operation by issuing annual operating permits. However, the nuclear regulator cannot act alone–the technical and scientific support is one of the important provisions for maintaining nuclear security systems in the country. The technical and scientific support organizations (TSOs), which providing the technical and scientific basis for decisions regarding nuclear and radiation safety, could be as part of the regulatory body or a separate organizations. In Lithuania the creation of TSOs starts together with the establishment of VATESI.

In March 1992 at the Lithuanian Energy Institute in Kaunas the Ignalina Safety Analysis Group (ISAG) was established. The goals of ISAG were to gain a thorough understanding of the basic processes of RBMK-1500 reactors; to gather and analyse design and operational data; to record and rank safety issues at Ignalina; to analyse the consequences of simulated accidents at the plant; and to provide professional technical and scientific consultation to the VATESI, the government and the international community. Later this group overgrows into Laboratory of Nuclear Installation Safety. The other organizations also took income into creation of TSOs–the temporary groups of specialists were created in Kaunas University of Technology (KTU), Vytautas Magnus University, Faculty of Physics of Vilnius University (VU) and the Institute of Physics (IP).

2. EDUCATION OF NUCLEAR ENERGY SPECIALISTS IN LITHUANIA

The nuclear energy specialists in Lithuania are educated in the Vilnius University (VU) and in the Kaunas University of Technology (KTU). KTU is oriented to engineering and VU to education of the physicists. The VU is one of the oldest Universities in eastern and central Europe, established in 1579. The Faculty of Physics of VU is running the study programme “Energy Physics” since 2008. KTU is the largest technological university in the Baltic States. The University shares the best traditions of classical universities, offering almost all fields of technological studies and research. In the KTU, in the Department of Physics there are educated annually 20 BSc and 10 MSc degree nuclear energy specialists in physics (according to the “Applied Physics” programme), and 7 specialists in biophysics (according to the “Medical Physics” programme). This program is designed for the training of professionals in radiation safety. The Department of Thermal and Nuclear Energy until 2015 also educates annually 5–10 BSc and 2–5 MSc degree nuclear energy specialists looking for work in the current nuclear technologies used in Lithuania. There is a close cooperation of the KTU and the Lithuanian Energy Institute (LEI). The scientists from LEI provide the teaching in Faculty of Electrical Engineering and Management, Mechanical and Mechatronics, Basic Sciences in KTU. Students have the possibility to use the LEI experimental facilities, hardware and software. KTU doctoral graduates performed their internships in the Lithuanian Energy Institute. The KTU and LEI has united doctorate in area of technological sciences “Energy and Power Engineering” [1, 2].

The paper deals about the LEI activities in the preparation of nuclear energy specialists. Few specific modules could be mentioned: “Modelling of Processes During the Transients in Nuclear Reactors” and “Safety Analysis at Nuclear Energy” for the MSc degree students and “Simulation of Accidental Thermal–hydraulic Processes” for the PhD students. The main goals of the modules for MSc degree students are: to master knowledges of principles of deterministic safety analysis and modelling, to indoctrinate the necessary skills for assessment of basic nuclear energy systems parameters and selection of specialized computer codes, to provide the main concepts on safety and risk, safety requirements in nuclear energy. The main aim of Module for PhD students [3] is: to gain knowledge about the principles of the deterministic safety analysis of accidents in Nuclear Power Plants, modelling of the single and two–phase flow and the design and beyond design basis accident analysis in the nuclear energy. The expected outcome of this Module is the background knowledge and understanding of the students on:

- Transient and accidental processes in NPPs, main principles of deterministic safety assessment;
- Modelling of processes in-reactor core; heat transfer mechanisms in-reactor systems;
- Two-phase flow dynamics and heat transfer; limits on safe power removal from reactor cores;
- Computational methods for simulation of reactor design basis and accidental processes (thermal hydraulic).

3. USE OF COMPUTER CODES AND SIMULATORS IN EDUCATION

The computer codes and simulators always were used in education process. In the beginning, when both Ignalina NPP reactors were in the operation, the RELAP5 model for the Ignalina NPP and Plant Analyser were created in close cooperation of LEI with Brookhaven National Laboratory and Science Application International Corporation from the USA. The Plant Analyser presents the scheme of RBMK-1500 reactor cooling circuit with the main equipment (fuel channels, main circulation pumps, steam-separators, headers, pipelines). The developed, by employing system thermal hydraulic code RELAP5, Plant Analyser allowed to model different transients (stop of pumps, turbine trip) and LOCA (break of pressure header, group distribution header and downcomer) cases. As can be seen from Fig. 1, in the analyser circuit, visible on a computer screen, three main colours are dominating: dark–symbolizes water, more light–saturated steam, and white–the superheated steam. All these colours during the transition process gradually moving entire range of shades. Digital information, which is presented in Figure 1, provides information not only about the numbering of the various components, but also provides the user with information according the coolant flow in different channels, shows the time from the beginning of the accident.

Currently, for the teaching of students the system thermal hydraulic code RELAP5 [4] is used. The few different models are presented for the students–starting from the very simple few elements model for the analysis of water flow and flashing and for the investigation of boiling crisis phenomena in ABWR fuel assembly (see Fig. 2). During the working classes the students are analysing the presented models, making changes, running the calculations and analysing the calculation results.

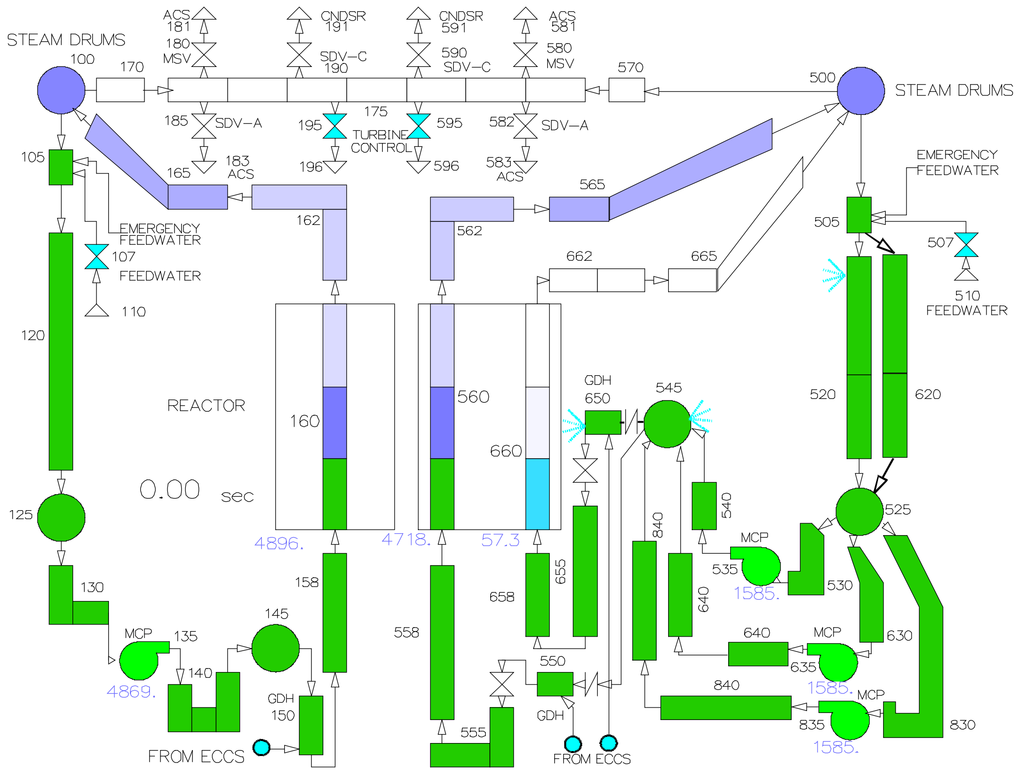
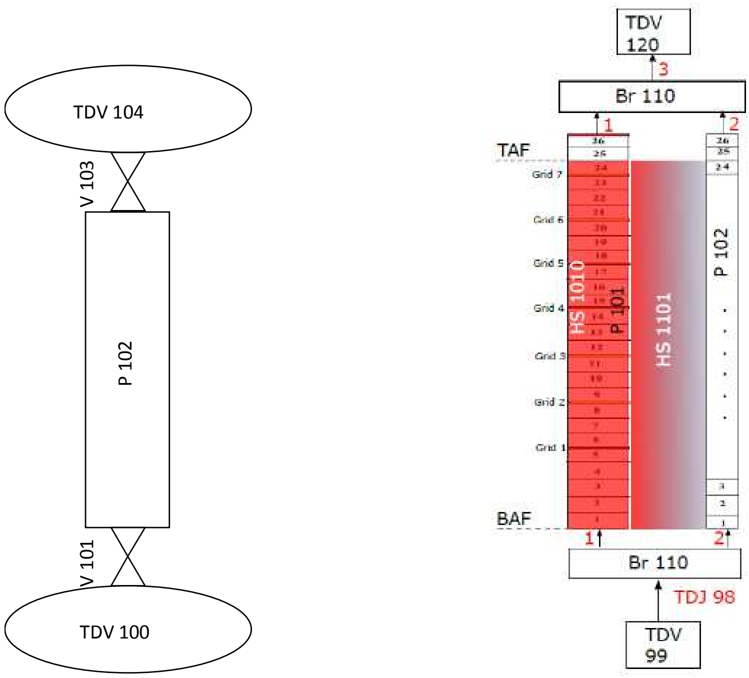


FIG. 1. Ignalina NPP plant analyser for the analysis of thermal hydraulic processes in RBMK–1500 reactor cooling circuit in the programme window.



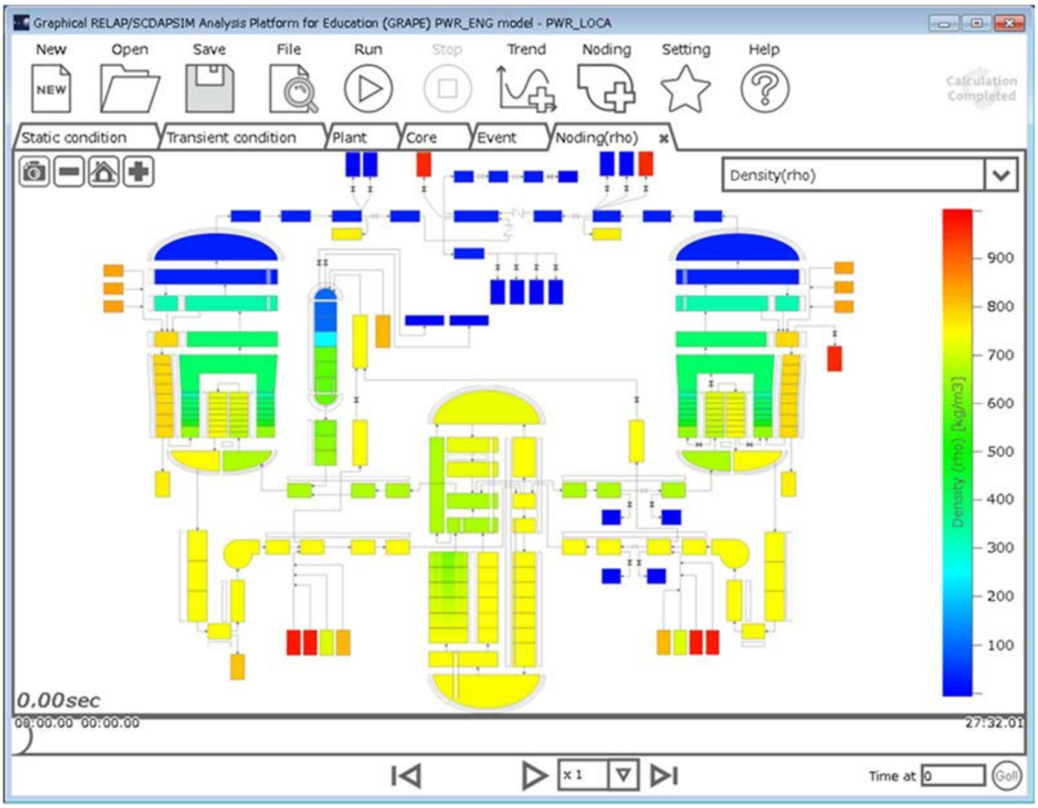
Simple three components model

(a)

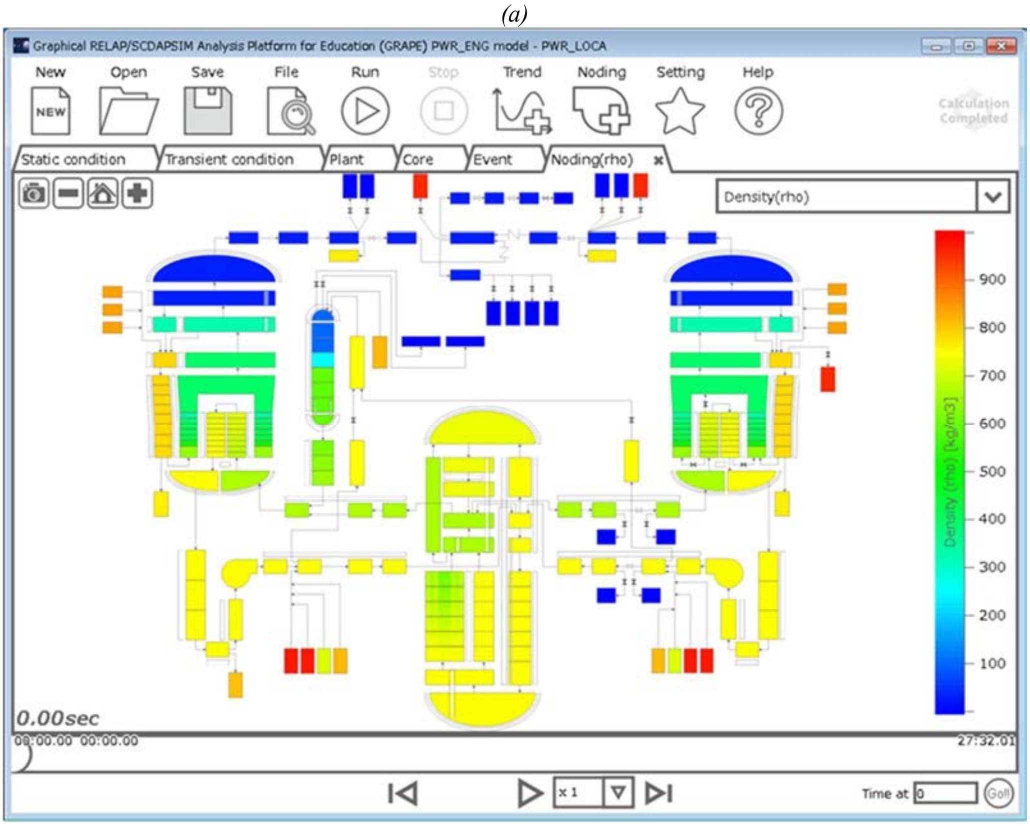
ABWR fuel assembly

(b)

FIG. 2. RELAP5 nodalization schemes: (a) Simple three components model, (b) ABWR fuel assembly.



(a)



(b)

FIG. 3. GRAPE simulators in the programme window for (a) PWR and (b) BWR.

For the more complicated cases the IAEA PC based basic principle simulators, especially the Boiling Water Reactor Simulator with Passive Safety Systems are used. This simulator combines reactor core with the model of control rods, reactor cooling loop, fedwater and steam extraction with turbine generators and turbine bypass, model of confinement and coolant cleanup–shutdown cooling systems. The IAEA Simulator allows demonstrating response of ABWR plant during the operational transients and LOCAs. As an example, the IAEA Simulators were successfully used during the European Technical Safety Organization Network Junior Staff Programme summer workshop in Lithuania (LEI) in 2013. During this summer workshop the two groups of participants analysed two cases of LOCA in ABWR:

- Steam line break inside drywell. This malfunction causes a main steam line break (before the main steam isolation valve) inside the containment drywell.
- Feedwater line break inside drywell. This malfunction causes a feedwater line break inside the containment drywell. The feedwater break flow into the drywell will increase rapidly, resulting in pressurization of the drywell.

For the educational purposes there is also possibility to use the GRAPE platform [5]. The GRAPE is Graphical RELAP5 based Analysis platform for Education & Engineering, created by Nuclear Engineering Ltd. The GRAPE simulator (see Fig. 3) uses the plant models developed with RELAP/SCDAPSIM code.

4. CONCLUSIONS

The Plant Simulators, with easy to understand interactive operations for specifying analysis conditions and rich visualization capabilities, makes the process of education easier. It allows not only to understand basic principles on nuclear power plant behaviours, but also to strengthen the knowledges on specific phenomena and how to perform modelling using computer codes.

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PRACTICE AND CONSIDERATION OF TRAINING CAPABILITY WITH SIMULATORS AFTER 30 YEARS OF NUCLEAR SIMULATOR DEVELOPMENT EXPERIENCE IN CHINA

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Abstract

With the rapid growth of nuclear power plants in China, the simulator has been used as one of the tool for personnel training to meet the requirement of sufficient supply of nuclear power employees. Current simulators oriented to different audience for corresponding training purpose in China has been described in the paper. The directions of improvement for simulators are addressed as well.

1. STATUS OF NUCLEAR POWER IN CHINA

Over the past three decades, China has made great progress in its nuclear power construction. At the end of 2016, China had 35 business units with a total installed capacity of 33.28 million kW, and 21 units under construction with a total installed capacity of 24.25 million kW. In the next five years following 2016, 6–8 newly constructed nuclear power units will be added per year, reaching a total installed capacity of 58 million kW by 2020.

2. NEEDS OF SIMULATOR FOR PERSONNEL TRAINING

To meet the demands of the fast-growing nuclear power industry, China has implemented a complete training system series in accordance with IAEA practices to ensure a sufficient supply of nuclear power employees. Regarding training methods and means, China mainly adopts classroom training, simulator based training, on–the–job training, laboratory, mock-up & workshop training, computer based training and so on. Simulator based training has the following advantages: visualization (the simulator can provide trainees with an environment which is similar to the real one), effectiveness (the trainees will learn efficiently and effectively), flexibility (the instructors/trainees can freely select training contents and time) and economy (the simulator can be used repeatedly for a long time, eliminating the higher costs and complex organization of classroom training). As such, it has become a good choice for pre job and follow up training for employees in the nuclear power industry. At present, China has carried out mandatory control for some simulator based training and examinations to ensure that the operators (including main control room operators, on site operators, maintenance personnel) gain the necessary skills and a deep understanding of the work content and workflow before they start work, so as to ensure the safe operation of nuclear power plants. For example, the national standard of “Nuclear Power Plant Simulators for Use in Operator Training and Examination” [1][2] provides that operators in the main control room must attend a given period of simulator operation training and pass the simulator operation exam before they can go on duty.

3. CURRENT SIMULATOR SYSTEM FOR TRAINING PURPOSE

At present, the simulator system, audience and training objectives of the training of nuclear-related personnel in China mainly include the following aspects:

- PC based principle simulator. This type of simulator briefly simulates the basic principles of a nuclear power plant for those relatively lacking in nuclear power knowledge. Its goal is to give users a conceptual understanding of the structure, main systems and operating principles of nuclear power plants. In China, nuclear power principle simulators are mainly used in the teaching of non-nuclear major institutions, as well as to inform the public at the nuclear science exhibition hall.
- PC based desktop multi-functional simulator. This type of simulator comprehensively simulates the main systems of a nuclear power plant, and can carry out basic operations under normal conditions or accident conditions. It is aimed at personnel with nuclear knowledge and a certain understanding of nuclear power plants. The training goal is to equip the users with a certain degree of familiarity and mastery of the operation of a nuclear power plant. Multi-functional simulators are mainly used in the training of nuclear related functional departments, nuclear power plant operators (for pre–training) and nuclear majors of colleges and universities.
- Full scope simulator. This type of simulator completely replicates the equipment in the control room of a nuclear power unit, comprehensively simulates the various systems and various working conditions of a nuclear power unit, and can basically achieve the same operation effect as the main control room in a real nuclear power plant. It is mainly used for pre–job training, license examination and on–the–job training for the main control room operators in nuclear power plants. In China, an average of two same-type nuclear power units is equipped with one corresponding full scope simulator.
- Severe accident simulator. After the Fukushima nuclear accident in 2011, the people resumed their focus on the development of severe accident and nuclear emergency response. To meet this need, China developed the severe accident simulator. On the basis of a multi–functional simulator or full scope simulator, this type of simulator extends its accident conditions simulation to the severe accident level. It is mainly used by nuclear power related departments and main control room operators to understand the evolution of severe accident and the familiarity of severe accident procedures. The severe accident simulator is currently used to train nuclear power plant employees in China.

In addition to the above mentioned simulators used for operation training in nuclear power plants, other simulator derivatives have also been developed for personnel training in such areas as equipment maintenance, fuel services and human error prevention. For example:

- Refuelling simulator. This type of simulator adopts a combination of instrument control simulation and virtual reality technology. It presents a refuelling process simulation training series with the physical control panel as the input and the virtual interface as the output. The refuelling simulator can be used for pre-job training and follow-up training for refuelling personnel in a nuclear power plant or operation & maintenance service company.
- Maintenance simulator. This type of simulator abandons the traditional training model with mock-ups. By applying computer simulation technology, it creates a virtual maintenance scene and achieves such interactive actions as equipment disassembly, assembly, maintenance, etc. so as to familiarize maintenance personnel with the workflow.
- Human error prevention simulator. This type of simulator consists of the instructor station, hardware panel, software panel and other parts. It stores on site operation procedures. By interacting with trainees, it simulates the operation procedures of on–site operators in accordance with the procedures. During training, the program will interfere with the trainer and set traps. Through this training, trainees can reduce the occurrence of unexpected consequences caused by human limitations so as to minimize the chance of making mistakes.

4. DIRECTIONS FOR IMPROVEMENT

After years of the development and application of simulators, China has established a relatively complete simulator based training system with a variety of training techniques. We have developed different types of products for the needs of various types of users to serve different training purposes. In order to further optimize the training effect, we are constantly trying to update and improve the simulators.

First, regarding the built in software (for example core neutron physics and thermal hydraulics software) of simulators, along with the increase in the performance of computer hardware, we considered replacing the simplified software that satisfies basic simulation training requirements with engineering analysis–level software. In so doing, the transient changes of the main simulation parameters under accident conditions are closer to the behaviour of the real unit, thereby achieving high fidelity and making the training more effective. This improvement is particularly important for the training of main control room operators in nuclear power plants.

At the same time, 3D virtual reality technology will be applied to training and integrated deeply with simulator technology. Such virtual reality technology as VR glasses, data gloves, joysticks, etc. allows trainees to interact with virtual devices in a three-dimensional virtual environment, and achieve almost the same training effect as in the real working environment, which is also called ‘immersive training’. This training method can greatly improve the training effect in on-site operators and maintenance and inspection personnel.

5. THE COMPREHENSIVE TRAINING SYSTEM OF THE NUCLEAR POWER PLANT

China's nuclear power plants are currently implementing separate training models for main control room operators and onsite personnel respectively. These two types of training models are not linked and do not interact with each other, so three way communication measures (such as human error prevention) are not included in the main control room training and onsite training. In order to solve this problem, the comprehensive training system of the nuclear power plant is now in the development phase. We have combined the full scope simulator with virtual reality technology to develop a comprehensive training system, which will realize both the joint training of main control room operators and onsite personnel, and independent training for onsite personnel, thereby expanding the training scope from main control room operation to whole plant operation. We can realize onsite training through the three dimensional reconstruction of the nuclear power environment, and achieve the combination of the actions of onsite personnel with the virtual environment through somatosensory capture technology. At the same time, through the data interaction of the virtual simulation training system and full scope simulator training system, we can achieve the linkage and interaction of the main control room and the site, so as to provide real training experience for nuclear power operators. By applying this system, we can improve the efficiency and accuracy of onsite personnel, and effectively identify the insufficient performance of operators in power plants, enabling the performance and capability of corresponding personnel to be improved through targeted training and special training.

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USE OF COMPUTATIONAL SIMULATORS WITHIN THE TRAINING PROGRAM FOR EXAMINERS OF THE LICENSING PROCESS FOR REACTOR OPERATORS AND SENIOR REACTOR OPERATORS OF NUCLEAR FACILITIES

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Abstract

Due to the current need of the National Commission on Nuclear Safety and Safeguards (CNSNS) to train new examiner personnel which is involved in the Licensing Process for Reactor Operators and Senior Reactor Operators of Nuclear Facilities, the Systematic Approach to Training (SAT) was applied, as the result obtained of the Competence Needs Assessment, that are necessary design and implement a Training Program. This Training Program includes the use of computer simulators as a basic aspect for the integration of knowledge. The Mexican Regulatory Authority considers the use of computer based simulators is an essential tool for the regulatory authority staff to obtain the basic knowledge to understand basic principles of nuclear reactors and improve the preparing of written and operational examinations for personnel applying for a reactor operator license.

1. SYNOPSIS

The Licensing Process for Reactor Operators and Senior Reactor Operators of Nuclear Facilities is intended to prepare, apply and graduate the written and operational examinations, in order to evaluate the knowledge, skills and abilities of the Reactor Operators and Senior Reactor Operators, required to ensure that they possess the competencies that enable the safe operation of nuclear facilities, thereby maintaining the safety of their personnel and the general public, during normal, abnormal and emergency conditions of nuclear installations.

The licensing process covers research reactors and nuclear power plants (NPP) in which the examiner staff prepares written and operational examinations in order to evaluate the fundamental knowledge that a Reactor Operator or a Senior Reactor Operator must cover.

The Mexican National Nuclear Standard NOM–034–NUCL–2009 [1] defines the education background, experience and training required for Reactor Operators and Senior Reactor Operators. The Reactor Operators and Senior Reactor Operators shall possess a Reactor Operator or Senior Reactor Operators license granted by the Mexican regulatory authority (CNSNS). In order to comply with such requirement, the CNSNS needs a set of examiners with the training, experience and skills necessaries to evaluate Reactor Operator and Senior Reactor Operators for obtaining a license.

Currently the licensee has a deficit of licensed personnel (Rector Operators and Senior Reactor Operators) because staff retirements, which requires new licensed personnel as well as examiners staff from the regulatory body responsible for the Licensing Process. Therefore, CNSNS requires increasing the number of examiners to meet the demand for the increase of new license requests to reactor operators.

2. RESULTS

According to the 10CFR 55.41 [2], 10CFR 55.43 [3] and 10CFR 55.45 [4], the written and operational examinations for Reactor Operators and Senior Reactor Operators licenses contain a representative selection of questions on the knowledge, skills and abilities needed to perform licensed operator duties. The knowledge, skills, and abilities will be identified, in part, from learning objectives derived from a systematic analysis of licensed operator duties performed by each facility licensee and contained in its training program and described in the Final Safety Analysis Report, system description manuals and operating procedures, facility license and license amendments, Licensee Event Reports and other materials requested from the facility licensee by the Commission. [5]

The objective of the "Training program for examiners of the licensing process for reactor operators and senior reactor operators of nuclear facilities" is to train examiner personnel of CNSNS to get the sufficient skills, knowledge and experience in order to prepare, implement and evaluate, written and operational examinations for personnel applying for Reactor Operator and Senior Reactor Operator licenses.

As part of the outline of the training program for the staff of the CNSNS, the following publications are used:

1) IAEA Safety Reports Series No. 79 "Managing Regulatory Body Competence" [6];
2) IAEA–TECDOC-1757 "Methodology for the systematic assessment of the regulatory competence needs (SARCoN) for regulatory bodies of nuclear installations" [7]

Safety Reports Series No. 79 describes a competence model which is based on a quadrant structure. Each quadrant comprises a set of quadrant competence areas, as illustrated in Table 1 and each of these quadrant competence areas comprises a set of specific competences referred to as knowledge, skills and attitudes (KSAs). The quadrant model described is generally applicable to all regulatory bodies. However, the specific KSAs associated with the quadrant competence areas need to be tailored to the individual characteristics of each regulatory body and the types of facilities under its regulatory supervision. This means each regulatory body needs to establish its own set of competences, assessment criteria (levels of competence) and standards for evaluation. [6]

TABLE 1. QUADRANT MODEL OF COMPETENCES FOR REGULATORY BODIES [6]

1. Competences related to the legal, regulatory and organizational basis 1.1 Legal basis 1.2 Regulatory policies and approaches 1.3 Regulations and regulatory guides 1.4 Management system	**2. Technical disciplines competences** 2.1 Basic science and technology 2.2 Applied science and technology 2.3 Specialized science and technology
3. Competences related to regulatory body's practices 3.1 Review and assessment 3.2 Authorization 3.3 Inspection 3.4 Enforcment 3.5 Development of regulations and guides	4. **Personal and behavioural competences** 4.1 Analytical thinking and problem solving 4.2 Personal effectiveness and self management 4.3 Communication 4.4 Team work 4.5 Managerial and leadership competences 4.6 Safety culture

As result of the Competence Needs Assessment for the examiner staff, the following technical disciplines competences were detected:

— Nuclear reactors technology (intermediate);
— Nuclear reactors technology (advanced);
— Transients analysis;
— Core damage mitigation;
— Severe accidents;
— Nuclear reactor simulators.

Training on nuclear simulators consists of two different phases:

1) Training on computer based simulators;
2) Training on full scope simulator.

Therefore, the training program includes training through computer based simulators as a basic aspect for the integration of knowledge for the training of the staff from the regulatory body and training on full scope simulator. The use of computational simulators within the training program for examiners of the licensing process to reactor operators and senior reactor operators of nuclear facilities includes a training based on the computers codes used on the technological areas; the Mexican regulatory body has the license of the computational simulator MELCOR [8].

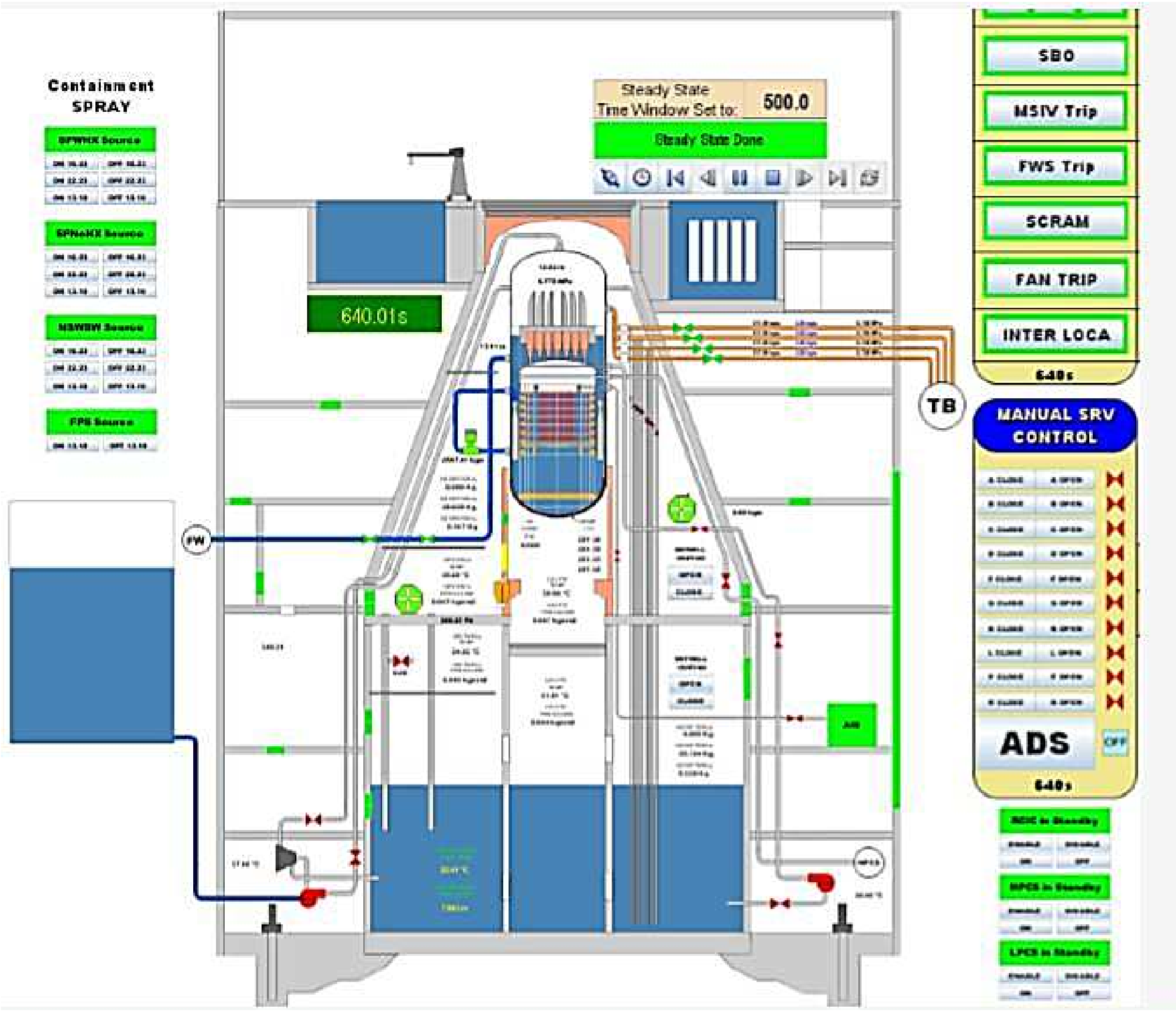

FIG. 1. MELCOR model for a boiling water reactor (BWR).

MELCOR is a fully-integrated, engineering-level computer code that models the progression of severe accidents in nuclear power plants, being developed at Sandia National Laboratories for the U.S. Nuclear Regulatory Commission (USNRC) and several groups within the U.S. Department of Energy (USDOE). The entire spectrum of severe accident phenomena, including reactor coolant system and containment thermal/ hydraulic response, core heat–up, degradation and relocation and fission product release and transport, is treated in MELCOR in a unified framework for a variety of reactors. [8]. Figure 1 shows an example of MELCOR model for a Boiling Water Reactor.

Mexico has a NPP called Laguna Verde, with two BWR´s designed and manufactured by General Electric (GE). These BWR are modelled with MELCOR and the principal features are:

- 10 uncollapsed Safety and Relief Valves;
- Two (2) recirculation loops;
- Seven (7) control volumes for the reactor vessel arrangement;
- Two (2) control volumes for the core (one for fuel channels and one for bypass element);
- Radionuclides package used to evaluate releases;
- Core modelled defining by four (4) radial rings and 13 axial nodes with 6 as active fuel zone;
- Hardened venting implemented system;
- Emergency core cooling systems modelled: high pressure core spray system, low pressure core spray system, reactor core isolation cooling system;
- Symbolic nuclear analysis package used to implement a graphical interface and dynamical control for interactive simulation. [8]

MELCOR will be used for training during the initial and fundamental training, focusing mainly on the technical concepts development of the model in the simulator. Examiners will be trained using basic principles simulator prior to train on full scope. The training course of computer simulator consists of 1 week with 8 hours of fundamental concepts and 32 hours of simulations. All scenarios must be planned and documented, for example:

- Turbine trip;
- Station black out (SBO);
- Loss of coolant accident (LOCA, SMALL, MEDIUM, LARGE);
- Closing of the main steam valves (MSIV's);
- Inadverted opening of safety relief valves (SRV´s);
- Trip of recirculation (RRC) pumps (1 or 2).

Specific pre–requisites for operator's examiners undertaking simulator training:

- Have a good basic science fundamental;
- Have a good knowledge of nuclear facility;
- Have a good knowledge of technical specifications.

3. CONCLUSIONS

The use of computer based simulator within the training program for examiners of the licensing process for reactor operators and senior reactor operators of nuclear facilities will be used as part of operational control technique learning to the basic understanding of reactor operating principals, improve mental representation of physical phenomena's and get an understanding of the specific system functions.

During the training course the examiners should identify important plant parameters to be monitored during each simulator scenario. The instructor should ask the examiners to record selected parameters. Parameter readings should be collected at meaningful intervals, depending on the parameter, the nature of the event, and the capability of the simulation. Malfunctions may be planned for a predetermined time or power level.

In addition to the MELCOR code, the training program for examiners of reactor operators and senior reactor operators intends to include other computational simulators as the International Atomic Energy Agency (IAEA) simulators, which would be used only for teaching in nuclear reactor technology, complying at all times with the corresponding conditions of its use.

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ACADEMIC AND INDUSTRIAL USES OF PC BASED NUCLEAR POWER PLANT SIMULATORS

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Abstract

This paper will explore various use cases of pc based simulators being used by academic institutions and power utilities for education, research and workforce development. The paper will describe the technical scope of two different simulation platforms and the resulting ability to use those platforms for education and research. These two platforms are the Generic Full Scope Pressurized Water Reactor Simulator (GPWR) and the Basic Principles Advanced Gas Reactor Simulator.

1. SYNOPSIS OF PAPER

The Generic full scope Pressurized Water Reactor simulator model was previously used by a utility for control room operator training and includes modelling of all plant system and plant logic and control, plant procedures, plant data, training scenarios etc. The "plant" is manipulated through soft panel representations of the control room instrumentation and controls, typically via touchscreens on a virtual panel.

EDF-Energy's Nuclear Skills Academy has converted its hard panel Basic Principles Simulator (BPS) to a PC based platform. The Basic Principles Advanced Gas Reactor Simulator provides an overview of the major systems and control philosophy with a graphical interface based upon system diagrams vs control room instrumentation.

Users of the GPWR that provided input on use, benefits and future plans were North Carolina State University, Texas A&M University, Virginia Polytechnic Institute and State University, Chattanooga State University and Augusta Technical College.

2. KEY RESULTS

North Carolina State University is using the GPWR with undergraduate students for introductory and fundamentals of operations. Texas A&M is mainly focused on undergraduate work promoting the senior level students understanding of plant system dynamic fundamentals and performance. Students manipulate the plant systems using the simulated plant logic and control systems to gain a better understanding of plant behavior. Operating procedures are used as case studies. [1]

Chattanooga State University uses the GPWR in fundamentals training particularly in-reactor theory classes where they demonstrate reactivity changes, reactivity coefficients and establish criticality. It is also used during electrical training by having students practice what they have learned in class by synchronizing the main generator to the grid. Finally, the simulator is used when discussing turbine controls in class and use the simulator to reinforce those discussions. [2]

Augusta Technical College currently uses the simulator in its course on Introduction to Nuclear Facilities. The GPWR shows the basic PWR components and typical flow including typical values for various parameters. For students typically faced with viewing the plant through time dependent parameter plots, the combination of such information with control room instrumentation provides an accelerated learning curve. [3]

Many of the schools plan to develop lab exercises using the GPWR in their reactors systems course. Labs will include basic operations such as power maneuvering and control rods, as well as selected transient and accident simulations. This will help students understand the reactor design in term of safety related aspects. [1] [2], [4], [6]

Several schools expect to expand the use of the simulator beyond introductory courses to more advanced courses, such as (1) a course for prospective operators dealing with response to alarms, abnormal operating procedures, and operating procedures (2) reactor plant components coursework showing how parameters change as individual components are manipulated, i.e., running various pump combinations, pressures and temperature variation as flows through heat exchangers are changed, electrical output as load is picked up, etc. [4], [5]

Others plan to expand the simulator use beyond the Nuclear Engineering program to Electrical Engineering, Mechanical Engineering Technology and Instrumentation and Control Technology curricula which will also benefit from certain aspects of the simulator. Finally, several universities plan to use the GPWR for Cyber security investigation and research. [3]

EDF's Basic Principles Advance Gas Reactor Simulator (BPS) helps bridge the gap between Generic Classroom training and starting their site based simulator training for control room operators. Topics include Conduct of Operations (standards & expectations) Control Room Management/teamwork and Technical Specification training (Operating rules). BPS training is used to install and develop the practical aspects of the behaviors and cultures desired of the operators in the Central Control Room (CCR) as well as to reinforce the fundamental reactor theory and plant system classroom sessions they have covered e.g. start-ups and mode changes.

The value of the BPS at this stage, before the trainee moves onto the full scope site simulator, is the ability to start to build upon the coping strategies employed by the CCR operator when presented with ever increasing amounts of information (sort out the wheat from the chaff and prioritize by firstly understanding reactor fundamental operation cause and effect). By the time they have finished on the BPS they are better equipped to recognize and cope with symptom based scenarios and employ this on the site simulators where a lot of initial training is scenario oriented.

The BPS is also used for training the Human Factors team and there are short simulator appreciation sessions built into the system engineers' courses and Operate technician sessions, and future plans are to build a more realistic generic turbine model to replace the simplistic existing model. [7]

3. CONCLUSIONS

From a vendor's perspective we see the need for industry to accelerate the learning curve for non-operational personnel entering the workforce. This includes engineers, etc. The fact that entire plant simulators can run on PCs expands the potential use of these "digital twins" beyond operator training and exposes the technology to a much broader audience.

However, the scope of simulation must match the anticipated needs. Often a full plant simulator may be too cumbersome in an academic environment. In those cases, industry needs to develop a different user interface environment that simplifies some of the plant operations steps while still providing a comprehensive plant response for better understanding of secondary and tertiary effects of plant design and operational issues.

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PC BASED REACTOR SIMULATOR LAB FOR EDUCATION AND TRAINING PURPOSES AT MALAYSIAN NUCLEAR AGENCY

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Abstract

Malaysian Nuclear Agency has established a Nuclear Reactor Simulator Lab in 2016 for education and training purposes. Two labs were established, one with PC based Reactor Simulator and the other was Part Task Simulator based on TRIGA Reactor console. A PC based reactor simulator consists of two operator console and one supervisor console with large display panel using PCTRAN AP1000, TRIGA and IAEA NPP simulator software. Those simulators can provide basic understanding in the operational of NPP, control systems, safety systems and simulate the transients and accidents behavior of the common nuclear power plant. While a Part Task Simulator was reassembled from the previous PUSPATI TRIGA Reactor console. In 2014, the existing reactor console was completely disassociated and replaced by new digital control system (REDICS) with a technology transfer from South Korea. The existing reactor console was reassembled again and merely replicated the new digital console for education and training purposes. The main purpose of this simulator is operator training and a dynamic test to validate the control logics in-reactor regulating system (RRS). In 2012, Malaysian Nuclear Agency has started its Education and Training to support human capacity and capability development in Nuclear Power Programme in the country. Several activities have been organized, including, Education and Training to Support Nuclear Power Program for APEC Economies, Nuclear School Experiments on Reactor Physics and Neutron Application for Asia-Pasific Region, Lab Experiment for local universities and more others. The Nuclear Reactor Simulator Lab for Education and Training was ready and is planned to include in the next training to cater for the educational programme in the country.

1. SYNOPSIS OF PAPER

The Nuclear Reactor Simulator Lab at Malaysian Nuclear Agency was a spin-off from the Reactor TRIGA PUSPATI (RTP) upgrading project. The reactor has been utilized for more than 30 years. Several structure, system and components are found archaic due to ageing and therefore, there is an urgent need to upgrade several of the structure, system and components to ensure a reliable and further workable safety system for the expansion life of the reactor. The RTP started its upgrading project in 2008 and up till now, several major systems has been upgraded including the ventilation, primary and secondary cooling, purification, several irradiation facilities and the latest was reactor console. The console upgrading project was started in 2012 with the aim to migrate from analogue to digital control of the reactor. The project also aims to build capacity and capability in the instrumentation and control through a technology transfer programme [1]. The project was awarded to Korea Atomic Energy Research Institute (KAERI) by international tendered over the direct negotiation. The vendor of this project was carefully selected based on certain criteria with high reputable achievement. At the very beginning of the project, several personnel were sent to Korea to work together with KAERI in designing, testing, fabricating the parts and components of the console as stipulated in the technology transfer program. Upon the completion of the project, the existing console was dissociated and relocated at the Nuclear Reactor Simulator Lab and reassembled again merely replicated the new digital as a Part Task Simulator console for education and training purposes.

The Nuclear Reactor Simulator laboratory (Figure 1) was deliberately able to cater for education and training purposes using both PC based and Part Task Simulator. In 2014, Malaysian Nuclear Agency has received a set of PC based Reactor Simulator from IAEA. Taking this opportunity, a programme was developed to actively used those simulators for educational to the university's student and also for staff trainings purposes to familiarize with various technology of nuclear reactors. Those simulators can provide basic understanding in the operational of NPP, control systems, safety systems and simulate the transients and accidents behaviour of the common nuclear power plant. Two sets of personal computer for operator and one set for supervisor console were provided for the PC based simulator. This console is connected to a large display panel for easy viewing. The students or trainers who enrolled to the Reactor Engineering Course will have an opportunity to participate in the PC based simulator exercises. Several simulators are available for the training such as TRIGA Pool Reactor Simulator, PCTRAN Simulator of a PWR with Active Safety Systems, Advanced PWR, Loop Large PWR, Conventional BWR, Advanced BWR, WWER1000, CANDU and ACR700. A PC based Nuclear Simulator teaching module was developed with the aim to give an overview of plant process control behaviour and basic understanding of the operation of nuclear reactor especially TRIGA and NPP dynamics and transients. In the exercises, they also able to operate essentially in close to real time, and have a dynamic response with high fidelity to provide plant responses during normal operations and accident situations. The simulator software has a user-friendly interface that allows direct interactions with the simulator during plant operation.

FIG. 1. PC based simulator lab.

Another type of simulator that available for education and training purposes is a Part Task simulator of our own TRIGA reactor (Figure 2). The main purpose of this simulator is for the operator training programme to certify a licensed Reactor Operator. Apart from that, this simulator also is used as a dynamic test bed (DTB) to test and validate the control logics in-reactor regulating system (RRS) of RTP. The simulator configuration is divided into hardware and software. The simulator hardware consists of a host computer, operator station, a network switch, control rod drive mechanism and a large display panel. The RTP hardwired panel was replicated closely to the RTP control system. A mathematical model of reactor kinetics and thermal hydraulics that implements plant dynamics in real time was developed using LabVIEW. An instructor station module worked as a host computer that manages user instructions through a human–machine interface module as is being used in RTP. In this simulator, a dynamic test bed and the modelling software used the actual RRS cabinet which consists of Programmable Logic Controller (PLC) S7–1500. The PLC was connected using a hardwired and network-based interface. The RRS cabinet generates control signals of the reactor power control based on the various feedback signals from DTB such as neutron detector signal and control rod positions. The DTB runs plant dynamics based on the RRS control signals. For this purpose, the Hardware–In–the–Loop Simulation between RRS and the emulated plant (DTB) has been developed and tested using this configuration. A normal and abnormal case test has been emulated in this project to ensure the simulation works well. The functions and a control performance of the developed RTP dynamic test bed simulator have been tested and it showed reasonable and acceptable results. However, a validation and verification of this simulator with RTP operational data are still needed to ensure the developed Part Task Simulator is properly working in confidence with high reliability and availability.

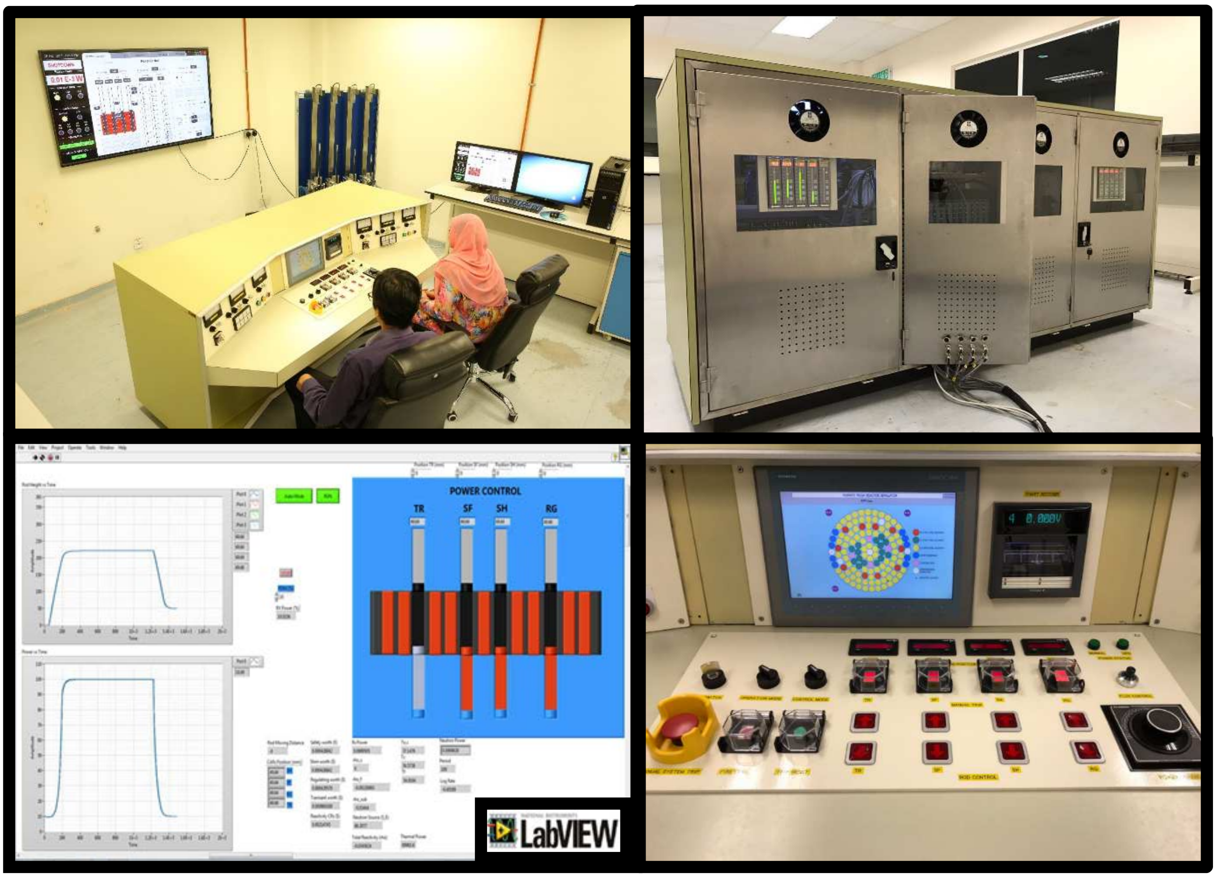

FIG. 2. Part task simulator lab.

2. (KEY) RESULTS

Throughout the years, Malaysian Nuclear Agency has conducted several trainings that are using the TRIGA research reactor. Figure 3 shows the number of students trained using RTP from 2010 to 2017 [2]. The bachelor degree students are the frequent user of the RTP, especially for their final year project and also a part of the universities requirement to graduate.

A PC based simulator has started to introduce in the training syllabus early this year. Two groups of Nuclear Engineering students had a chance to learn using PC based simulator and Part Task Simulator in the training. A set of experiments conducted using the simulator were startup checklist, power ascension performance in NORMAL operation mode, full power operation, power declension, MANUAL Trip and Reactor

SHUTDOWN. At the end of experiments the students should be able to understand the dynamic behaviour of nuclear reactor TRIGA PUSPATI and reactor control. They also are able to understand the plant operation of reactor TRIGA PUSPATI through learning by doing (Figure 4).

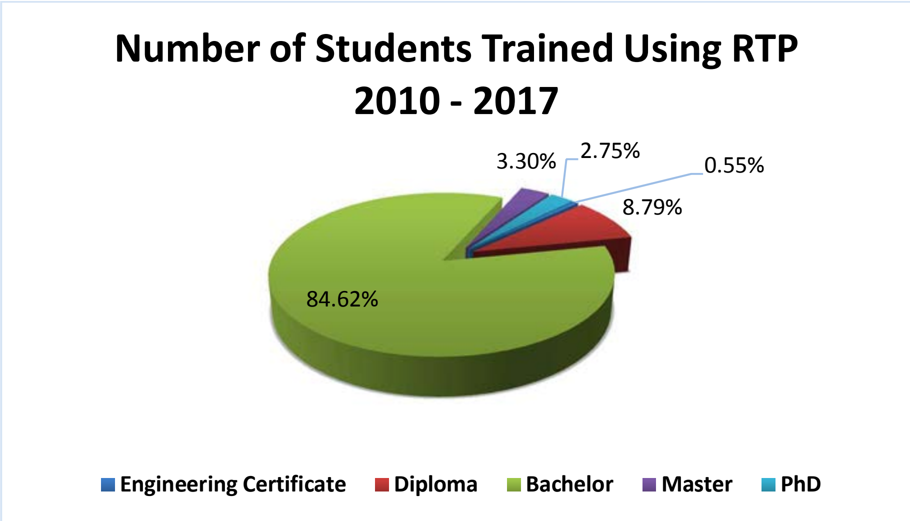

FIG. 3. Number of students trained using RTP 2010–2017.

FIG. 4. Experiments using part task simulator of RTP.

3. CONCLUSIONS

Education and training using the nuclear simulator either PC based or Part Task Simulator is very useful for the capacity and capability building of human resources to support the nuclear power programme in the country. The simulators are found very useful to assist the students and trainees to understand basic operation of various types of nuclear reactor, including the research reactor. The establishment of the Nuclear Reactor Simulator laboratory in Malaysia will open an opportunity to the university students to learn about nuclear reactor technology and also perform research and development in this area. The development of competent and qualified personnel in national nuclear technology and applications is ongoing and shall be continuous. A comprehensive and integrated planning and implementation to develop national human resource ready for national nuclear power programme shall involve all relevant stakeholders within the Nuclear HRD network in Malaysia.

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SIMPLIFIED IN CORE FUEL MANAGEMENT SOFTWARE FOR EDUCATION AND TRAINING

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Abstract

In this study, simplified in-core-fuel management software consisting of six computer programs was developed to model in-core-fuel management. These programs are based on one and two dimensional core loading pattern neutronic solvers and genetic algorithm optimization software. Neutronic parameters of Almaraz II Nuclear Power Plant data are utilized to perform power and burnup dependent full core neutronic calculations.

1. INTRODUCTION

The main goal of in-core-fuel management activities is to meet the design objectives. Safety is major concern during the operation of a nuclear power plant, and requires the knowledge of power distribution and depletion characteristics of the fuel assemblies from the beginning of cycle (BOC) through the end of cycle (EOC). Other unknowns, such as amount and enrichment of the fresh fuel assemblies, fraction of the depleted assemblies to be removed, burnable poison (BP) requirements and core loading pattern map, must be determined.

In order to study burnup dependent features of core neutronic analysis, one and two dimensional core neutronic solvers are used based on the analytical nodal method for 1D slab geometry and simplified nodal method for 2D core model. In this study, the nodal methods are employed to determine core neutronic properties during the operation of reactor from BOC to EOC.

With the emergence of artificial intelligence tools and further advances in computer performance and architecture, adaptive optimization techniques were developed. However, these adaptive methods such as simulated annealing and genetic algorithms need to evaluate large numbers of trial loading patterns. One of the drawbacks of these techniques is the computational cost which mainly depends on the technique used to obtain core power distribution and the total number of trial loading pattern evaluation. In this study, the computation time of the neutronic solvers used to perform burnup dependent analysis takes times almost less than a seconds and large number of core loading patters are evaluated in the order of a few minutes.

The main goal of the in core fuel management tool developed in this study is to demonstrate the features of in-core management and give some insight to users about optimization constraint used in such a calculations to meet design objectives.

Simulation platform uses one and two dimensional burnup dependent neutronic solver and they are coded in FORTRAN to acquire results quickly. To perform constrained and unconstrained optimization, genetic algorithm was developed and it is also coded in FORTRAN. Remaining programs are graphical user interface programs which were coded in Python programming language. Calculation programs are; 1DNodal, RPM–HUNEM and RPM-Genetic, graphical user interface programs are; Py1DNodal, PyRPM, PyRPM–Genetic.

1DNodal software is based on 1 D core loading pattern. Py1DNodal software is a graphical user interface for loading pre–chosen fuel types as an input to the 1DNodal software. PyRPM code is used to specify fuel loading pattern, burnup and power for RPM–HUNEM calculation software. PyRPM–Genetic graphical interface is designed for supplying number of fuel assemblies and required input parameters used in genetic algorithm software. The developed software has been tested using the benchmark data of Almaraz II Nuclear Power plant with different inputs and all are open for further development.

2. NODAL METHODS

One and two dimensional nodal methods are used to demonstrate burnup dependent core neutronic calculations using burnup dependent reactivity model. The reactivity model for fuel assemblies are generated using lattice cell codes to determine reactivity as a function of power level of assembly, burnup and soluble boron concentration. In Figure 1, the loading pattern of 1/8 symmetric core is shown. The fuel assembly type dependent neutronic properties are already given as external functions and power history is given as input to determine burnup dependent core properties such as soluble boron concentration, assembly burnup and power peaking factors.

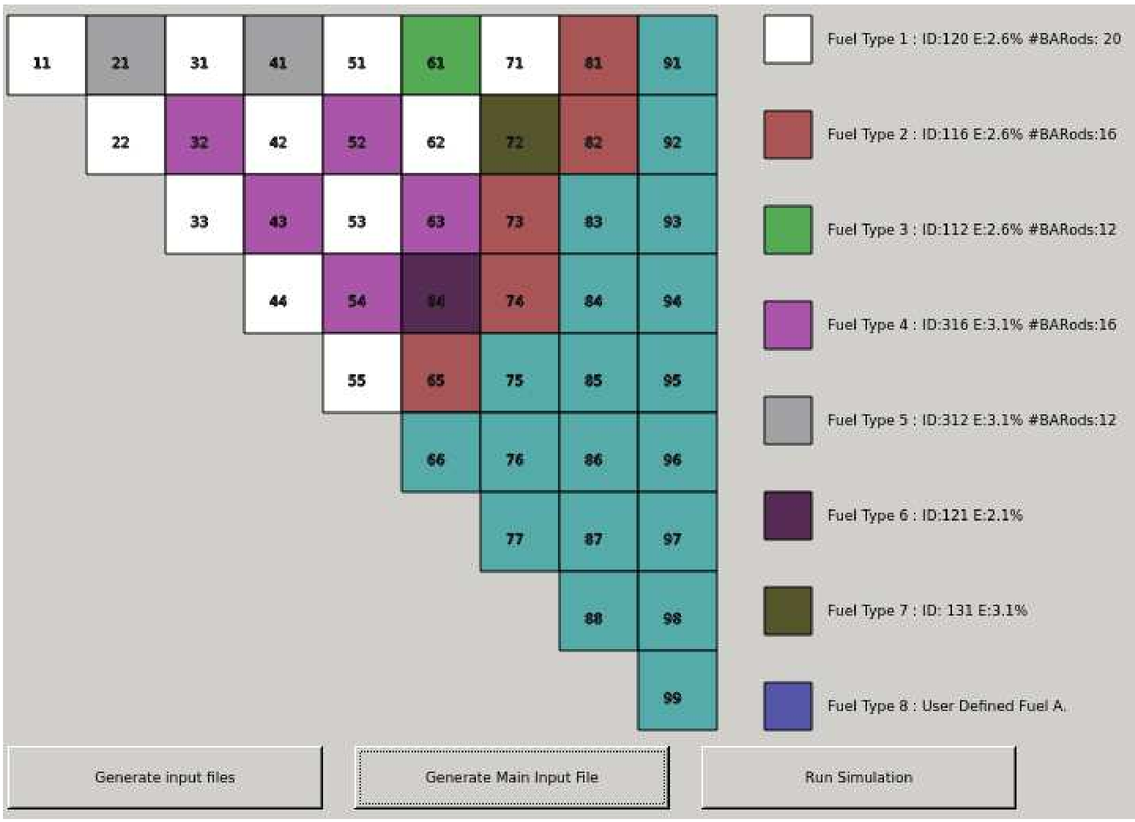

FIG. 1 The loading pattern of 1/8 symmetric reactor core

3. GENETIC ALGORITHM

Genetic algorithm, first introduced by Holland in 1970's, is one of the stochastic optimization techniques that have become popular in the last decades. In GA, each individual is represented by a chromosome which is a 1/8 symmetric core loading pattern, and a gene denotes the type of assembly in the 1/8 symmetric core loading pattern and its fitness is the value of objective function. During the evolution of loading pattern, fitness calculations are performed with 2D Burnup Dependent Diffusion Code based on the computer code RPM developed by Sauer and Driscoll and loading pattern is given in Figure 1. The code was utilized to calculate the power peaking factors at BOC and EOC, boron concentration as a function of cycle length, from BOC to EOC.

A set of LP for the initial population is generated and their fitness values evaluated by using neutronic results and definition of objective function. The individuals are ranked by using the fitness values. New population is generated by using GA tools like mutation and crossover of selected individuals. New individuals are used again to determine their fitness values. This process continues until the fitness values converge to some desired level at which safety related constraints were satisfied.

4. CONCLUSIONS

In this study, 1D and 2D nodal solvers are introduced for burnup dependent core neutronic calculations. The Genetic Algorithm code is developed to use for education and training in the field of in core fuel management. As a feature work, we want to add time dependent module to analyse reactivity induced accidents.

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NEED TO INTRODUCE A SYSTEMATIC EDUCATION AND TRAINING APPROACH USING PERSONAL COMPUTER IN THE NUCLEAR ENGINEERING EDUCATION PROGRAM AT THE ENSMR

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Abstract

The Engineering School of Mines–Rabat (ENSMR) enrolls students after a strong process of selection and offer them master degree education programs in several fields of science and engineering. The incorporation of new methods of teaching and training using PC based simulators in the current curricula is encouraged to support capacity building and knowledge management in an active environment between the teachers and the professionals of the industry sector. The ENSMR being under the authority of the Ministry of Energy and Mines of Morocco which is in charge of the National Nuclear Energy Programme, introducing new educational approaches using PC based simulators for nuclear power programmes will help motivate the students in this field and bring a high benefit for human resources development. Such initiative will lead to new career pathways that provide the skills needed in developing the national nuclear power programme.

1. INTRODUCTION

The Engineering School Mines–Rabat (ENSMR) offers nuclear engineering courses in its current education programs; works to upgrade these materials and improve knowledge are in progress: introducing a training approach using personal computer based simulators for nuclear power programs will enable to improve the capacity building process of the ENSMR and will contribute to study efficiently the benefit and the impact of introducing nuclear power in the mix energy system, as the Moroccan national energy strategy is encouraging the recourse to carbon free technologies, i.e. solar and wind power, and is considering the introduction of nuclear power at medium term.

2. NUCLEAR ENGINEERING EDUCATION PROGRAM AT THE ENSMR

Several graduated education programs of science and engineering are deployed at the Engineering School Mines-Rabat as shown in Table 1; nuclear energy & applications modules are incorporated in current engineering masters and the ENSMR is continuously subject to launching new educations programs in conjunction with the employment sector needs.

TABLE 1. ENSMR DEPARTMENTS AND AFFILIATED MASTERS

Departments	Engineering Science Masters
Mines	MiningEnvironmental Engineering
Earth Sciences	Hydro Geotechnical
Materials	Materials Science
Industry Process	Energy Systems –Chemicals
Electromechanical	Electromechanical –Maintenance –Quality Control
Computers	Computer Systems –Supply Chain –Management

The nuclear engineering courses are delivered in the Energy Engineering Master while other master programs include lectures and exercises related to the multidisciplinary fields of nuclear energy/radiations applications mainly in the industry sector.

The Nuclear Energy semester module covers:

- Foundations of nuclear physics;
- Nuclear power technology;
- Basis of neutron physics;
- Radiation protection;
- Introduction to nuclear security concepts and methods.

The main objective of this module is to equip student with the basic knowledge of nuclear sciences and technology through theoretical lectures, exercises and case studies.

The Energy Management related semester module covers:

- Energy accounting methods;
- Energy chain analysis;
- Electricity demand analysis;
- Power project assessment.

This module aims to study alternative scenario for sustainable energy development and to assess the potential contribution of nuclear energy in securing affordable and clean supplies of energy. The teaching approach is based on student projects illustrated by lectures and short exercises.

The curricula and the detailed work plans of these two modules are available.

3. BENEFIT OF INTRODUCING A SYSTEMATIC EDUCATION AND TRAINING APPROACH USING PERSONAL COMPUTER BASED SIMULATORS

Introducing an innovative learning by doing approach using Personal Computer based simulators is a key factor to level out the knowledge from different backgrounds: related subjects expertise can be developed, communication between involved trainees and trainers would be facilitated, enabling to join professional networks and share knowledge and experience in the multiple areas of nuclear engineering: it will be possible to develop dedicated learning packages for targeted audiences of teachers and users and build capacity in the specific fields of the nuclear engineering education tools currently deployed:

- Nuclear technology models, improvements, innovation;
- Nuclear fuel cycle options, nuclear waste management;
- Scenarios assessment in the context of the climate change mitigation

The nuclear supply chain is a complex scheme that highlights the big challenge posed by the human resources needed to support a nuclear power program; using such approach will enable to reach successfully the global objective of sustainability as capacities and competencies would be developed in place at the right time.

HUMAN RESOURCE EDUCATION PROCESS FOR NUCLEAR ENERGY AREA IN ARMENIA

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Abstract

Armenia is the only country in the Caucasus region that has been operating nuclear power plants for over 30 years. Qualified specialists exist at the Armenian Nuclear Power Plant (ANPP), the Armenian Nuclear Regulatory Authority, the Nuclear and Radiation Safety Centre, and other institutes. A significant portion of the current ANPP workforce is approaching retirement age and will not be available for future nuclear energy in Armenia. The future development of nuclear energy in Armenia needs to address emerging issues and challenges in view of the decision. This paper presents a discussion of a study to define the programmes for development of the human resource infrastructure needed for a human resource education process for nuclear energy area in Armenia.

1. SYNOPOSIS OF PAPER

A country embarking on a nuclear power program should make a realistic assessment of its organizational, educational and industrial capabilities and determine the requirements for developing the quality and quantity of manpower needed. There is no universally applicable organizational framework that is equally applicable to every country and in each situation. The manpower development program for each country has its own unique characteristics.

By the Governmental Decision № –54–13 in 10 of December, 2015, was adopted “The energy system of long-term development ways (up to 2036)” [1]. In the Program it was envisaged to put into operation the new nuclear unit after the shutdown Unit 2 of ANPP in 2026 to cover the loss of its generating capacity.

Currently, two departments of the National Polytechnic University of Armenia (NPUA) and Yerevan State University (YSU) give specialists in the field of nuclear energy. However, enhancement of Integrated Education System for Nuclear Sector in Armenia is essential for Armenia. NPUA has been involved in educational process in nuclear energy area since 1993, when Government of Republic of Armenia (RA) adopted decision to restart units of Armenian NPP. Up to now many reforms and modernizations have been in the educational process in the nuclear energy area.

2. RESULTS

A Concept on human resources management was developed and endorsed by the Government of the RA on 8 July 2010 [2]. Implementation of Knowledge Management for all phases, including design, construction and commissioning, operation and decommissioning both for the existing and future NPP units are the main parts of the Concept.

In addition to fundamental scientific and technical education, nuclear workers typically require several years of specialized training in safety, security and radiation protection and in the design and operation of the specific technology chosen for deployment. The specialized training, and even the fundamental education to some extent, can be obtained from the vendors and suppliers of the nuclear system and its systems and components.

Human resource development needs vary widely, depending upon the national decision to fill the needs through indigenous development or purchase the capabilities through a turnkey project. Even if a turnkey project is the preferred approach, consideration of developing indigenous capabilities should be considered for the long term. The development of such indigenous capabilities will require significant attention to education and training.

In accordance with the concept approved by the Government, incentives will be established to increase student interest in nuclear-related courses at NPUA and YSU. In addition, further curricula development is planned based on the following approach:

- Surveys of normative reports, standards and guidelines in the Russian Federation, the USA and at the International Atomic Energy Agency to identify staff positions that should have a university education and to identify related knowledge requirements that should be covered by university curricula;
- Comparison of Armenian curricula with knowledge requirements and with curricula from the USA and central European countries; and
- Development of actions to upgrade Armenian curricula at NPUA and YSU.

Improvement of nuclear education curricula in Armenia was developed based on surveys of international publications and comparison of existing curricula in Armenia with similar curricula in the USA, the RF and the other EU countries. The RF and Bulgaria were included because of their shared histories and similar approaches of institutions of higher education and because the reactor selected for Armenia is a Russian design.

The curricula studied were for specialties “Nuclear Power Plants and Equipment” at NPUA.

In order to define the expected outcomes of a nuclear education, the study defined functions to be performed at NPPs, nuclear support organizations, the nuclear regulator and regulatory technical support organizations that require a university level education. The nuclear-related functions fall into eight categories: nuclear safety; radiation safety; emergency preparedness, NPP operation; NPP maintenance and repair; engineering support; NPP training; and nuclear oversight/inspections.

Based on the surveys of publications, a listing of knowledge requirements that should be addressed within nuclear education curricula was developed. The knowledge requirements were defined in the following areas: 1) Nuclear Physics, Reactor Physics, Reactor Engineering, Reactor Control; 2) Radiation, Radiation Protection, Dose Assessment; 3) Radioactive Waste Management; 4) Safety Assessment; and 5) Emergency Preparedness and Response.

Armenia has committed to the Bologna Process and has adapted curricula that previously took five or more years into curricula for four-year bachelors’ and two years Masters’ degrees. The bachelors’ curricula span semesters 1 through 8 and the masters’ curriculum involves four semesters, sometimes identified as semesters 9 through 12. Armenian curricula are assigned credits under the European Credit Transfer System based on 30 academic hours per credit. At NPUA, a typical semester involves 30 credits, with a total of 240 credits for a bachelors’ degree and 91 credits for a Masters’ degree. Completion of a bachelors’ degree involves completion and defense of a detailed diploma project. A Masters’ degree involves preparation and defense of a masters’ thesis. The Armenian academic hour is 40 minutes of instruction, lab work, and seminars or self–work.

Armenia has no research or training reactor. NPUA uses training simulators at NPUA laboratory and the Armenian NPP training center.

The training simulator is based on a sufficiently full and precise model of physical and technological processes of a NPP, and thus is intended to build practical skills in instrumentation and control of power facility process equipment.

NPUA training simulator of special educational laboratory allows the following:

- Practical classes for students within the university curricula in the field of nuclear physics and NPP technologies;
- Scientific research by students, postgraduate students and research fellows of universities;
- Classes aimed at mastering and control of theoretical knowledge by the nuclear power plant personnel at NPP training centers.

Besides, laboratory equipped with a complex and high-precision model of the nuclear power installation (computer NPI analyzer) can be effectively used to adjust the power facility control algorithms in operation modes that currently lack operational experience, the control procedures being accordingly insufficiently regulated.

Figure 1 presents the NPUA NPP simulator used in the classroom.

The NPUA has also simulation program of calculation of release from NPP during normal operational mode and accidents (Figure 2).

FIG. 1. Simulator classroom setting and the simulator used in the classroom.

The existing curriculum for the Nuclear Power Plants and Equipment specialty at NPUA provided a sound base in engineering fundamentals along with basic nuclear science and engineering. Additionally, the program gave practical details on equipment and systems at NPPs and included courses that dealt with plant operation, reactor operation, calibration (adjustment), etc. It was recommended that the NPUA bachelors' curriculum be considered as preparing personnel to perform NPP staff functions at the entry level such as: reactor operation; radiation protection; radiation surveys and measurements; radioactive waste management and transport; and system engineering.

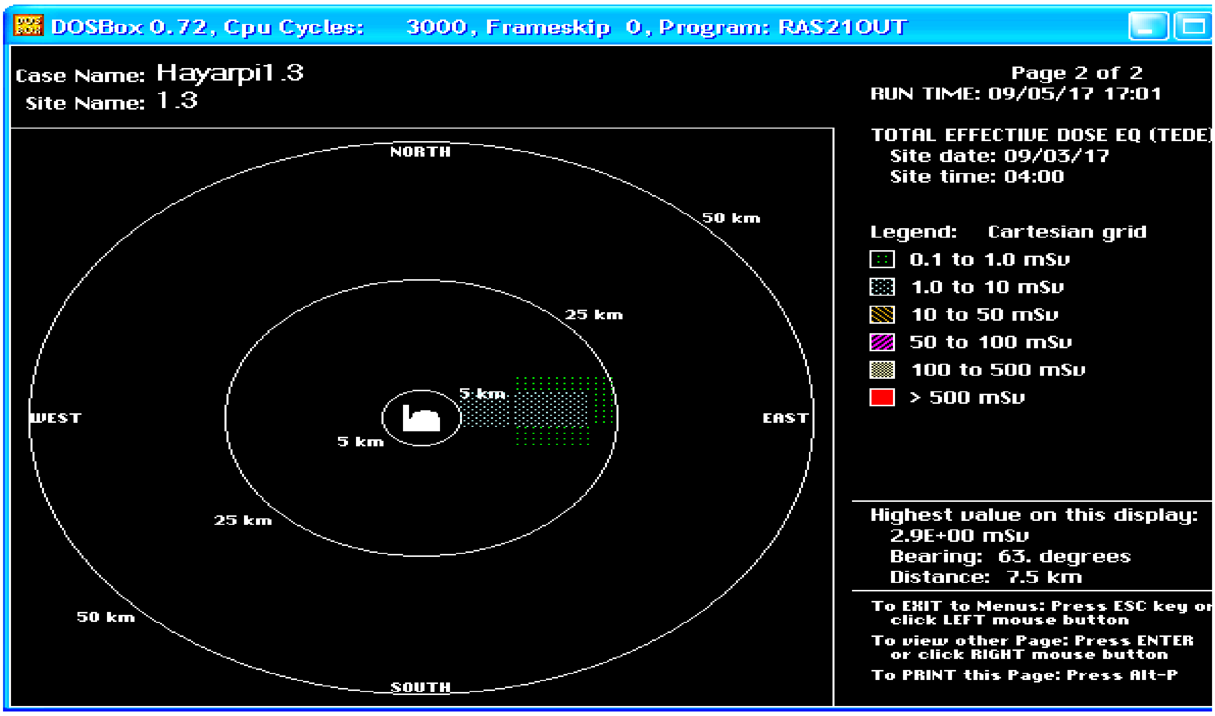

FIG. 2. Screenshot of calculation of release from NPP.

3. CONCLUSIONS

The NPUA has developed revised bachelors' and Masters' study programme "Nuclear Power Plants and Installations" based on the recommendations stakeholders. NPUA has received Ministry of Education and Science licenses for bachelors' and masters' study programme. Development of instructional materials and preparation of faculty to teach the revised study programme have begun.

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SESSION 2

REACTOR TECHNOLOGY TEACHING WITH BASIC PRINCIPLE SIMULATORS

TECNATOM´S IMPLEMENTATION OF PERSONAL COMPUTER BASED SOLUTIONS FOR NUCLEAR POWER TRAINING PROGRAMMES

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Abstract

Training with simulators has always been evolving along with the improvement of simulation technology. In the nuclear industry, the use of simulators was initially confined to training sessions with Control Room Full Scope Simulators, designed specifically for nuclear power plant (NPP) operators. In the last years, generic simulators have emerged to support initial training of licensed operators, but also to introduce the fundamentals principles to other NPP workers (such as non-licensed operators, maintenance technicians, engineers), other nuclear industry professionals (regulators, suppliers), or students/professors specialized in this nuclear field. This expansion to other target profiles has been possible thanks to the generic nature of these training tools (e.g. PWR, BWR). This training flexibility has changed the philosophy of the theoretical portion of the training programmes, by introducing the simulator through different stages of the training programme: 'learning by doing'. Other tools under development include a new tutoring system allowing minimal presence of training instructors, and therefore, these simulators aim to monitor the learning experience by optimizing the lessons while assuring the trainee learning needs are met. The intention of the paper is to describe Tecnatom experience over the following three topics related to the use of simulation tools on nuclear power programmes:

- Use of PC based basic principle simulators in teaching and training on various reactor technologies;
- Part task simulators, concept simulators and special purpose simulators and their place in an integrated education and training programme;
- Demonstration of extremely rare circumstances in plant operation using PC based simulators (for example, reconstructing the Three Mile Island accident).

The successful experience of Tecnatom at these three areas makes the content of the paper worthy to be shared with the Nuclear Industry.

1. SYNOPOSIS OF PAPER

The role of the simulators within the nuclear training has changed significantly through the history of the nuclear power operation.

It was in the 70's when the first computer based simulators appeared in the nuclear operations training. These simulators were limited in both scope and plant fidelity due to the computer capabilities existing by that time. It was at the end of this decade, in the year 1979 to be more specific, when the Three Mile Island (TMI) accident occurred and changed considerably the concept of the simulators for nuclear training. By the time the accident occurred, there were very few Main Control Room (MCR) Simulators in the world. These simulators used not validated models with a design/layout very different from the plant. This made the training received by the operating crews very inefficient. In addition, the simulators were not located on-site but at a different facility located in some cases far away from the plant. This arrangement complicated the site specific nature of the simulator, and required long trips for receiving the training. The Simulator Training was exclusively envisioned for MCR personnel that received just one to two weeks of simulator training for initial licensed training, and 1 week/year for continuing training

It was in the 80's when the Lessons Learned from TMI accident was incorporated to the Simulator Training. This meant both more requirements for simulator itself and a greater reliance in simulator exams for the Qualification, Authorization and Licensing of MCR personnel.

Nowadays approach for nuclear simulator training is far away from the concept described before. All NPPs have training on Full Scope Simulator (FSS) for initial and continuing training, being about a 90% of them site specific. During the construction of the NPP, FSS is ready before the operation of the plant. The plant specific content of the FSS is not a desired feature but a requirement by the Regulatory Authorities. Most of the FSSs are located on-site with all the benefits that it involves. FSS training is not only aimed at MCR personnel. In fact, it is used for other non-training purposes such as operating procedures validation, HHFF MCR design and implementation of plant design changes.

Considering now the possibility of using PC based basic principle simulators for teaching and training on various reactor technologies, the following question may be asked: "why does a Nuclear Training Institution need a simplified scope simulator?" In response to this question, Tecnatom identifies, among others, the following reasons:

- The limited availability and high cost of the SS–FSS, which is prioritized for MCR personnel training;
- The enhanced operational prospective of the initial licensed trainees when using simplified scope simulators before reaching the SS–FSS Training;
- The ease of these simulators to be installed at any regular classroom;
- A junior instructor can rapidly learn how to use it;
- It extends the spectrum of industry personnel receiving simulator training;
- The SS-FSS is NOT always the most adequate training tool to acquire the learning objectives.

The first section of the paper describes the successful implementation by Tecnatom of the Learning Station, an example of PC based simulator, within the Spanish NPP training programmes. The incorporation of the Learning Simulator in the training programmes has brought great benefits to both trainees and instructors. The theory is now transferred during the initial phases of the training combining the traditional methods with practical demonstrations performed by the instructor first, and by the trainees themselves afterwards. This powerful training tool offers a wide variety of functionalities that may be useful for different portions of the training programmes:

- Process diagrams;
- Trending tool;
- RCS 3D thermal hydraulic visualization tool;
- 3D generic components;
- Training exercises tool;
- Advanced alarm system.

FIG. 1. Learning station.

The Learning Station (Fig. 1 and Fig. 2) is currently used in the initial training of licensed and non-licensed personnel of Spanish NPPs at the following modules:

- NPP fundamentals;
- Reactor theory and thermal hydraulics;
- Systems;
- Transient analysis.

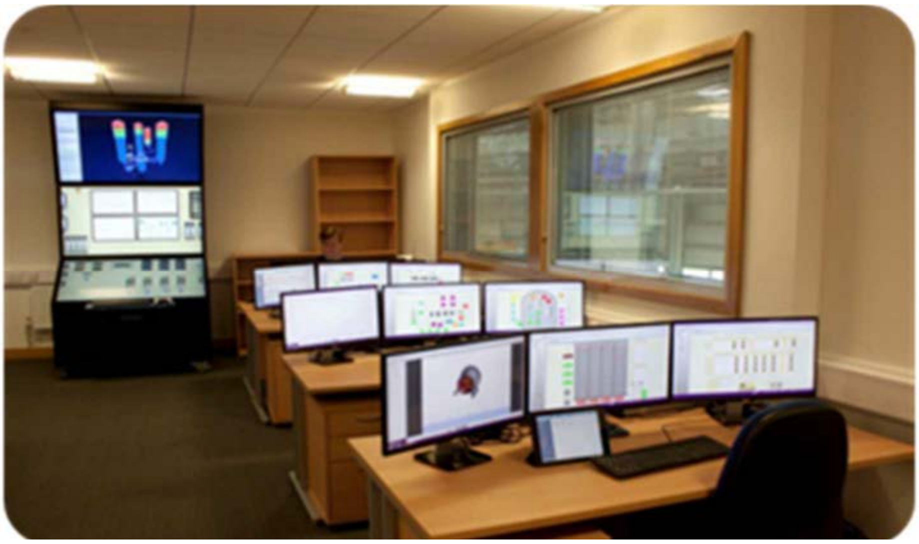

FIG. 2. Learning station installed in classroom.

In continuing licensed training, it is still a powerful tool to analyse particular transients in a rapid manner. It is also used for PWR Technology courses delivered to utility management staff, university students and other industry workers. The tool can be used in two teaching modes:

- Demo Mode: The Instructor can simulate plant operations and accident scenarios, and display a real time parameter evolution using several graphical tools;
- Operation Mode: Up to four trainee stations can be connected to the instructor station. Trainees can operate and decide the systems or parameters to display on several screens.

and in two different configurations:

- Instructor and trainees connected to the same scenario/simulation;
- Each member of the classroom running an independent scenario/simulation.

Beyond the technical knowledge, the training of soft skills is getting more and more important within the Nuclear Training Programmes nowadays. Current Nuclear Training Programmes contained subjects such as:

- Communications;
- Decision making;
- Teamwork;
- Human performance tools;
- Cognitive skills;
- Leadership.

The integration of these new competences within the training, demands the development of new training tools. In connection with this, Tecnatom developed the “STAR Simulator”, an example of part task/concept simulator, aimed at the reinforcement of the Human Error Prevention Tools (Fig. 3).

This simulator training addresses the trainee to execute several commands such as component operation or verification of component status. It is included as part of the Human Factors training module, and is loaded onto the Tecnatom eLearning platform / LMS.

After the Fukushima accident, the role of the training on the emergency management changed significantly. Severe Accidents are beyond the scope of FSS code, and the evolution of Severe Accidents takes too long to be analysed within the time allocated for the training sessions. Based on this, Tecnatom developed a severe accident module and its integration in the Spanish NPP Almaraz Simulator (Westinghouse PWR 3–Loop). The resulted Severe Accident Simulator developed presents the following features:

- The Severe Accident module is based on MAAP4 code (just NSSS and Containment);
- The simulation is continuous from normal up to severe accident conditions;
- The simulation can be speed-up up to 60 times faster than real time;
- The displays can be duplicated with physical values instead of instrumental ones;
- SACAT–SAMG stimulation;
- Different training Configurations can be used:
  - Licensed Operations personnel training:
    - Practice of Severe Accident Control Room Guidelines;
    - TSC represented by the instructor.
  - TSC staff training:
    - Practice of Severe Accident Management Guidelines;
    - MCR crew represented by the instructor.
  - Mixed sessions licensed personnel –TSC:
    - Practice of Communication skills;
    - Procedure Transition training: NOP –EOP –SAMG.
  - Phenomenology training configuration:
    - Available information: physical values.

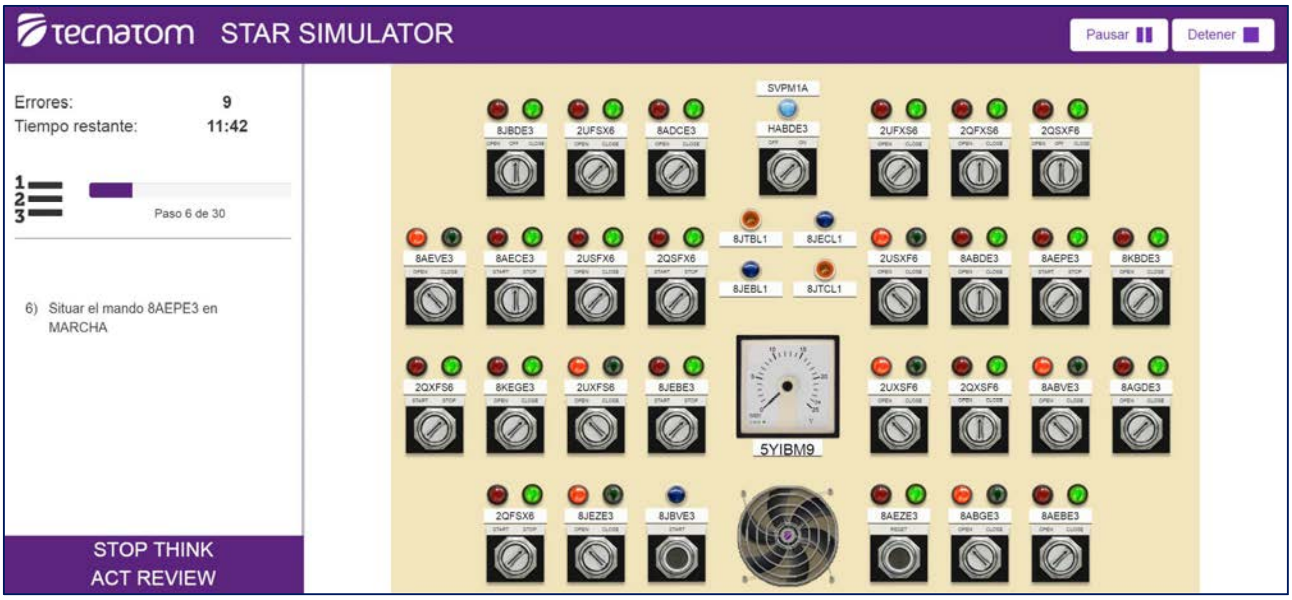

FIG. 3 STAR simulator.

This simulator offers a wide variety of applications in Training:

- Training in severe accident phenomenology;
- Training in severe accident control room guidelines (SACRG);
- Training in new system alignments and operation strategies;
- TSC Training in SAMG;
- Definition and assessment of severe accident mitigation strategies.

The target personnel are mainly the personnel involved in the management of severe accidents, that is, MCR personnel and Technical Support Centre (TSC) staff.

2. RESULTS

The major Training advantages Tecnatom has experienced from using the Learning Station in the NPP Training Programmes have been the following:

- The “learning by doing” methodology provided by the Learning Station increases the trainees’ comprehension and retention of the subjects;
- The Learning Station is a training tool more effective for training on fundamental concepts than full scope simulators;
- The trainees get to the FSS training portion with a better operational prospective, making FSS training time much more efficient;
- The trainees get more engaged to the training due to the more active approach of the lectures;
- The trainees gain independence in the learning process, making the training more flexible.

With the implementation of the STAR simulator within the training programmes, the trainees get consciousness about how easy failing is when operating a control panel with due to similar component names, display arrangement, timing, overconfidence. This training tool has proved its objective, which is to promote the Promotes the use of the STAR philosophy when operating a component: STOP –THINK –ACT –REVIEW.

Although still not sufficiently extended within the Spanish NPP training programmes, the Severe Accident Simulator opens a new window of possibilities to enhance the NPP training programmes on severe accidents.

3. CONCLUSIONS

Following the Systematic Approach to Training (SAT) methodology, the following questions should be formulated to forecast the future role of simulator in the nuclear training:

Analysis:

- Needs Analysis: Which will be the Training needs of the future Nuclear professionals?
- Job Analysis: Which Tasks will be required for their Job Performance?
- Task Analysis: Which are the Knowledge and Skills to perform such Tasks?

Design:

- Learning Objectives to acquire trainee competences: New Training settings for the acquisition of such competences in the shortest time.

Development:

— Training Tools and Methodologies that maximize the training efficiency.

In addition to that, the economical concept is essential to understand this evolution or trend in the simulation training. The Nuclear Industry is demanding new training approaches:

— "Delivering the Nuclear Promise", what involves among other, the reduction of the Training costs;
— Implement Blended and Active Learning, so that the trainee gets more independent and involved during the training process;
— New generations of trainees grow up with different learning methods. Old-fashioned training methodologies are no longer efficient. Consequently, a higher technological content of the training is required now;
— The training is not just focus on the enhancement technical skills, but also on the development of soft skills as well. Therefore, new assessment and training tools associated are required now.

As a final conclusion, Tecnatom envisions the near future of the simulators as innovative training tools required to carry out the new approach of the nuclear training: "to enhance the Nuclear Industry performance, while making nuclear power generation a competitive solution over other energy sources".

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THE USE OF SOFTWARE SIMULATORS AND FULL SCOPE SIMULATORS FOR THE TEACHING OF REACTOR PHYSICS

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Abstract

The paper presents the convenience of using software simulators for the teaching of Reactor Physics to staff on Nuclear Power Plants, and proposes some methodologies to optimize such use.

1. SOFTWARE SIMULATORS FOR TEACHING REACTOR PHYSICS

When teaching Reactor Physics to staff of NPPs, many of the concepts analyzed theoretically can be observed and / or measured experimentally. These measurements can be made:

- In a Nuclear Reactor;
- In a full scope simulator;
- Using a software simulator.

In a nuclear reactor, for example, the different operating states of a reactor can be observed, the relationship between reactivity and neutron flux can be analyzed and also the action of the reactivity control mechanisms. But the nuclear reactors usually available to be used for didactic purposes are of zero power or of low power (in the case of the University Center of Nuclear Technology the Nuclear Reactor RA–0 is used for that purpose), reason why they are not apt for make measurements that show the effect of feedback mechanisms of reactivity.

In the case of full scope simulators, they usually only exist in nuclear power plants. On the other hand, even in the case of having one, its availability is limited since its main function is to train operators.

In the case of full scope simulators, some feedback phenomena can be analyzed, for example the contribution of reactivity due to the variation of the ^{135}Xe concentration, but the feedback mechanisms that appear in longer periods of time cannot be observed, such as the effect of the ^{149}Sm, the ^{239}Pu or the burning of the fuel.

Using software simulators solves all the above mentioned problems:

- Availability: A software simulator can be made available to as many Reactor Physics students as needed. In addition, each of these students can choose the most appropriate time to use the simulator, repeating if necessary an experience to understand the underlying theoretical concept.
- Diversity: practices can be programmed to measure or analyze the effect of both the mechanisms of control of the reactivity and the mechanisms of feedback of the same, regardless of the time in which they manifest themselves in reality.

One or more software simulators are therefore a powerful tool for the teaching of Reactor Physics.

2. PROPOSALS TO INCREASE UTILIZATION

In order to optimize the use of software simulators for the teaching of Reactor Physics, it is proposed:

- Elaborate a practical guide that includes a brief theoretical introduction of the subject to be treated, the simulator to be used in each practice, a detailed description of the simulation and the list of variables to be analyzed. Propose different variations to each simulation in the same guide.
- For each simulation, generate a video in which the teacher explains the basic simulation to execute, and the choice of the simulator based on the concepts of Physics of Reactors to develop.
- For each simulation, generate a video in which a teacher analyzes the simulation once executed, relating it to the corresponding theoretical concepts.
- Make available to the Reactor Physics teachers the set of Simulators, the Simulation Practical Work Guide together with the videos generated before and after the simulation.

Once implemented this can be tracked, evaluating the number of students who effectively use the simulators to learn Reactor Physics, and receive feedback in order to improve the whole system.

USE OF PC BASED BASIC PRINCIPLE SIMULATORS FOR TEACHING AND TRAINING IN THAILAND

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Abstract

The current and planned usage of PC based basic principle simulators for teaching and training in Thailand is described in this paper. The PC based simulators is applied as learning tools in two graduate level courses, namely, Nuclear Power Engineering (basic course) and Nuclear Power Plant Simulation (optional course) as well as in the annual training programme (10 hrs.) for the new engineers at the Electricity Generating Authority of Thailand (EGAT). Some class activities, the simulator types and student assignments for each class are introduced. Finally, the plan for usage of PC based basic principle simulators for undergraduate level class and advanced PC simulators are proposed.

1. INTRODUCTION

This According to Thailand National Power Development Plan 2015 (PDP 2015) [1], Thailand expects to have the first nuclear power plants 2×1000 MWe by 2036. The infrastructure in the area of human resources is being prepared to support the nuclear power programme of the country. Chulalongkorn University located in Bangkok is the only one educational institute in Thailand provided the graduated level of master and Ph.D. courses in nuclear power engineering by the department of nuclear engineering, faculty of engineering since 1972. Starting from August 2017, to support the nuclear programme of the country, the department will officially launch the bachelor degree programme in nuclear and radiological engineering for Thai students in the first time of the country.

The PC based basic simulators provided by IAEA have been used in the graduate level programme at the department of nuclear engineering, Chulalongkorn University for more than 15 years. The PC simulators have been used in the lecture of two courses in the graduate level, namely, Nuclear Power Engineering (the required course) and Nuclear Power Plant Simulation (the elective course). Furthermore, the PC based basic simulators have been applied in the annual training programme (60 hrs. course) for the new engineers at the Electricity Generating Authority of Thailand (EGAT), the main electricity utility company in Thailand.

2. CURRENT AND FUTURE USE OF PC BASED BASIC PRINCIPLE SIMULATORS

For the required course of Nuclear Power Engineering, the PC based basic simulators run on the DOS system, namely, IAEA Advanced Reactor Simulation (ARS) Version 1.1 [2], have been applied in the class teaching. It is noted that since the department never have the students who have background in the nuclear power engineering before entering of the master degree programme, it is necessary to give the students the basic knowledge of Nuclear Power plants (NPPs) operation including the NPP related topics of fluid dynamics and heat transfer which are provided in this course. In this regard, the IAEA ARS simulator is utilized as an introductory tool for the students to develop their understandings of the principles of NPPs operation. The period for learning the simulation in this course is approximately six (6) hrs. The normal conditions including startup and shutdown of different NPPs operations are utilized as the base cases of course studying. Abnormal transients or accidental analyses are introduced as an advanced topic in the final lecture. Demonstration and learning by doing is the common technique used in this class. The class evaluation is based on how much the students can reflect their understanding through a selected case study of the simulation. Also, the student feedbacks for each semester are always used to improve the case studies and the teaching approaches in the class.

Only the students who pass the required course of Nuclear Power Engineering can take the elective course of Nuclear Power Plant Simulation (45 hrs. course). This course intends that the student could gains the full broad range of knowledge and experiences of the nuclear power plant operations under the normal and abnormal conditions after completion of the study. Currently, the department utilities the latest versions of IAEA PC based basic principle simulators available in the IAEA web site [3, 4]. The teaching techniques in the course are totally the learning by doing. The active learning by the group discussion is fully implemented. The students need to prepare the full report including the basic principles, the simulated results, and their own analysis compared with the commercial simulators (if available) of the selected case study using the simulators as well as the class presentation in the end period of academic semester. Again, the student feedbacks for each semester always used to increase the teaching quality for this course.

Lastly, the PC based basic simulators applied in the annual training programme (10 hrs) for the new engineers at the Electricity Generating Authority of Thailand (EGAT) is a kind of the intermediate class level between the required course of Nuclear Power Engineering and the elective course of Nuclear Power Plant Simulation. Since the trainee are not the full time students and has a limited time of the study, some contents or teaching concepts applied in the graduated level courses are adopted to accommodate the EGAT requirements.

The current challenge of using basic principle PC simulators for teaching and training in the department of nuclear engineering is the design of class outlines for the course of bachelor degree in nuclear and radiological engineering which is available in the department around August 2018. The class materials and teaching techniques for the undergraduate students are being modified and prepared based on the teaching experiences in the graduated level courses. Furthermore, the Micro–Physics Simulator (Lite Edition) [5], the latest software to visualize the reactor core section in a generic two loop PWR is being considered to add in some courses in the graduate level (e.g. the course of nuclear reactor engineering) including some class in the undergraduate level.

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THE INTEGRATION OF POINT KINETIC METHOD WITH STANDARD THERMAL CALCULATION FOR HTGR SIMULATOR DEVELOPMENT

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Abstract

BATAN (National Nuclear Energy Agency of Indonesia) is proposing the construction of experimental power reactor (named RDE reactor) based on High Temperature Gas Cooled Reactor (HTGR) with thermal power of 10 MWe. For owning the reactor technology of HTGR, the research activities are (i) carrying out the standard code verification and validation, (ii) transient calculation for RDE safety analysis report, (iii) the development of RDE's basic design as well as (iv) the development of RDE simulator. The simulator development in personal computer implemented the coupled neutronics-thermal calculation for simulating the transient reactor. The standard thermal calculation was employed by using KTA calculation standard.

1. SYNOPSIS OF THE SIMULATOR

BATAN (National Nuclear Energy Agency of Indonesia) is proposing the experimental power reactor (RDE reactor) for pursuing the public acceptance on NPP development plan, proofing the safety level of the most advanced reactor by performing safety demonstration on the accidents such as Chernobyl and Fukushima, and owning the generation fourth (G4) reactor technology. RDE reactor is a High Temperature Gas Cooled Reactor (HTGR) typed reactor with designed thermal power of 10 MWe that employed pebble bed fuel and helium coolant [1-2]. The reactor has planned to be constructed at Serpong, Tangerang Selatan, Indonesia, where is close to RSG-GAS research reactor with thermal power of 30 MWt [3]. For owning the reactor technology, the research activities are (i) carrying out the standard code verification and validation, (ii) transient calculation for safety analysis, (iii) development of RDE's basic design as well as (iv) development of RDE simulator.

The development of NPP simulator could be grouped in four classification level based on the simulator objective. The simulator objective is for basic study, classroom teaching, engineering and full scale for NPP staff operator training. The conventional full scale simulators using digital technology such as HTR-PM simulator is dedicated for NPP operators. The engineering simulator is for initial training of the operator [4]. An example of engineering scale simulator has been developed by implementing a standard code of RELAP [5] and MELCOR [6]. The commercial NPP simulator such as PCTRAN is utilized for transient analysis [7]. Those developed simulators are mostly dedicated for understanding the accident process. However, the previous studies of method development [8-10] are a basic method for either normal and accident operation simulation. Therefore, the development of basic and classroom scale simulator with normal operation simulation is important to be done before carry out accident simulation.

The objective is to develop a RDE reactor simulator that employs neutronics, core thermal, and Nuclear Steam Supply System (NSSS) modules and investigates the steady state calculation result. The code development utilized LabVIEW software developer and Personal Computer for implementing the coupled neutronics–thermal calculation. The standard calculation of HTGR core used Germany standard of KTA [11]. The simulation demonstration followed the power increase arrangement by regulator and has a reactor operating pattern for avoiding shutdown by developed Reactor Protection System. Moreover, the reactor control employs PID and advanced technology to control the reactor, helium circulator, feedwater pump and steam valve in once time. Therefore, the normal and accident operation could be simulated with the developed RDE simulator including reactor core cooling system (RCCS). The designed RCCS contains of three trains of cavity pipe, evaporation tank and smaller cooling tower. The main cooling tower is utilized by the reactor for normal operation. For enhancing the user interaction, the simulator utilized three computer screens to show the reactor control, balance of plant and cavity cooling system as shown in Fig.1.

FIG. 1. Simulator with three computer screens to show the reactor control, balance of plant and cavity cooling system.

2. RESULTS

The simulator development was done. The simulator human interaction is using three computer screens as shown in Fig.1. The investigation for steady state calculation must be done first for assessing transient calculation results. For this development objective, the setting for reactor protection considers the operation and safety limit as shown in Table 1. The designed simulation limits the maximum helium outlet temperature of 720°C for RDE operation during normal condition and 740°C for safety value to activate SCRAM during accident condition.

The steady state calculation results are shown in Table 2 at 100 % power level. The simulator run startup and continues to raise the thermal power until 100% power level. After the 100% power level continues to be stable, the simulated reactor is assumed in steady state condition. All calculation results have been averaged. Based on the result in Table 2, the simulated value and designed value are in good agreement for the steady state condition. To discuss and verify the transient results, the research is on progress by employing several standard codes such as THERMIX–VSOP, RELAP with modification and FLOWNEX. However, the modelling in standard code requires time cost to assure accurate calculation, especially during accident to predict the maximum fuel temperature. Moreover, the modelling could be done after the RDE's design process has been finished. In other hand, the calculation for designed value [12] and its modification are targeted to fix the basic design of the RDE reactor. With the simulator in development in a parallel with the design process, the verification of RDE simulator could be accelerated.

TABLE 1. ASSUMED SAFETY LIMIT FOR RDE REACTOR

No	Parameter	Limit	
		Operation	Safety
1	Max. neutron flux at low power (>1 MWt)	150 %	1 MW
2	Max. neutron flux at middle power (1-5 MWt)	110 %	120 %
3	Minimum reactor period	45 s	20 s
4	Max. Helium outlet temperature	720 °C	740 °C
5	Max. Helium inlet temperature	270 °C	290 °C
6	Max. He flowrate	110 %	130 %
7	Max. thermal power increase	2.3 %/min	3.5 %/min

TABLE 2. STEADY STATE CALCULATION RESULTS AT 100% POWER LEVEL

Parameter	Designed Value [12]	Averaged Calculation Result
Reactor outlet temperature (10% power)	700.00 °C	699.22 °C
Helium flowrate (10% power)	0.43 kg/s	0.42 kg/s
Reactor outlet temperature	700.00 °C	702.12 °C
Helium flowrate	4.30 kg/s	4.31 kg/s
Helium pressure	30 bar	30 bar
Steam temperature	530.00 °C	530.32 °C
Steam flowrate	4.00 kg/s	3.55g/s

3. CONCLUSIONS

The development of RDE simulator has been done. The investigation of RDE simulation for steady state condition was carried out in which the simulated values and designed values are in good agreement. The verification for transient condition is on progress by utilizing standard codes.

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SESSION 3

NPP SIMULATORS: *SOFTWARE EXAMPLES*

25 YEARS OF EXPERIENCE IN THE USE OF SELF-DEVELOPED PC BASED BASIC PRINCIPLE SIMULATORS

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Abstract

At the Institute of Nuclear Techniques, Budapest University of Technology and Economics, basic principle simulators have been developed and used for education in the last 30 years. Five different simulators were developed in the past, of which the primary circuit simulator PC^2 is the most popular among teachers as well as students. Nevertheless, this simulator was written for old DOS operating system and thus nowadays is of restricted applicability. Therefore, with support of a national research grant and based on the training experience accumulated, the development of a new simulator started in 2015. The new PC^2 simulator is developed taking into account principles such as modularity, standardization and portability (platform-independence). The new simulator has various extensions and new features compared to the old program. Manuals for eight different exercises will also be developed.

1. INTRODUCTION AND HISTORY

In the last three decades, five different simulators have been developed at the Institute of Nuclear Techniques of Budapest University of Technology and Economics (NTI BME). These are the following (in chronological order):

– PC^2 primary circuit basic principle simulator (DOS, 1987–88);
– REMEG reactor trip analyser (DOS, 1989–96);
– STEGENA steam generator analyser ('part task simulator') (DOS, 1991–93);
– SSIM secondary circuit basic principle simulator (MS Windows, 1993–95);
– PC^2 for Windows primary circuit basic principle simulator with a more complex calculation model (MS Windows, 1997–99);

With the exception of the program REMEG, all the above simulators are related to the WWER440 nuclear power plant type. Accordingly, they show the fundamental processes, construction and control principles of a PWR with the aid of a WWER440 as example. The program REMEG, on the other hand, makes it possible for students to study the phenomenon of reactor trip, using the example of the small power Training Reactor of BME.

2. INTEGRATION OF THE SIMULATORS INTO EDUCATION

The mentioned simulation programs have been integrated into the training courses (both in Hungarian and in English) of our Institute. Normally the programs are used in a computer lab course of some nuclear topic. Most of the students encounter the simulators three to four times during their studies, each occasion being approximately four hours long. For many years, a course named 'NPP simulation exercises' was organized, every occasion of which was dedicated to computer simulations. Nevertheless, during this course not only our self-developed simulators but other computer programs, such as ANSYS CFX and APROS were also presented.

At the beginning of the 2000's, a course named 'Simulation methods' was held four times. In frame of this course, students had the chance to learn from the experiences obtained during the development of the simulators.

In accordance with the above facts, a large amount of experience on both the development and application of simulators have accumulated at NTI in the last two decades. One may consider strange that even today the most often and most widespread used simulator is the one developed first, i.e. the PC^2 primary circuit simulator. Most probably this fact has been caused by two circumstances. On the one hand, the calculation model of this simulator is practically analogue to the volume of knowledge presented during the lectures on reactor physics (theory) and thermal hydraulics. On the other hand, the user interface is simple enough so that student can learn it very quickly and thus they may gain interesting simulation experience and new knowledge even during a single 4 hour long exercise. With more complex tools, such as the simulator 'PC^2 for Windows', getting to know the controls may take several hours. Therefore, such tools can only be used for longer courses (which span several occasions). Another intelligent trait of this simulator is that the graphics screen representing the time behaviour of physics quantities is very easy to understand due to the well thought –out ergonomic design.

At the time of birth of the PC^2 simulators, not only the simulator programs but also ten exercises were developed. The exercises, which conform mostly to the theoretical and laboratory courses, and which are most often used in the education are the following:

- Study of the effect of reactivity feedback on the operational parameters of the primary circuit;
- Analysis of the self–regulating ability of the reactor and the power control system;
- Study of the phenomenon of xenon poisoning in-reactor physics and operational aspects.

These exercises have become fundamental elements in the Hungarian and English courses on nuclear energy at our Institute.

3. RENEWAL OF THE BASIC PRINCIPLE SIMULATOR PC^2

The basic principle simulator PC2, which is used most often at our Institute, was developed in DOS operating environment and in FORTRAN source code in the second half of 1980s. The renewal was absolutely necessary since today it is practically impossible to run such programs on modern, mostly 64 bit architectures without functional errors.

A plan for the renewal was developed about a decade ago. Nevertheless, the actual work was only started at the end of 2015 in frame of the National Nuclear Research Programme supported by the National Fund for Innovation and Development (program id: VKSZ_14–1–2015–'0021). The renewal is practically equivalent to fully replanning and recoding the program. If the financial resources allow, the secondary circuit simulator SSIM will also be renewed.

Based on our earlier software development experience, the most important planning and development principles during the renewal were the following:

- Modularity;
- Standardization;
- Portability (platform-independence).

According to our intention, these principles help to develop a simulator program package, which is stable, maintainable for a long time and which can be developed further.

Modularity means:

- The option to use various programming languages (mainly C/C++ and Fortran);
- Handling of the functionally separable part as separate units;

– Modular handling of the units of the simulation model in order that simpler or more complex simulations may be possible to run on the same software, according to the requirements of the application.

Standardization is manly used for the programming languages. When writing the C++ sources, the 2011 C++ standard was used, while for FORTRAN, the FORTRAN95 standards and related recommendations were applied.

Due to portability requirements, only software equally available for operating systems MS Windows, Linux and OSX were used.

According to the above specified principles and aspects the following software development tools were chosen and used:

– C++ and FORTRAN compilers (GCC/Gfortran) of the GNU Operating System [1];
– Code::Blocks: a free, open source, cross platform integrated development environment (IDE) [2] –for the maintenance of source codes;
– FLTK (Fast Light Toolkit): a cross platform widget (graphical control element) library (GUI) [3] –for the creation of user interface of the simulator (which serves for, among others, setting of simulation parameters and initial values of some simulated variables);
– Cairo (Graphics): an open source, vector graphics-based, device independent, 2D graphics programing library (API) [4] –for the visualization and animation of graphical schemes and plotting;
– ZeroMQ: a high-performance asynchronous messaging library [5] –for the communication between the simulation model computing and user interface (visualization/interaction) program modules.

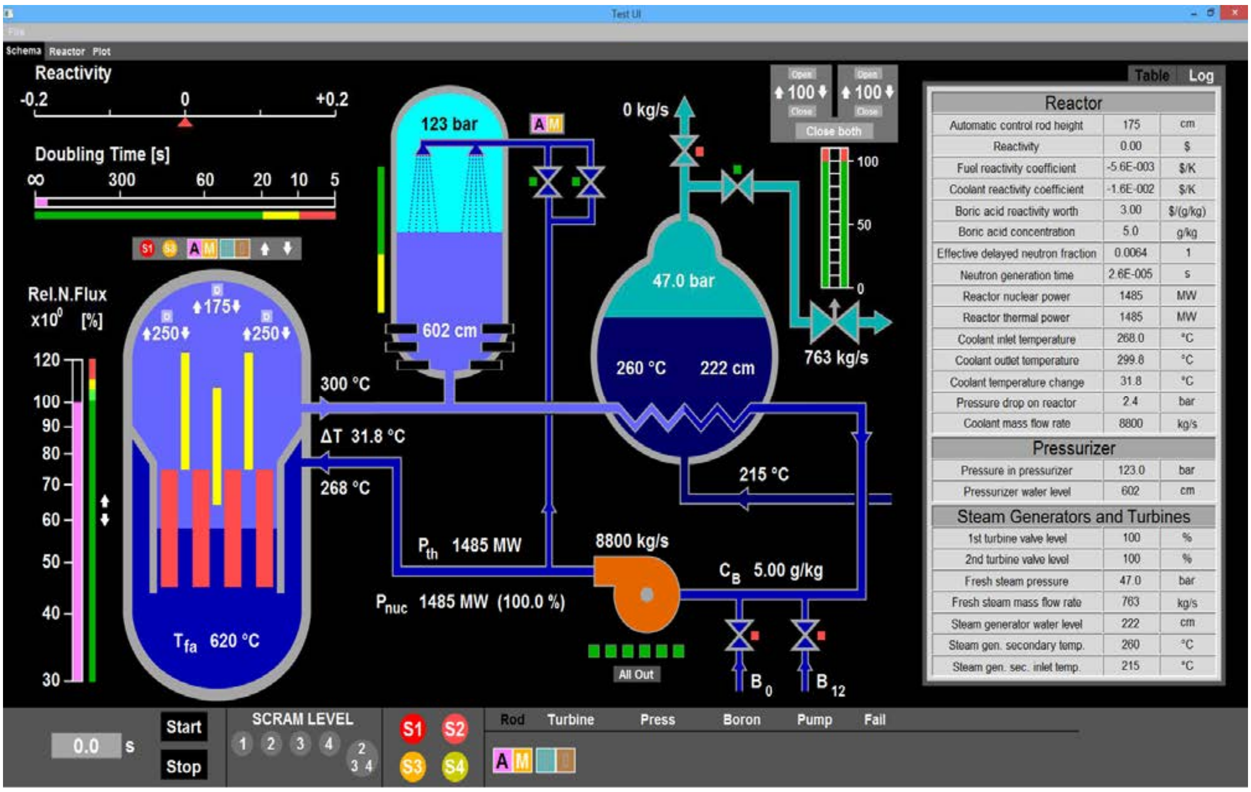

FIG. 1. Primary circuit scheme of the new PC² simulator.

In some cases parts or functions of a simulator may be too difficult to understand for students at lower levels of education. For such cases it is considered very important that certain functions of the simulator can be turned on or off, depending on the level of education. In this way, the instructor can adjust the amount of information to convey during the training session to the course participants. As an example, the temperature dependence of reactivity coefficients may be mentioned. In courses/training sessions short of time, constant coefficients (in lieu of the temperature dependent ones) may be used, depending on the consideration of the instructor.

Due to the above mentioned factors, the new simulator has the following characteristics:

- Platform-independent (momentarily tested on Windows and Linux systems);
- 32 bit and 64 bit versions equally available;
- There is fast, message-based communication between the user interface (screen) program unit and the simulation model computing program block;
- The user screen and the model are two separate programs (executable codes), which may run on a single or on two different computers as well (in the latter case, TCP/IP network connection must exist between the computers;
- Edge smoothed vector graphics representation, prepared to appear on HIGH DPI monitors.

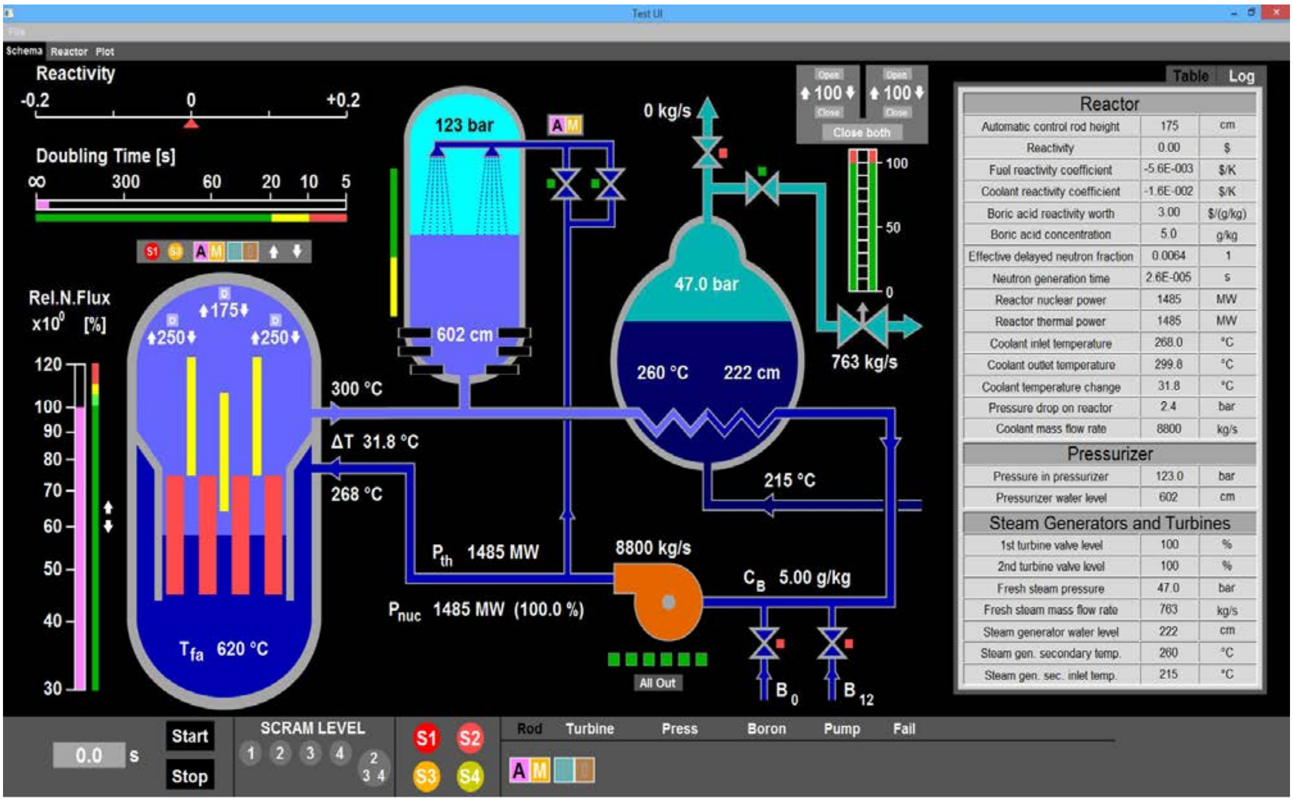

FIG. 2. Reactor scheme in the renewed PC² simulator.

The new simulator has various extensions and new features compared to the old program, most of which are of didactical importance:

- Now the simulation can take into account the dependence of vertical power profile on the burnup;
- Neutron flux depression effect of the control and safety rods is modelled;
- Remnant heat power is now modelled with a more accurate scheme.

According to the preplanning and recoding, the quality and details of the documentation have increased considerably.

It is planned that eight diverse manuals for exercises with the new simulator will also be developed.

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THE USE OF PERSONAL COMPUTER BASED SIMULATORS FOR NUCLEAR POWER PROGRAMMES

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Abstract

The use of Personal Computer Based Simulators for Nuclear Power Programmes is very important for education of the students and operators. Sometimes it can be more important than full scope simulators, because it is easier to access and easier to teach. In Armenia we use two types of PC based simulators based, the Multi-functional Simulator (MFS) for the ANPP WWER440 reactor und Maintenance Simulator. According to the experts, 40% of cases of abnormal nuclear power plant operation are due to staff errors. One third of these are due to maintenance staff errors.

1. INTRODUCTION

The Armenian Nuclear Power Plant (ANPP) consists of two units with WWER440 (V–270) reactors. The ANPP units were put into commercial operation in 1976 (Unit 1) and in 1980 (Unit 2). The installed power of each unit is 407.5 MW(e), the design service life is 30 years. Following the destructive earthquake in Spitak, by the decision of the Council of Ministers of the USSR Units 1 and 2 were shutdown in 1989 (in February and in March respectively). Following the USSR collapse the subsequent political cataclysms in 1990–1993 resulted in a blockade of Armenia and, as a consequence, in a grave energy crisis in the republic. The existing situation caused to make the only acceptable decision to restart the Armenian NPP.

In 1993 the Government of Armenia took a decision to restart the ANPP Unit 2. After performing repair and recovery work and safety enhancement activities in November, 1995 the Unit 2 was connected to the grid. Unit 1 is in a long term shutdown mode. The restart of the unit is not scheduled. The share of the Armenian NPP in the overall electricity output in the republic is 40%.

The nuclear power engineering is one of the main energy sources in Armenia and it is of crucial importance to the national power supply system.

2. DEVELOPMENT

2.1 Multi-functional Simulator for the ANPP WWER-440 reactor

Under the EC financial support the Consortium consisting of BELGATOM (Contractor) and CORYS TESS (Designer) developed ARARAT Multi functional Simulator (ARARAT MFS) for the ANPP WWER440 reactor. On 24 November, 2000 the MFS was put into operation for main central room (MCR) operators' training and qualification maintaining. The MFS consists of five (5) workstations with SUN computer system and server and UNIX software. Out of these five workstations, one is used for an instructor to control the simulator and the remaining four are dedicated to the operators (plant, reactor department (RD), turbine department and electrical department, shift supervisors). The training set-up is shown in Fig. 1, while Fig. 2 (a) to (e) show the fragments of the simulator capabilities.

FIG. 1. PC Based Simulators Training Lab in Republic of Armenia.

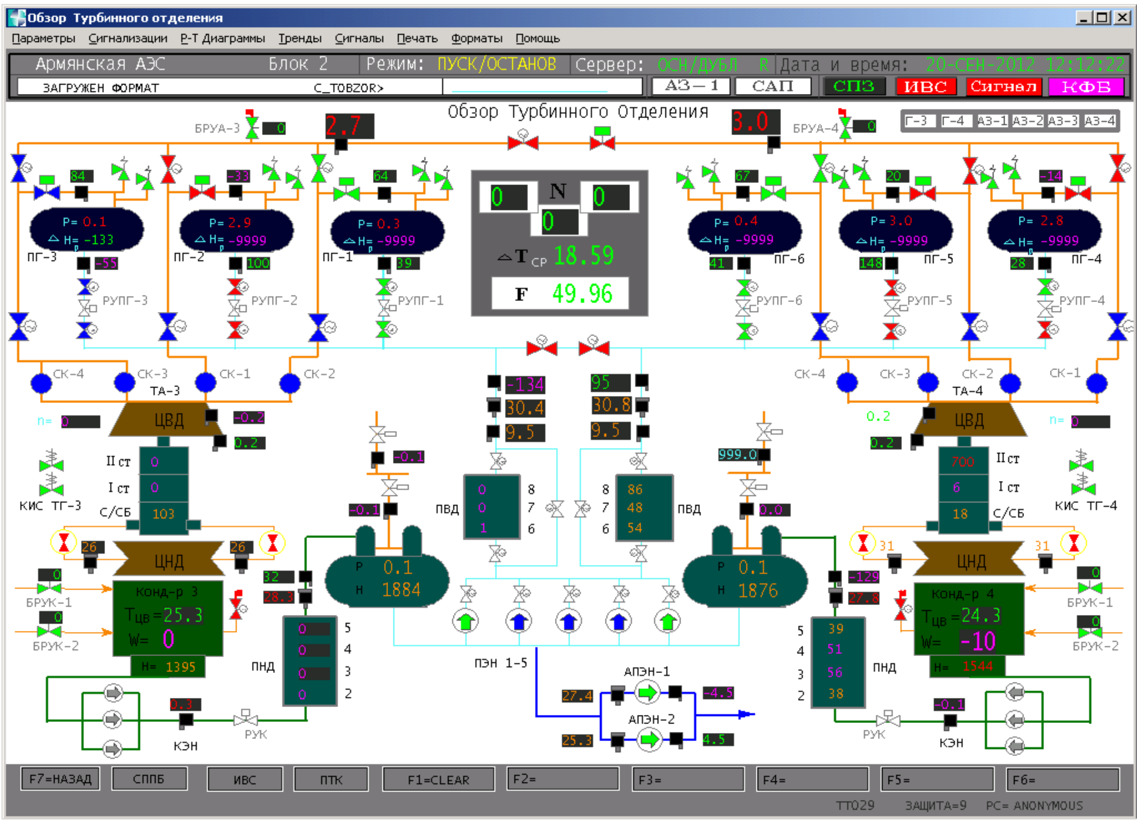

FIG. 2 (a) PC Simulator: TURBINE HALL OVERVIEW.

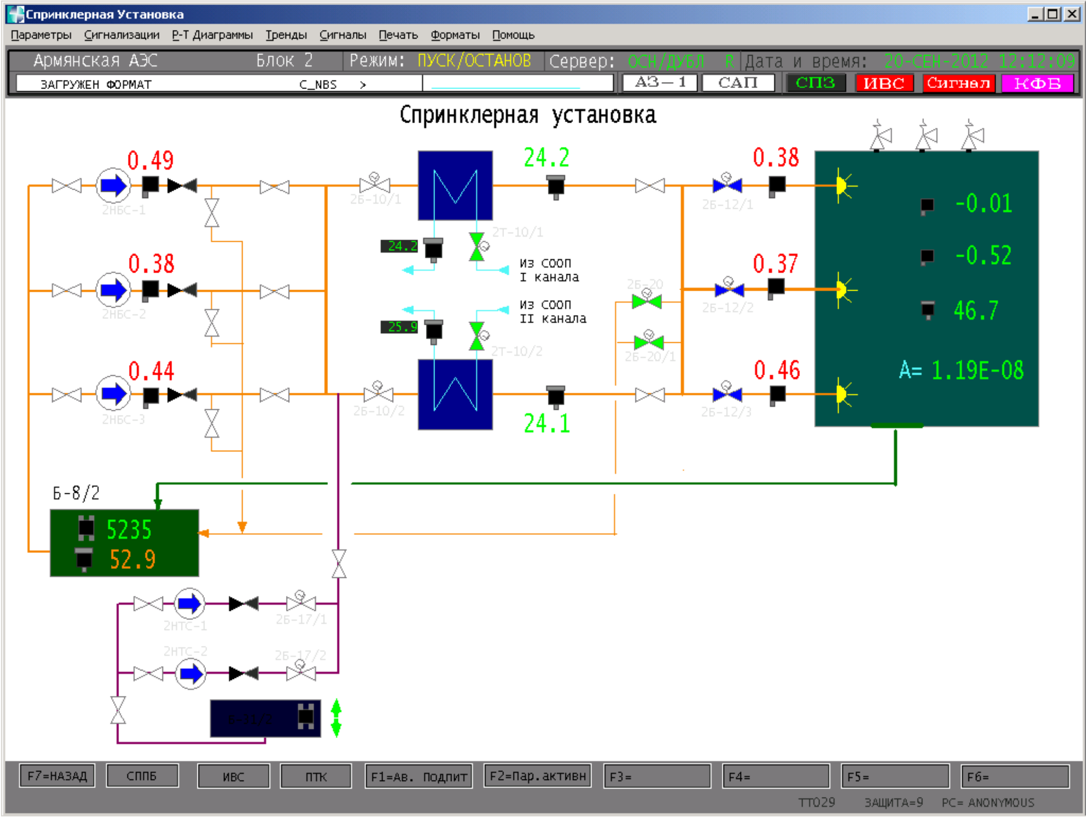

FIG 2 (b) PC Simulator: SPRAY SYSTEM.

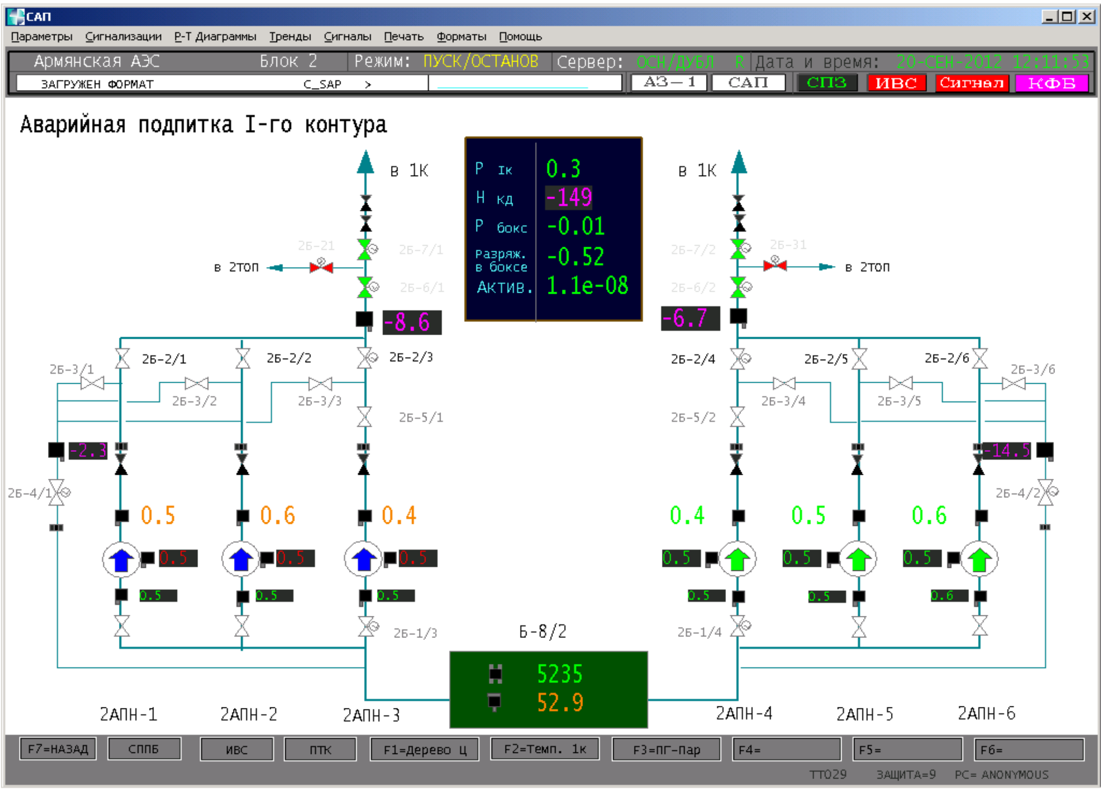

FIG. 2 (c) PC Simulator: PRIMARY CIRCUIT EMERGENCY MAKE-UP.

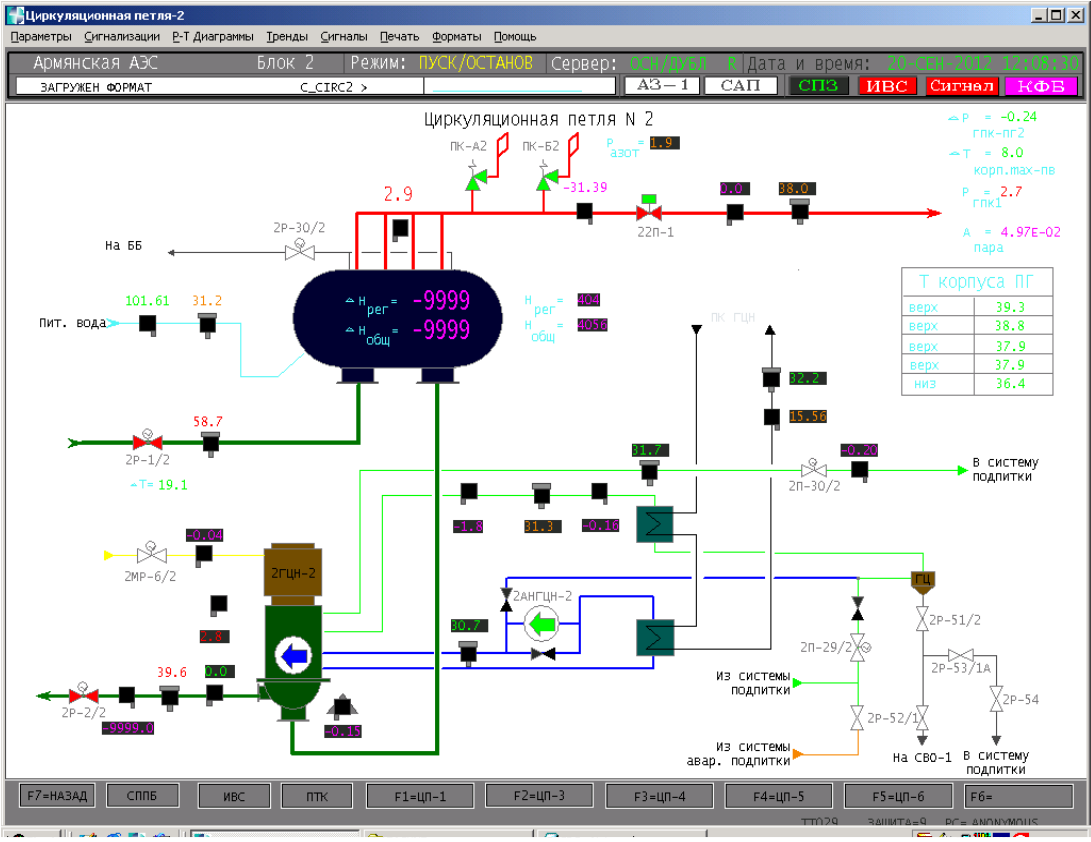

FIG. 2 (d) PC Simulator: CIRCULATION LOOP №2.

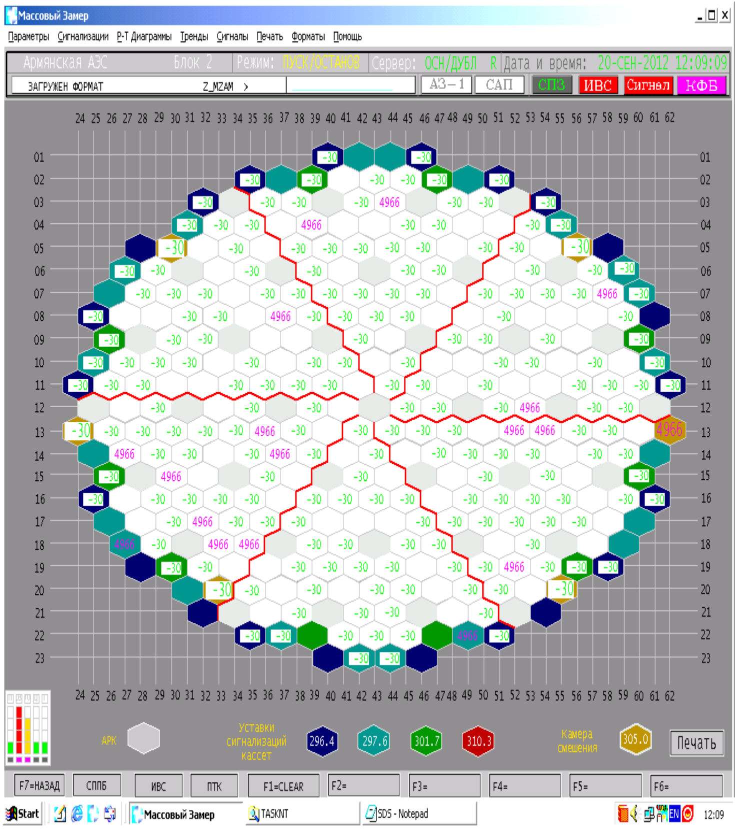

FIG. 2 (e) PC Simulator: MASS MEASUREMENT.

2.2 Maintenance Simulator

A reduction in equipment malfunctions due to maintenance staff errors, and a shorter duration of maintenance activities leads to the generation of additional electric power and increases the overall economic efficiency of NPPs. Decrease of the duration of activities, carried out in the areas with a high radioactivity background, will result in decrease of staff irradiation doses. Training system is a software package based on the use of multimedia technologies, designed for applying as teaching aids in training for the NPP maintenance and operating staff, as well as for the staff involved in the NPPs decommissioning process.

The objective of Maintenance Simulator implementation is to move the maintenance staff training process of NPP to a higher level. The computer based training system provides the following types of training activities reducing the training time for maintenance staff training:

- Study of technological knowledge;
- Training;
- Assessment of knowledge level.

In the study phase, the trainee learns about equipment configuration, characteristics, purpose, arrangement of its units, possible faults and the reasons of their occurrence, as well as about the organization of maintenance activities. The training includes demonstration in “automatic” mode of the processes of equipment dismantling and assembly.

In the training mode the trainee can independently perform operations of equipment dismantling and assembly using screen images of separate components and modules (if necessary, a prompting message is given to the trainee). The training system provides an assessment of the knowledge of the trainee by using tests or performing exercises on dismantling and assembly. The training course includes two main types of training activities:

- Study;
- Assessment of knowledge level.

For study the following sections are included in the menu:

- Functional concept;
- Technical characteristics;
- Key components;
- Key parts;
- Maintenance;
- Malfunctions;
- Demonstration (of disassembling and assembly of equipment);
- Self-training (exercises and tests).

The fragment from the section “functional concept” is shown in Fig. 3.

FIG. 3 (a) Fragment from the Lithuanian simulator section "Key parts".

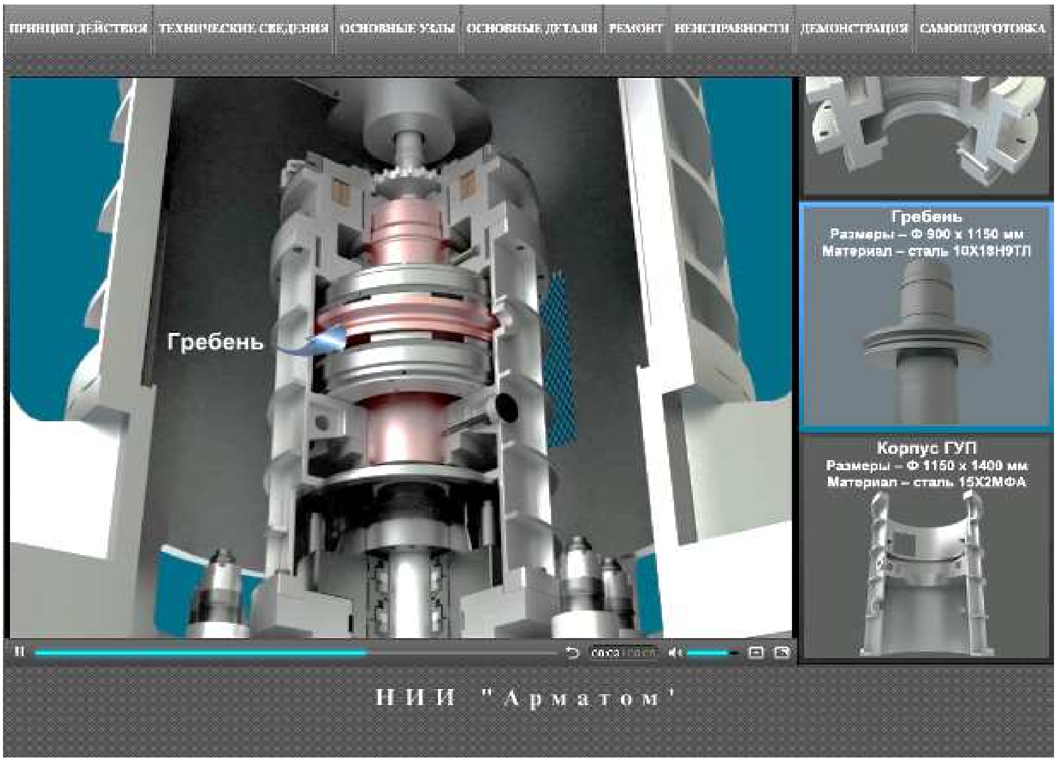

FIG. 3 (b) Fragment from the Lithuanian simulator section "Demonstration".

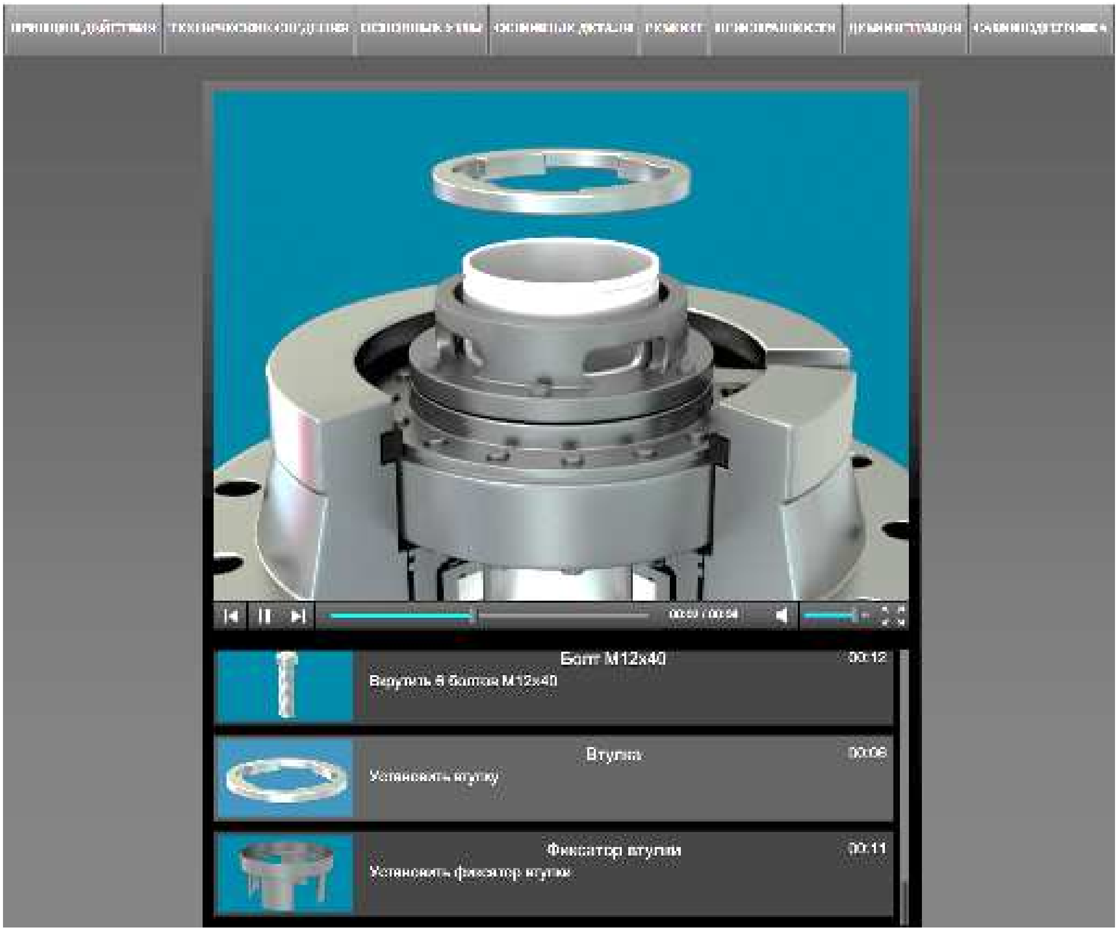

FIG. 3 (c) Fragment from the Lithuanian simulator section "Self-Training".

3. CONCLUSIONS

In this type of simulators students und operators have good experiences and positive feedback. They demonstrate their skills, practical und theoretical knowledge. They can understand related technology of the NPP. The use of PC in education process is very important and this process will be developed to constructed a new simulators based on PC.

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OVERVIEW OF SOFTWARE DEVELOPMENT FOR ANALYSIS AND DESIGN OF NUCLEAR POWER REACTORS IN MEXICO

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Abstract

The paper aims to present an overview of the efforts and achievements reached in Mexico to develop a set of software for design and safety analysis for nuclear power reactors by AZTLAN platform project. This project aims to modernize, improve and incorporate the neutronics, thermo-hydraulics and thermomechanical codes developed as result of a joint work between institutions, universities and research institutes in Mexico, in an integrated platform, established and maintained for the benefit of the Mexican Nuclear knowledge. The scope of the software in their initial phase covers their use for training purposes in the regulatory authority as well as universities.

1. SYNOPSIS OF PAPER

The simulation platforms consider an extensive set of important physical phenomena in the design and safety of nuclear reactors, the most obvious and measurable phenomena being the fission heat source, heat transfer mechanisms to the refrigerant, as well as the thermal and mechanical behavior of the materials that make-up the fuel rods under extreme stresses that determine the integrity of the safety barriers under normal and abnormal operating conditions. All this multi-physical character is focused on the reactor core, which is where the nuclear fission occurs and whose power produced in the form of heat must be removed by the refrigerant [1].

This paper presents an overview of the efforts and achievements reached in Mexico to develop a set of software for design and safety analysis for nuclear power reactors. The scope of the software in their initial phase covers their use for training purposes in the regulatory authority as well as universities [2]. In first place in the AZTLAN platform Project, it is being developed a set of software to analyze and design nuclear power reactors. This initiative is led by the National Nuclear Research Institute (Instituto Nacional de Investigaciones Nucleares –ININ) which brings together the main public universities in Mexico with activities in the nuclear field: The National Polytechnic Institute (Instituto Politecnico Nacional, IPN), the National Autonomus University of Mexico (Universidad Nacional Autonoma de Mexico and the Metropolitan Autonomus University (Universidad Autonoma Metropolitana, UAM). The project goals are to modernize, improve and incorporate the neutronic, thermal hydraulic and thermomechanical codes developed in house, in an integrated platform, established and maintained for the benefit of the Mexican Nuclear knowledge. The neutronics modules under development are the following: One is a 3D transport code which solves numerically the multi-group time independent Discrete Ordinates neutron transport equation, shown in Figure 1; another, is a 3D diffusion module that solves numerically the time dependent neutron diffusion equations in Cartesian geometry; and the other, is a 3D diffusion module that solves numerically the time dependent neutron diffusion equations in hexagonal *Z* geometry. The thermal hydraulics module is a module based in lumped and distributed parameters approximations, which includes the reactor vessel, the recirculation loops, the fuel pin temperature distribution, the core, lower and upper plenums and the pressure and level controls, as shown in Figure 2. In the AZTLAN platform, an internal coupling with an explicit scheme for the numeric coupling, like the ones shown in the Figures 3 and 4 are to be implemented. An integrated platform is under development to strength research and education activities, contributing to maintain and enhance highly qualified human resources in the analysis and design of nuclear power reactors areas, this platform will be maintained by Mexican experts.

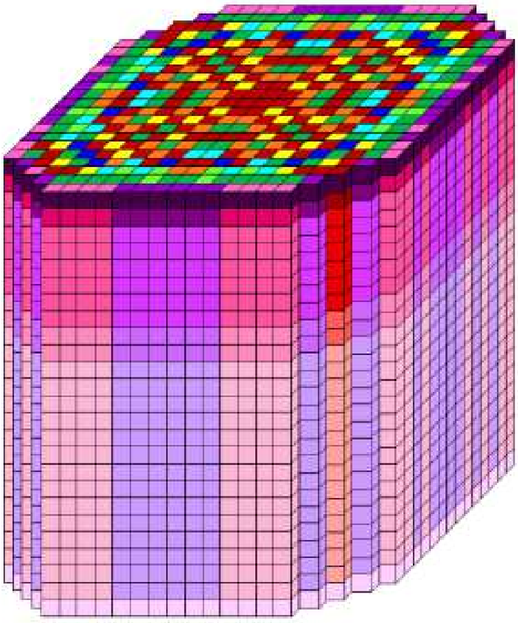

FIG. 1. Views of a typical nuclear core in 3D array for neutronic module, which solve numerically the time dependent neutron diffusion equations, [2].

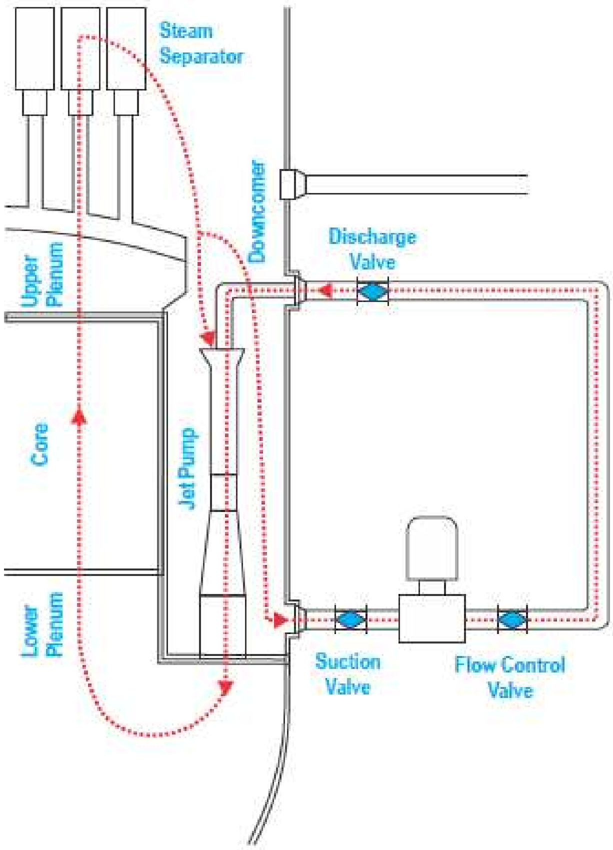

FIG. 2. Recirculation system flow path (BWR) considered in the thermal–hydraulic model, [2].

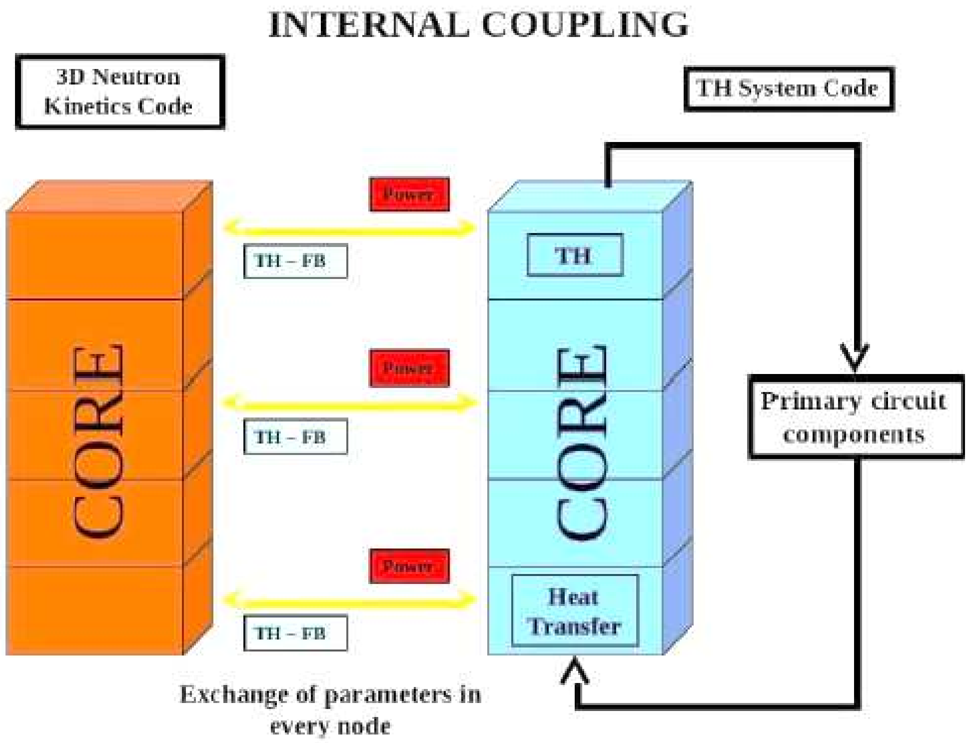

FIG. 3. Internal coupling of neutronics and thermal hydraulics codes, [2].

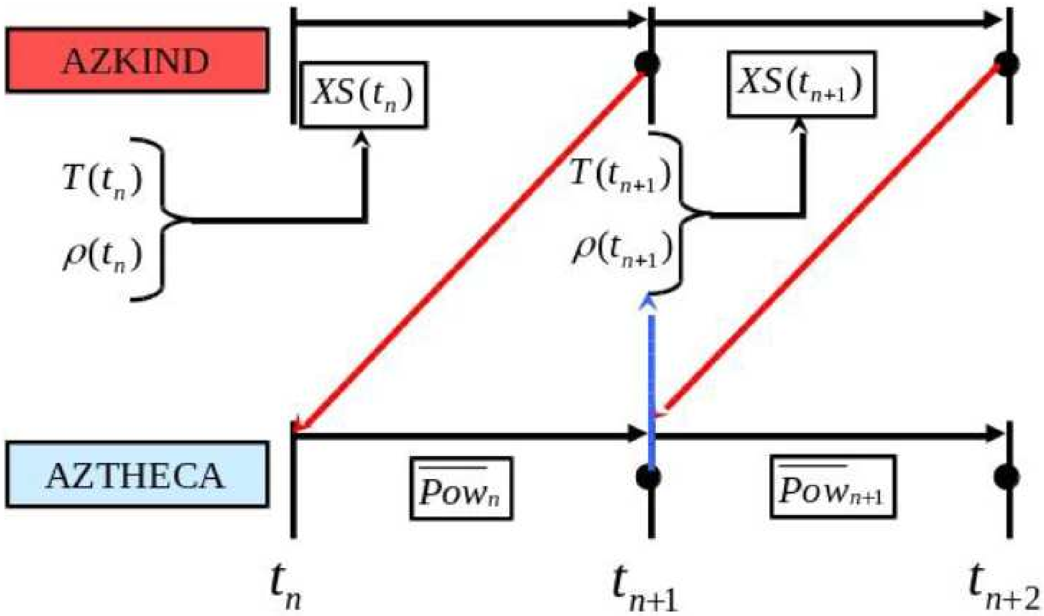

FIG. 4. Example of an explicit numeric coupling scheme between the AZTLAN modules AZKIND AND AZTHECA, [2].

Other efforts are coming from the regulatory side along with the work done by their staff that is working on their PhD degree, for instance developing a theoretical physicist-mathematical model to understand, describe and interpret the heat transfer processes that occur during a severe accident when the molten core materials reach the bottom vessel and interact with the remaining water. The expected output is to provide a model to analyze the coolability of the molten material taken into account the gap between the lower crust and the inner wall of the reactor vessel, as shown in Figure 5. A wide range of assumptions on the parameters that drives the coolability are being analyzed to estimate if the heat flux from the molten material to the gap does not exceed the heat removal capacity allows to retention the melt core material in vessel, [3]. For the analysis of the phenomena of heat transfer, each of the regions is treated separately to consider the behavior of the main phenomena that happen around them. The main proposed heat transfer mechanisms for both debris and vessel material cooling are heat transfer by conduction, convection and a pebble bed heat transfer region are considered, and presented in Figure 6.

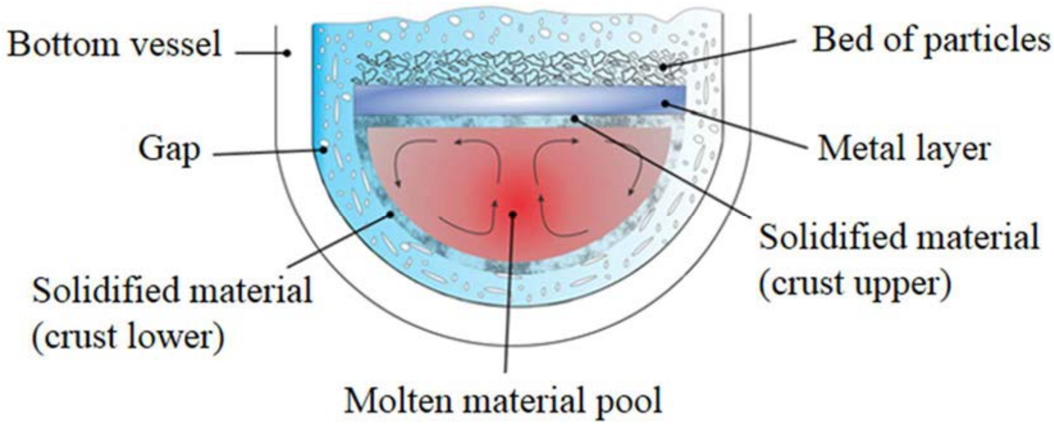

FIG. 5. Proposed geometry to analyse cooling of material relocated in the bottom vessel with remaining water, [3].

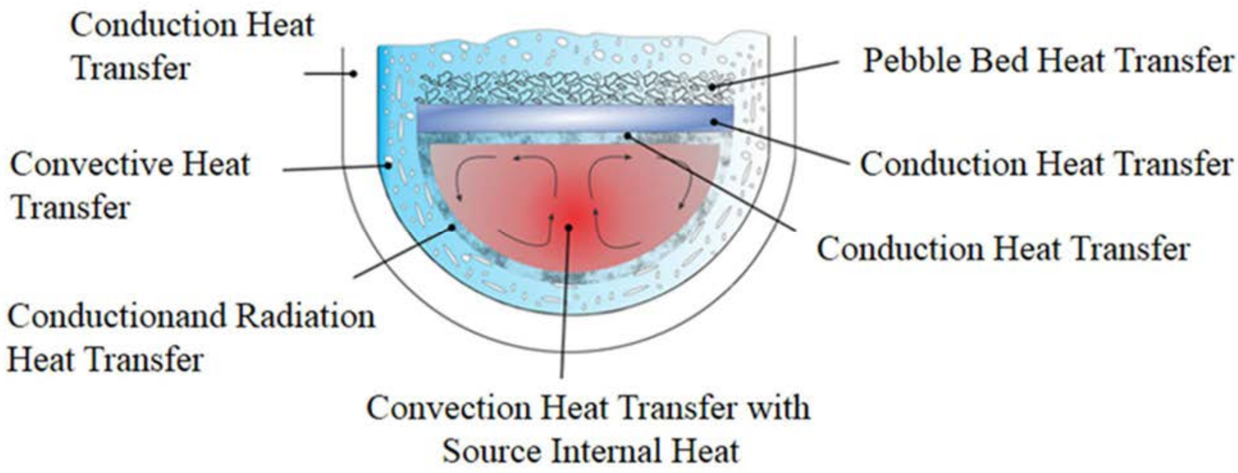

FIG. 6. Mechanics of heat transfer considered in the mathematical model, [3].

2. MAIN RESULTS DESCRIPTION OF THE SIMULATION

The computer program AZTRAN (AZtlan TRANsport), Is a code that is part of the AZTLAN platform, for analysis of nuclear reactors. This program solve the neutron transport equation in discrete ordered and XYZ geometry using Source Iteration method, in steady state using RTN–0 method (Raviart–Thomas–Nedeléc) [4]. In order to verify the under development solver inside AZTRAN an exercises from Bencmark ANL–7416 was performed, which consists of a 2D 7x7 fuel assembly, for two energy groups, as shown in Figure 7. The results obtained with the AZTRAN computer program were compared with the results presented in the benchmark mentioned above and presented in Figure 8. The error varies in the different fuel rods, however, it has a value lower than 0.4% which indicates that the results obtained with the AZTRAN computational program developed are acceptable.

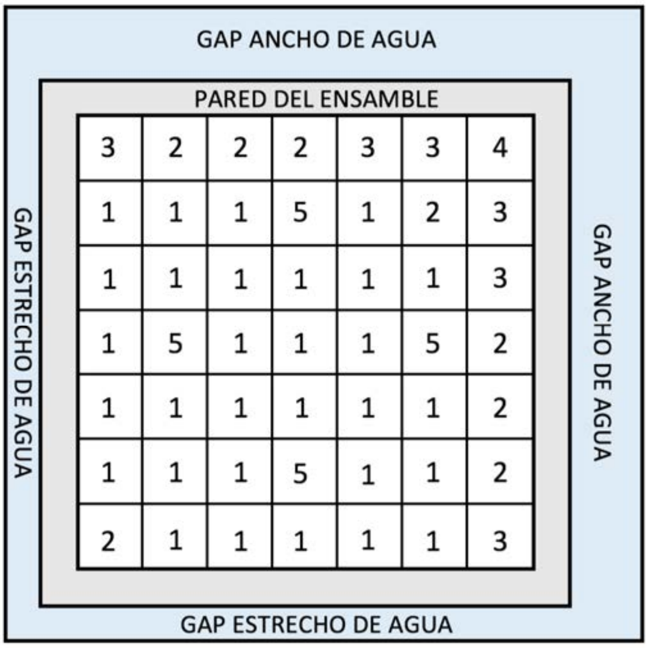

FIG. 7. Benchmark ANL7416 exercise, 7X7 2D fuel assembly with two energy groups, [4].

0.1760 0.1767 0.41	0.1751 0.1757 0.32	0.1761 0.1764 0.20	0.1788 0.1793 0.29	0.1788 0.1792 0.21	0.1777 0.1780 0.19	0.1752 0.1755 0.19	0.1717 0.1721 0.24	0.1656 0.1660 0.21	0.1624 0.1629 0.33	0.1623 0.1629 0.38	0.1618 0.1625 0.43
0.1773 0.1779 0.36	0.1768 0.1774 0.33	0.1785 0.1788 0.17	0.1815 0.1819 0.20	0.1817 0.1820 0.17	0.1805 0.1808 0.15	0.1780 0.1783 0.18	0.1743 0.1747 0.21	0.1678 0.1680 0.11	0.1638 0.1642 0.27	0.1632 0.1638 0.39	
0.1783 0.1788 0.30	0.1793 0.1797 0.20	0.1825 0.1827 0.09	0.1861 0.1863 0.13	0.1861 0.1862 0.03	0.1849 0.1851 0.13	0.1823 0.1824 0.08	0.1786 0.1788 0.10	0.1715 0.1716 0.04	0.1660 0.1663 0.18		
0.1838 0.1840 0.12	0.1862 0.1864 0.10	0.1926 0.1924 -0.12	0.1971 0.1970 -0.06	0.1965 0.1964 -0.04	0.1944 0.1944 -0.01	0.1923 0.1922 -0.03	0.1892 0.1891 -0.04	0.1807 0.1805 -0.09			
0.1917 0.1920 0.15	0.1947 0.1949 0.08	0.2024 0.2023 -0.07	0.2065 0.2064 -0.06	0.2050 0.2048 -0.08	0.1998 0.1999 0.03	0.2016 0.2015 -0.05	0.1985 0.1984 -0.04				
0.1952 0.1954 0.11	0.1980 0.1980 0.03	0.2049 0.2048 -0.06	0.2082 0.2080 -0.10	0.2083 0.2082 -0.06	0.2071 0.2071 -0.01	0.2055 0.2055 -0.01					
0.1969 0.1972 0.17	0.1994 0.1995 0.05	0.2056 0.2054 -0.08	0.206 0.206 0.02	0.2096 0.2096 -0.02	0.2099 0.2098 -0.04						
0.1974 0.1976 0.11	0.2001 0.2000 -0.04	0.2068 0.2066 -0.11	0.2102 0.2100 -0.08	0.2105 0.2103 -0.09							
0.1967 0.1969 0.08	0.1996 0.1997 0.05	0.2070 0.2067 -0.12	0.2113 0.2111 -0.09								
0.1926 0.1928 0.09	0.1950 0.1951 0.04	0.2018 0.2014 -0.18									
0.1901 0.1906 0.26	0.1913 0.1916 0.15										
0.1905 0.1910 0.28											

FIG. 8. Comparison of the results obtained with AZTRAN and presented in benchmark ANL–7416.

Another one computer program of AZTLAN platform is the module called AZNHEX, which is a neutron diffusion solver for hexagonal–*Z* geometry currently under development for nuclear core simulations. To verify the under development solver inside AZNHEX was simulated the reactor simulated is a 3600 MWt MOX-fueled core as defined in the SFR benchmark Task Force of OECD/NEA Working Party on Reactor Systems (WPRS) [5], shown in Figure 9. The main objective of this exercise is to compare the performance of AZNHEX against the deterministic codes DYN3D and PARCS, and the MC code SERPENT, as part of the verification and validation process of AZNHEX. In order to verify the under development solver inside AZNHEX, the same Serpent generated cross sections sets for each material were exported to AZNHEX format for four different states (as in DYN3D and PARCS). The parameters to be compared between the codes are four:

— Reference case in which the multiplication factor (k_{eff}) is the compared value;
— Doppler constant;
— Sodium void worth ($\Delta\rho_{Na}$);
— Total control rod worth ($\Delta\rho_{CR}$).

Comparison of the AZNHEX with other deterministic codes is shown in Table 1.

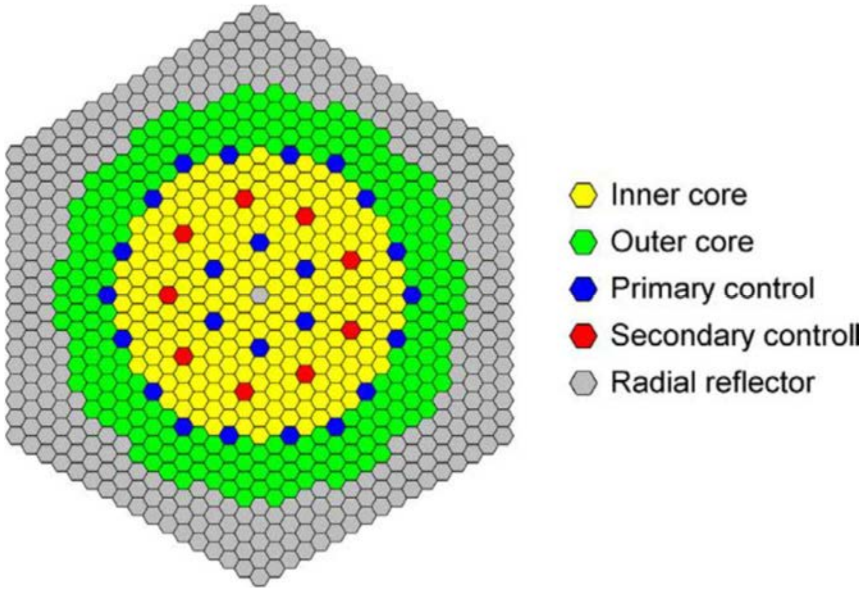

FIG. 9. Layout of the modelled core [5].

TABLE 1. RESULTS OF CORE SIMULATIONS WITH SERPENT, PARCS AND AZNHEX, [6]

	Serpent	DYN3D	PARCS	AZNHEX
k_{eff}	1.01070	1.00940	1.00984	1.00873
K_D	–852	–867	–868	–878
$\Delta\rho_{Na}$	1864	1951	1945	2019
$\Delta\rho_{CR}$	–6046	–6173	–6227	–6046

Table 2. shows the differences in absolute value when comparing AZNHEX against the other three codes, where we can see a quite good agreement in the direct comparison with DYN3D (–66 pcm in k_{eff}) and PARCS (–109 pcm in k_{eff}) and therefore against the Serpent reference solution (–194 pcm in k_{eff}). On another hand, the numerical model solution of the physical-mathematical model developed for a doctoral degree project was implemented in commercial MATLAB® code. The main results are shown in Figures 10 and 11 for the regions of layer of metal and inferior crust. Figure 10 shown the window time to obtain the steady state for both regions, this is obtained maintaining temperature of the remanent water constant while the initial temperatures of different materials reaches a temperature profile in equilibrium. Figure 11 shown the behavior of a transient when the accumulated material at the bottom of the vessel is cooling with remanent water, it mean, with the initial conditions of the system, obtained in steady state, the transient simulation is performed in which the heating and evaporation of the remaining water is allowed due to the removal of heat from the molten material.

TABLE 2. DIFFERENCES IN PCM (ABSOLUTE VALUE) AZNHEX VS OTHER CODES, [6]

	AZNHEX vs Serpent	**AZNHEX vs DYN3D**	**AZNHEX vs PARCS**
$k_{eff}(pcm)$	194.9	66.37	109.9
$K_D(pcm)$	26	11	10
$\Delta\rho_{Na}(pcm)$	155	68	74
$\Delta\rho_{CR}(pcm)$	0	127	181

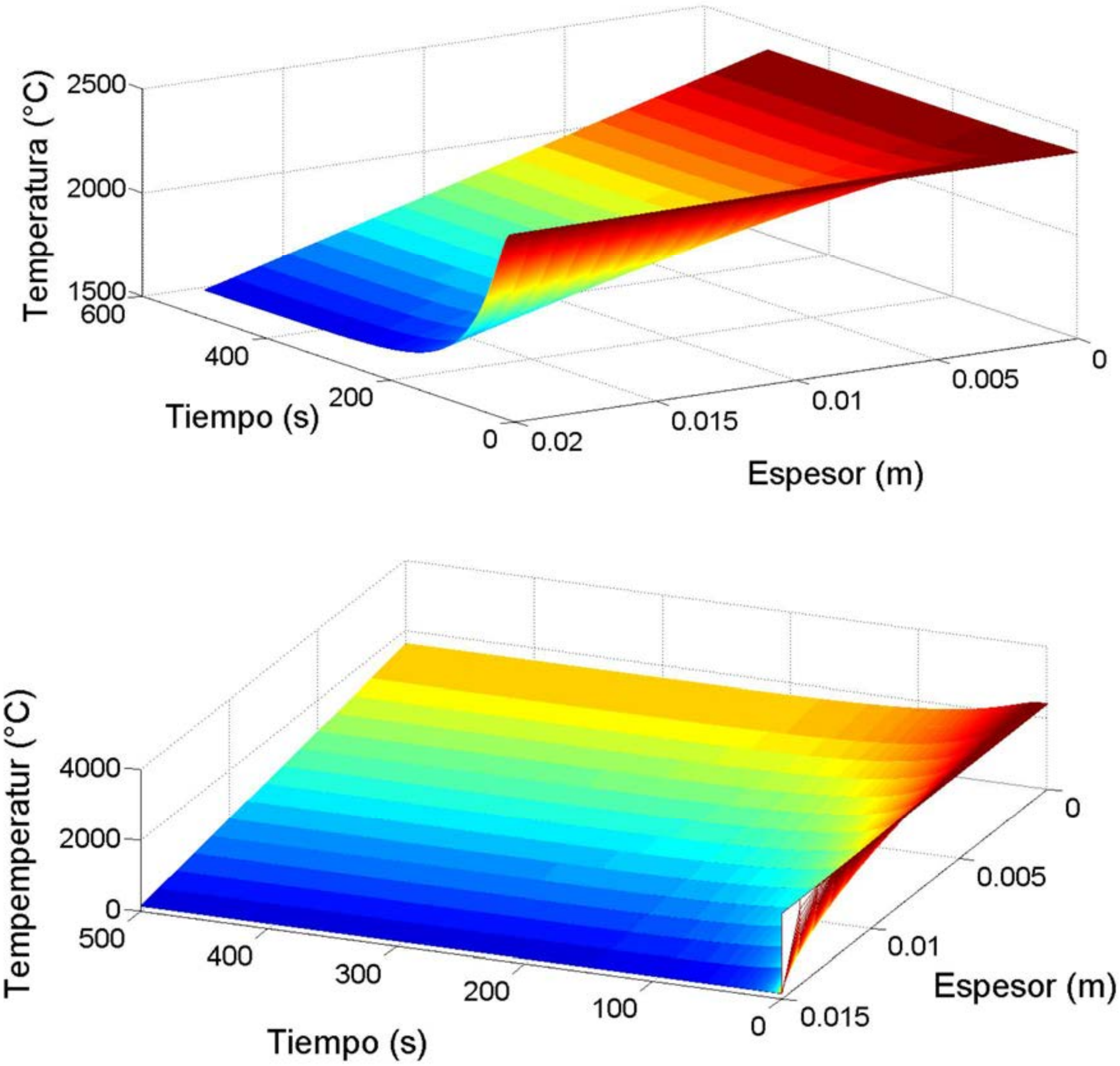

FIG. 10. Temperature of the layer of metal and inferior crust during the stationary state window, [3] [temperatura = temperature; tiempo = time; espesor = thickness].

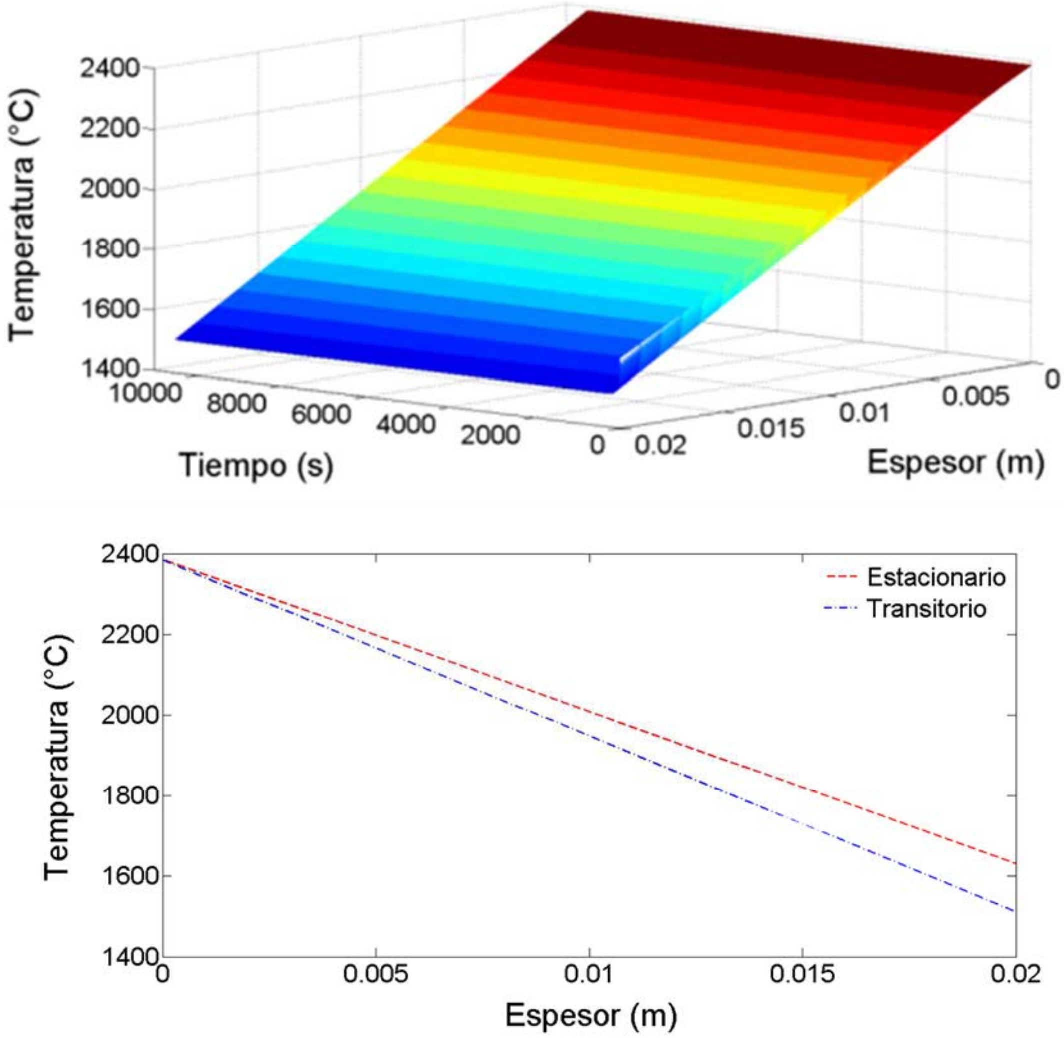

FIG. 11. Temperature of the metal layer during heating of the remaining water, [3] [temperatura = temperature; tiempo = time; espesor = thickness].

3. CONCLUSIONS

The development of this platform began two years ago, good results have been obtained from the work, human resources have been trained in the academic institutions involved, and production of articles published in magazines, congresses and international indexed journals, as well as the project has been presented through different events.

The scope of this tool considers applications in analysis of reactors in operation, regulation in power reactors, research and teaching. The methodology of this project contemplates mathematical models and numerical models fully developed and implemented by the Mexican institutions, mainly the aforementioned ones.

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DEVELOPMENT AND APPLICATION OF WWER1000 PC BASED SIMULATORS FOR EDUCATION AND TRAINING IN NRNU MEPHI

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Abstract

The computer based informational and educational tools of different type are very attractive for students, useful and effective for education in Universities. Two WWER1000 reactor PC Based simulators for education are presented in the paper. Basic Principle WWER1000 PC Based Simulator is used for informational and educational purposes, while WWER1000 PC Based Analyzer can be used in steady state and transient analysis in education and research.

1. SYNOPSIS OF PAPER

The WWER1000 PC Based Simulator is a part of IAEA collection of PC Based Simulators for education. Simulator provides insight of the design as well as a clear understanding of the operational characteristics of WWER1000 reactor and demonstrates main physical phenomena in WWER1000 reactor (Fig. 1). The WWER1000 PC Based Simulator can be used as an introductory educational tool as well as a tool for developing of nuclear engineering courses.

The WWER1000 PC Based Simulator was originally developed for personnel training. It is executed on a personal computer in real time and provides a dynamic response with sufficient fidelity. After reducing the scope of modelling to the systems essential for overall correct response and fidelity and cutting out a number of auxiliary systems the Simulator becomes suitable for educational and information purposes. Application of Simulator is limited to providing general response characteristics of WWER1000 reactor. The WWER1000 PC based simulator is not intended for using for plant specific purposes such as design, safety evaluation, licensing or operators training.

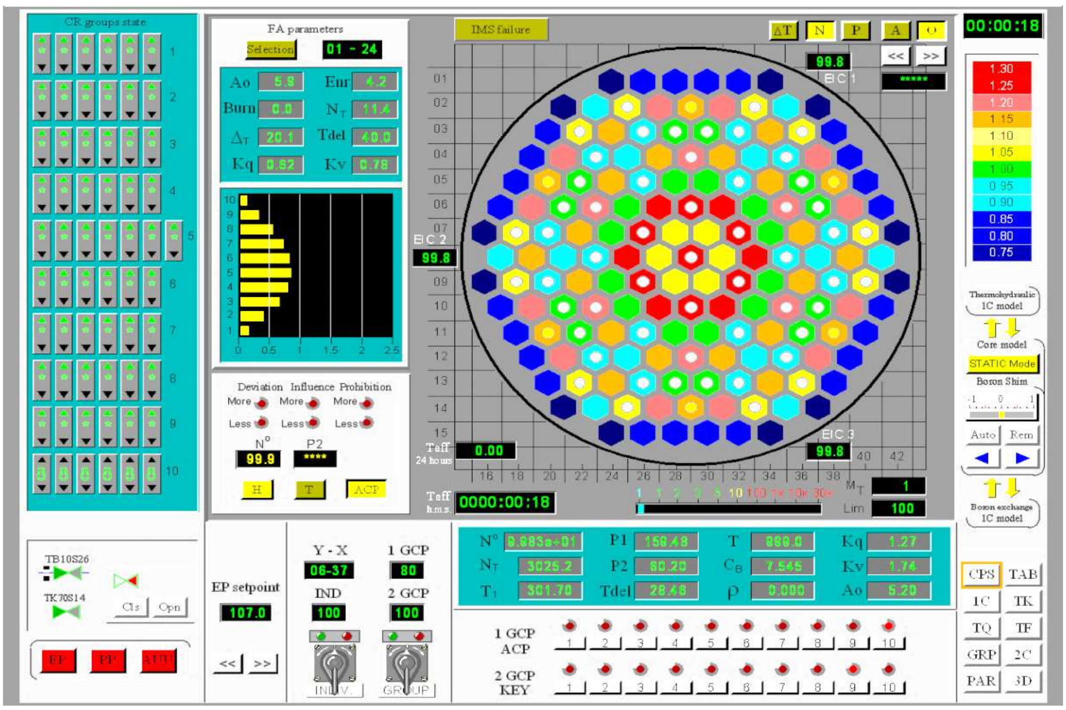

FIG. 1. WWER1000 PC based simulator graphical user interface.

Scope of modelling covers reactor, primary circuit, pressurizer and primary circuit pressure compensating system, primary circuit feed and bleed system, including boron regulation, secondary circuit steam lines and feedwater pipelines, control and protection system and safety systems.

Scope of simulation covers normal operational conditions, including reactor startup, working at rated power level, reactor shutdown and abnormal operational conditions like reactor cooling pump trip, valves closure etc. If malfunction can be removed it's possible to come back to normal operational conditions.

Main physical phenomena simulated into reactor core are transients on prompt and delayed neutrons, xenon transients coursed by changes of reactor power level, xenon radial and axial power distribution oscillations, samarium poisoning, fuel burnup (without core refuelling) and residual heat.

The WWER1000 PC based simulator training tasks give Simulator user practical skills of Simulator control, help to become familiar with reactor construction and operational experience and demonstrate main physical phenomena in the reactor and reactor core. Simulator workshop materials provide description of every training task that gives learning objectives, sequence of actions to be performed by Simulator user and reference to the corresponded Simulator display pages outputs and controls.

The WWER1000 Reactor Department Multi Functional Analyzer (MFA–RD) is an upgraded and extended modern analogue of WWER1000 Reactor Department Simulator. MFA–RD was benchmarked against a wide range of WWER1000 experimental and calculated data and it was certified for WWER1000 type reactors computations by the State Atomic Inspection of Russia. As a result of MFA–RD specific adaptation to solution of numerous educational problems in the field of neutron physics, thermal hydraulics and control of nuclear power plants, the Educational and Research (E&R) Laboratory 'Reactor Physics, Control and Safe Operation of WWER type NPP' was developed [1].

The WWER1000 PC Based Simulator gives an understanding of the reactor construction and operational characteristics while E&R Laboratory can be used for WWER1000 reactor steady state and transients' analysis.

Currently Educational and Research Laboratory Reactor Physics, Control and Safe Operation of WWER type NPP is used for educational purposes in the National Research Nuclear University MEPhI, Russian Federation, Moscow; in the Belorussian State University (BSU) and in the Belorussian State University of Informatics and Radio electronics (BSUIR), Minsk; in the State Engineering University of Armenia (SEUA), Yerevan. E&R Laboratory was installed in BSU, BSUIR and SEUA under IAEA's Technical Cooperation projects.

The WWER1000 PC Based Simulator is used for IAEA Training Courses; last two courses took place in Jordan Atomic Energy Commission (JAEC), Amman, Jordan, 22–26 November 2015 and in Arab Atomic Energy Agency (AAEA), Tunis, Tunisia, 11–15 July 2016. WWER1000 PC Based Simulator is distributed free of charge among IAEA member states institutions.

The NRNU MEPhI experience in WWER1000 PC Based Simulators and corresponded educational and training courses development and application [2] demonstrates high efficiency of learning by doing methodology in human resource development for nuclear industry in different countries and different institutions.

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PC BASED SIMULATOR OF NPP WITH WWER1200 REACTOR: OPERATION AND SAFETY ANALYSIS ORIENTED TRAINING AND EDUCATION IN VINATOM

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Abstract

The PC based Generic WWER1200 Simulator has been installed in the Nuclear Training Center of VINATOM and it is expected to be training tool to maintain human resource not only for VINATOM employees, but also for training and education in universities. Verification of simulator for normal operation and transient scenarios has been performed and main parameters are presented in the paper.

1. INTRODUCTION

In the framework of IAEA TC Project VIE2010 on Developing Nuclear Power Infrastructure, the Generic WWER1200 Simulator has been supplied for Vietnam in December 2015. Vietnam Atomic Energy Institute (VINATOM) in cooperation with Vietnam Atomic Energy Agency conducts the utilization of the simulator.

The simulator is supplied by Western Service Co. (WSC), US with 3KEYMASTER™ modelling tools which include 3KEYMASTER™ Instructor Station and thermal hydraulics, Balance of Plant (BOP) and Reactor Core using CMS tool (JET, Russian Federation). 3KEYMASTER™ Instructor Station is a full featured Windows based system for the control and monitoring of simulators. The 3KEYMASTER™ Instructor Station is used to control the simulator and run training scenarios, to monitor and record student and instructor actions, it includes: run, freeze, snapshot, initialize, backtrack, etc. These models combine to form the engineering simulator as defined by IAEA.

The simulator of nuclear power plant with WWER1200 nuclear reactor runs in real time mode. It is PC based simulator with one server for instructor and four clients for trainees as shown in Figure 1. The system can simulate the NPP in normal operating conditions as well as in the transient or accident scenarios. The startup and shutdown procedures are given in detail.

The simulator has been used in nuclear engineering courses (in particular, fundamentals of nuclear engineering and safety assessment of nuclear power plant). In the simulator lab, the instructor can introduce a malfunction or accident scenarios in the server computer and thereby allowing students to realize the phenomena and propose actions to react to unknown and identify cause and corrective action. For the advanced users like researchers simulator is also employed in research to evaluate human performance in case of accident scenarios. Since nuclear energy projects are not only initiated in the country, but also in the regional area, the simulator also serves as an excellent learning tool for people to understand about technologies and safety of nuclear power plants.

A 2004 report by the IAEA [1] highlights the historic development of training simulators and defines four different types of plant simulators: basic principles simulator, full scope simulator, other than full scope control room simulator and part task simulator. PC based generic WWER1200 NPP simulator is one of other than full scope control room simulator.

2. VERIFICATION FOR NORMAL OPERATION

Verification of simulator scenarios for normal operation and some accident scenarios has been performed and main parameters are reported in Table 1. It is expected to ensure that specified learning objectives can be achieved and the simulator performs in accordance with design.

TABLE 1. DESIGN PARAMETERS IN OPERATION IN NOMINAL POWER

Parameter	Simulator [2]	Ninh Thuan Project [3]	AES 2006 Generic Design [4]
Reactor thermal power, MW	3212	3212	3212
Nominal electric power, MW	1178–1183	1186	1198
Reactor Outlet pressure, MPa	15.91–16.11	16.2 ± 0.3	16.2 ± 0.3
Reactor coolant flow rate, m^3/h	86333	88000(+2100 –3100)	88000
Reactor coolant inlet temperature, ^0C	297.6	298.2 +2 / -4	298.2
Reactor coolant outlet temperature, ^0C	328.8	328.6 ± 4	328.9 ± 5
Reactor heat-up, ^0C	30.5	30.7	30.7
Pressurizer level, m	8.13 ± 0.01	8.17 ± 0.15	8.17 ± 0.15
SG water level, m	2.7 ± 0.01	2.7 ± 0.05	2.7 ± 0.05
SG steam pressure, MPa	7.0 ± 0.02	7.0 ± 0.1	7.0
Steam temperature at SG outlet, ^0C	284.8	285.8 ± 1.0	287 ± 1.0
Feedwater temperature, ^0C	226.8 ± 0.15	225 ± 5	225 ± 5
Feedwater flow in SG1/2/3/4, t/h	1614–1668	1602 + 112	1602 + 112
Operation at load of (%Nnom):			
- 4 RCPs;	100 %	100 %	100 %
- 3 RCPs;	64 %	67 %	67 %
- 2 RCPs (opposite);	49.5 %	50 %	50 %
- 2 RCPs (adjacient)	40 %	40 %	40 %

TABLE 2. FAILURES SIMULATED IN THE SIMULATOR

Failure Code	Number of failures	Description
CCxx	2	Damage in CC H/X elements or pumps
CHxx	2	Air leak into the containment or into the annular space between outer and inner containment shells
CPxx	7	Damages in condensate system (pump, LPH tube leak…)
CVxx	9	Failures in CVCS system
CWxx	2	CWS header leak or Clogging of treatment filters CWP
EDxx	17	Failures in electrical system
EGxx	13	Failures in generator system
FWxx	9	Failures in Feedwater system
MSxx	13	Failures in main steam lines
NIxx	3	Failure in measuring channel FMS, RIMS
RDxx	14	Malfunctions or failures in control rod groups
SIxx	4	Failures in Emergemncy Core Cooling System (ECCS) and spent fuel pool
SWxx	3	Failures in-service water system
TCxx	10	Failures in turbine systems (steam supply, control valve …)
THxx	17	Leak, break or ruptures in RCS
TUxx	4	Failures in turbine unit (oil cooler leak, rotor vibration…)
Total	129	

Malfunctions simulated by the Simulator are summarized in Table 2. On the view points of safety analysis, the accident scenarios frequently analyzed are in groups of THxx, FWxx, MSxx and RDxx for examples: Loss of coolant accident (LOCA), feedwater line break (FWLB), main steam line break (MSLB) or reactivity insertion accident etc.

The training courses and practices using the Simulator can be specified by three levels as follows:

1. Understanding of Technical features and main parameters of NPP, in which the trainees or students should check for:

— Main technical specification data and generic layout of AES2006 plant;
— Main normal operation systems/equipment of a WWER1200 unit;
— List and explain design basics of safety systems/equipment of a WWER1200 unit;
— List and explain design basics of auxiliary systems/equipment of a AES2006 plant.

2. Practice to startup and shutdown operations:

— List and explain WWER1200 standard operation states;
— Explain main operations sequence in transition between standard operation states.

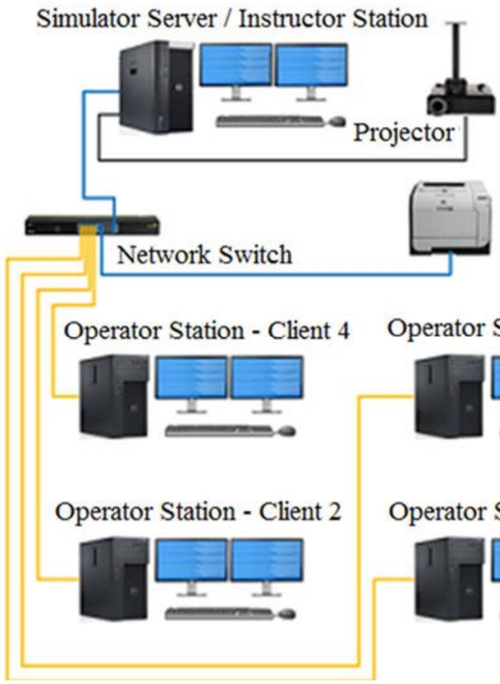
3. Accident simulations:

— Explain main operational limits and conditions;
— List and explain malfunctions and simulate the accidents with or without operator’s actions.

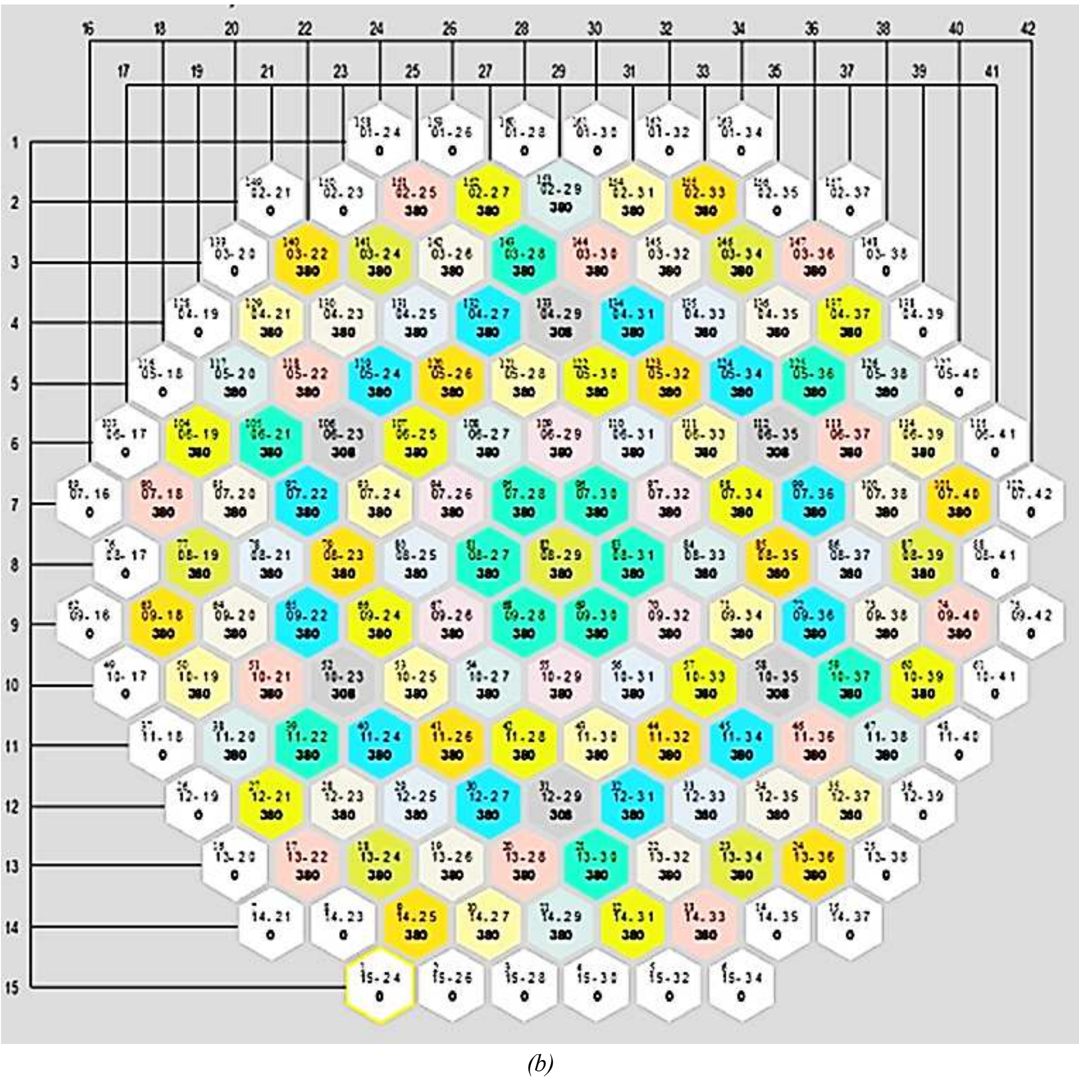
Tentative plan for utilization of the simulator is to train staff of related organizations like technical support engineers, operations management and research engineers. To maintain the human resources, students, lecturers, teachers from universities are expected to be trained on the simulator. For the R&D works, it is also useful for strengthening of capacity through carrying out research/study supporting activities such as safety assessment and analysis and performing of training courses on the thermal hydraulics and technology of advanced generation of WWER reactors.

3. EXAMPLE ON REDUCED POWER OPERATION WITH ONE MCP SWITHCHED OFF

In the operation of WWER1200 which permits one or two MCPs to be switched off. The signals from the system initiates control protection system with control rods and drives will reduce power or prohibit power rise, so that it can avoid the reactor trip and prevent violation of safety limits and conditions. Figure 2 shows the flow rate of RCP–1391 used in WWER1200 NPP and its rotation speed when one out of four operating RCPs trips compared with the results from the simulator. The further studies on the simulator of WWER1200 should be performed to gain better understanding of operation processes and safety systems in modernized WWER nuclear reactors.

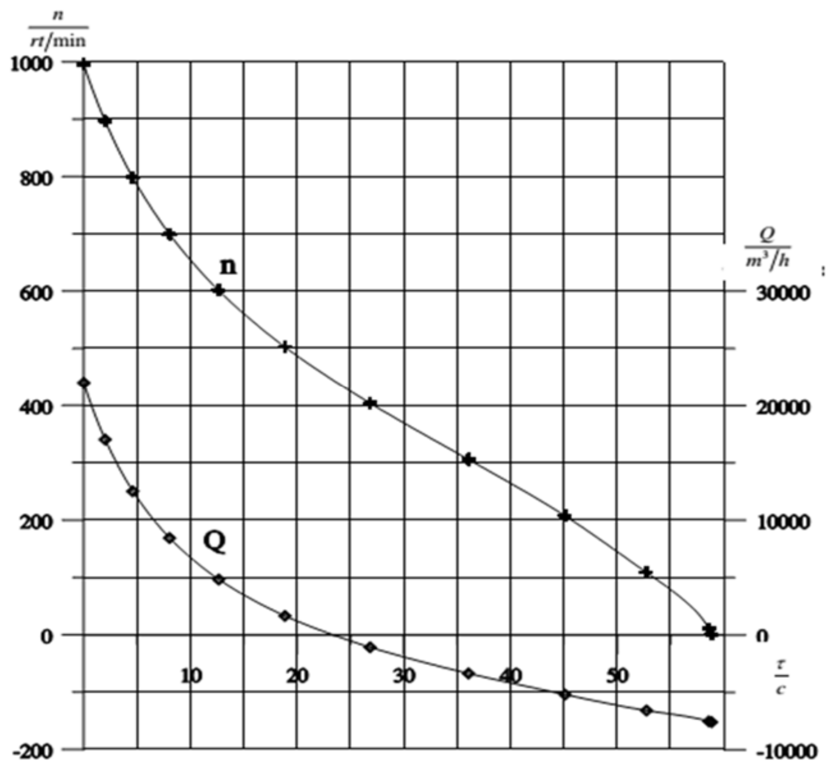


(a)

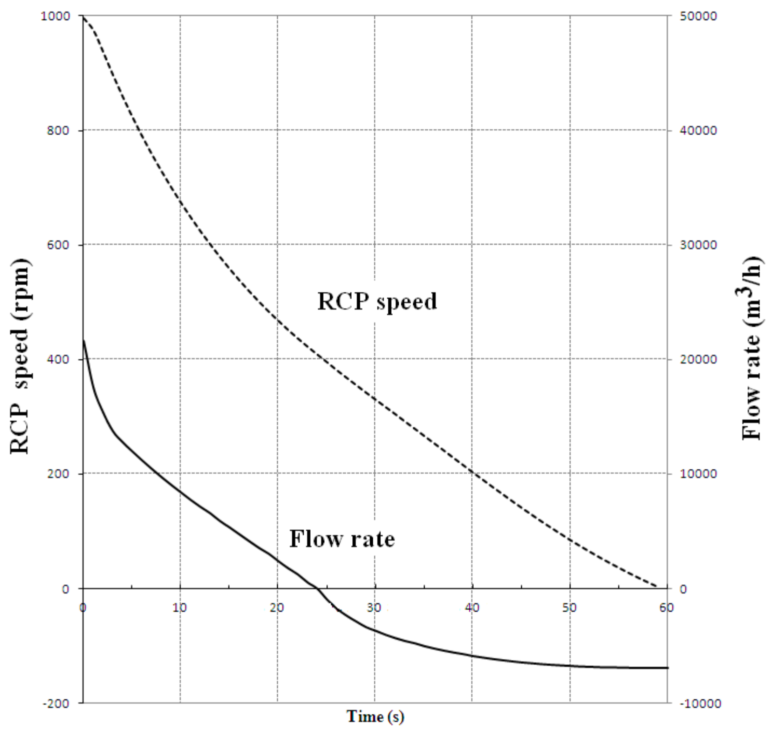


(b)

FIG. 1. (a) Simulator layout; (b) Control rod groups in-reactor core of the simulator.



(a)



(b)

FIG. 2. (a) Mass flow rate of MCP–1391 and rotation speed when one out of four operating MCPs trips (FSAR[3]), (b) Simulator.

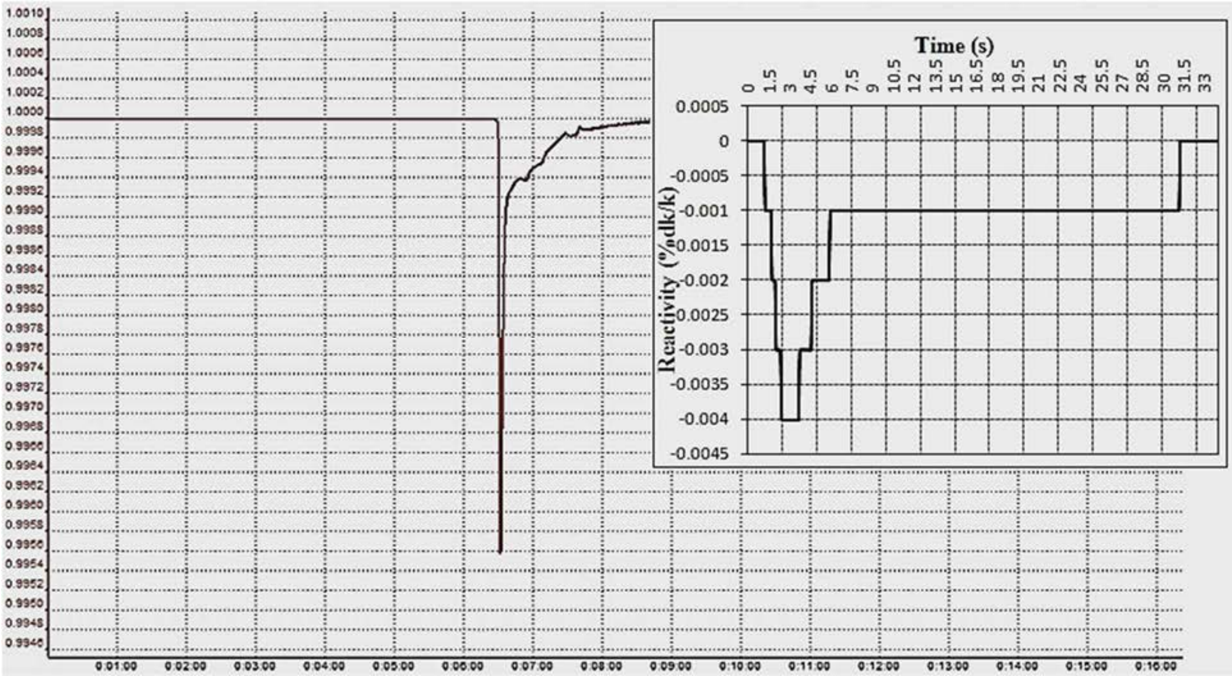


FIG. 3. Variation of reactivity during transient (MCP#3 OFF).

4. CONCLUSIONS

The PC based Generic WWER1200 Simulator has been installed in the Nuclear Training Center of VINATOM and defined as training tool to maintain human resource not only for VINATOM employees, but also for training and education in universities.

For the education, the use of the simulator in the link with universities it is expected to improve effectiveness and better interconnection between study subjects delivered in universities, training courses and simulator training.

Upon completion of the training courses on the simulator, participants are expected to understand basic systems, components and operating principles for WWER; learn more in design characteristics and safety concepts for WWERs; and get better understanding of various kinds of plant behaviors during normal operation, transients and accidents.

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UNIVERSITY OF UTAH RECENT LESSONS LEARNED IN PC BASED SIMULATOR TRAINING WITH EXAMPLES

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Abstract

The Utah Nuclear Engineering Programme (UNEP) has implemented the use of small PC based computer nuclear reactor simulators in the training and education of students and prospective research reactor operators. The specific simulators in use by UNEP are two simulators provided by the International Atomic Energy Agency (IAEA) called PCTRAN Research Pool Reactor and PCTRAN Two Loop PWR simulators and the in house designed simulator called the University of Utah TRIGA Reactor (UUTR) simulator. The three simulators serve different purposes in the training process to either simulate actual UUTR operation or demonstrate reactor theory and core concepts. Students are allowed to experiment and master the simulators and then tasked with teaching other students about their assigned simulators. This enhances the learning process by giving the students learning by doing atmosphere. Severe accidents from the history of nuclear power such as the Three Mile Island accident are replicated and demonstrated for student understanding and edification of the implications of nuclear reactor accidents. Feedback and testing of students that have been trained using the simulators has resulted in positive feedback and retention of key nuclear concepts.

1. INTRODUCTION

The Utah Nuclear Engineering Programme (UNEP) is home to a 100 kW TRIGA Reactor which has been in operation since 1975. UNEP has implemented novel educational and training programmes that have resulted in better trained operators [1–5]. One aspect of this improvement process was the development of a new U.S. Nuclear Regulatory Commission (NRC) licensed reactor operator training programme in the past 5 years. The Program includes two graduate level classes developed for educating and training the students toward their operator licenses. On average the facility accommodates 6 to 12 students each year who successfully complete the training requirements. Part of the revamped training tasks new trainee reactor operators to experiment and learn reactor theory and operational skills by utilizing PC based computer simulators.

2. PC BASED SIMULATORS IN USE BY THE UTAH NUCLEAR ENGINEERING PROGRAMME

UNEP has selected a variety of different PC based simulators to be utilized in the training including training simulators made available by the International Atomic Energy Agency (IAEA) along with a simulator developed by students at the University of Utah to specifically model the University of Utah TRIGA Reactor (UUTR) [6]. The two IAEA provided simulators that have been utilized by UNEP in the reactor operator training are the PCTRAN Research Pool Reactor simulator and the PCTRAN Two-loop PWR simulator as seen in Figures 1 and 2 respectively [7].

The PCTRAN Research Reactor simulator is based on a TRIGA type 250 kWth power reactor and is a useful tool for demonstrating operator actions and basic reactivity trends. Its basic operation limits its capabilities; however, it displays several values such as k_{inf} and k_{eff} which are not typically available during reactor operation. These are used to enhance understanding of basic principles of nuclear reactor physics. The PCTRAN two loop PWR simulator is based on a generic two loop PWR with inverted U–bend steam generators and dry containment system. The thermal output of the plant is approximately 1800 MWth (600 MWe). This simulator is useful in demonstrating the complexity and interactions of the various systems in a full power plant as well as exhibiting severe accident conditions.

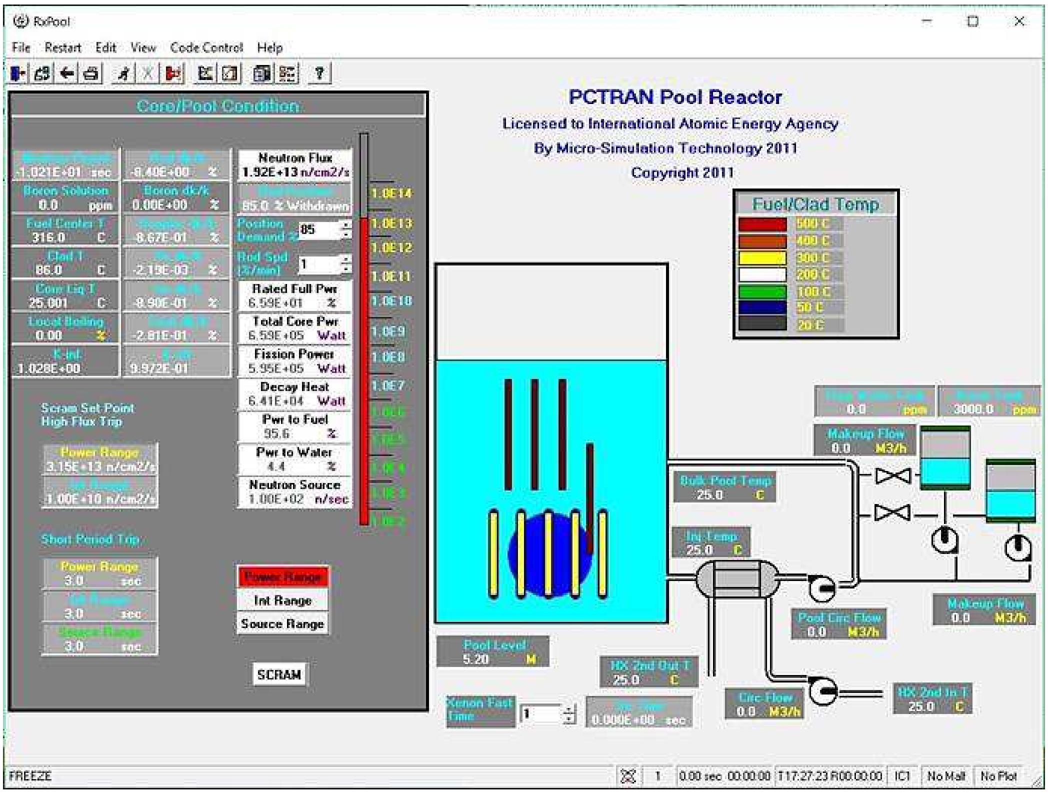

FIG. 1. PCTRAN research pool reactor.

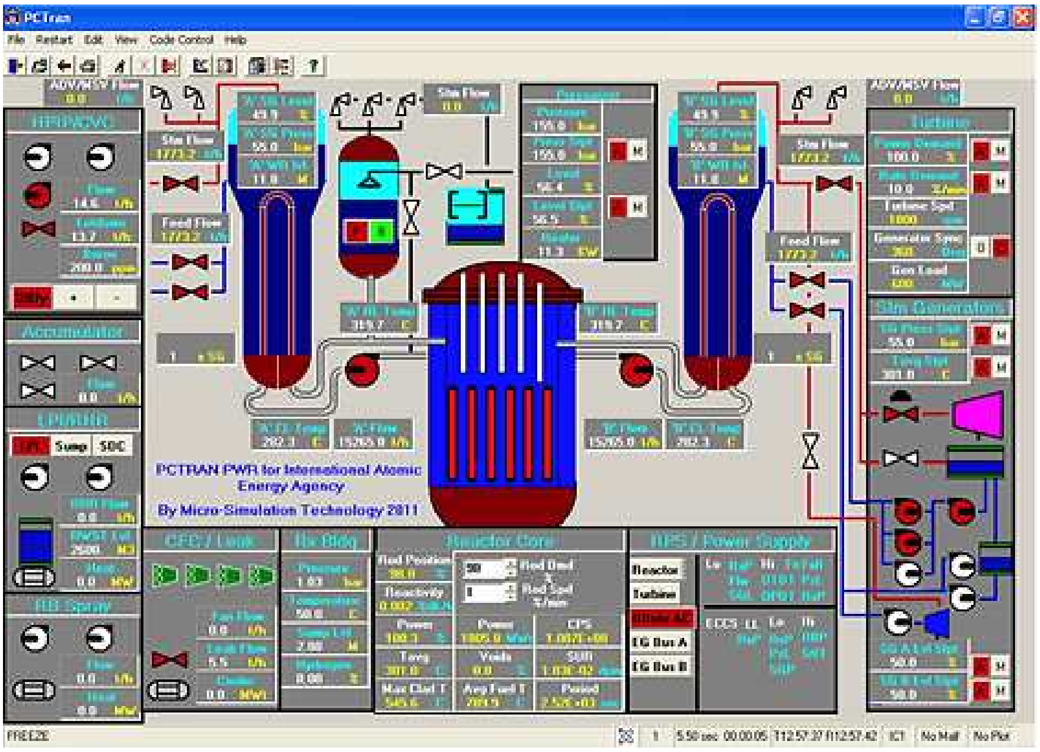

FIG. 2. PCTRAN two-loop PWR.

The final simulator for reactor operator training was developed by UNEP students and is a PC based simulator in python code that imitates the UUTR (UUTR Simulator). The UUTR Simulator replicates the operator interface of the University of Utah TRIGA Reactor console. This is ideal for learning to operate the UUTR and understanding what information will be available to an operator. The simulator provides a realistic interface and knowledge gained can easily be transferred to observation of actual reactor operations. The main operator screen can be seen in Figure 3.

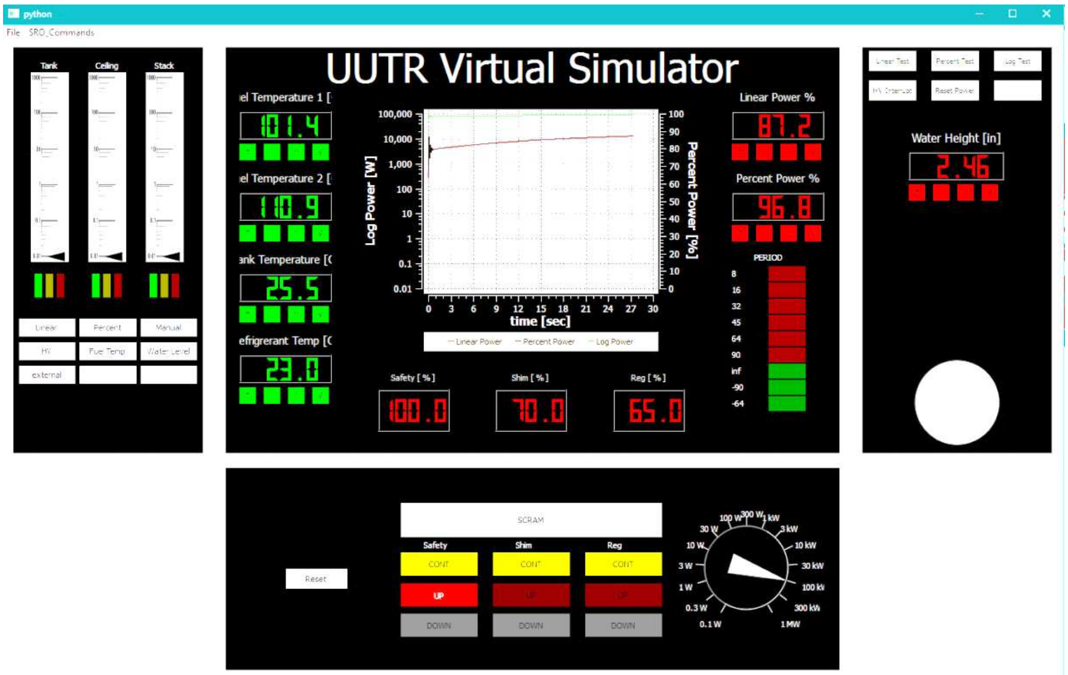

FIG. 3. UUTR simulator: interactive simulated console interface.

The simulators are first introduced to all of the students in a general overview lecture format. Then the students are split into teams that become the designated 'experts' of the different simulators. This allows the students to experiment on their own and learn the capabilities of the different simulators by experimentation. Once the students have been given adequate time on their assigned simulator, they then become the teachers and trainers to the other students. This not only utilizes the learning by doing concept of employing the PC based simulators but also allows the students to retain their knowledge and information by teaching others. This on its own represents a support to the overall nuclear engineering programmatic approach on active learning derived from the Bloom's taxonomy of cognitive domain.

The PCTRAN Research Reactor Pool simulator is utilized to reinforce reactor theories and concepts from operations such as the expected negative period obtained during a reactor SCRAM from high power, subcritical multiplication, and 1/M plots during a reactor startup.

The UUTR Simulator allows students to practice the actual controls of the TRIGA reactor and become accustomed to how power of the reactor responds to control manipulations. The students can also practice actual startups of the reactor and become familiar with switch and indication placement and operations.

Lastly, the PCTRAN two loop PWR Simulator allows students to visualize and discuss the impacts of power plant emergencies and severe accidents. Students and participants have gained a better understanding of severe accidents and given positive feedback on the severe accident reproduction of the Three Mile Island (TMI) accident using the PCTRAN two loop PWR Simulator. Students are taught how to reproduce the TMI–2 accident scenario that occurred on March 29, 1979 in the simulator [8]. The following sequence of events is introduced into the simulator:

1. Loss of the condensate pump leading to loss of both main feedwater pumps.
2. Both sides' auxiliary feedwater isolation valves are tagged out of service so that auxiliary feedwater is never available.

3. After the steam generators (SG's) are boiled dry and the primary pressure increases to lift the Power Operated Relief Valve (PORV), it stays open despite the pressure dropping below the reseat set point.
4. Continued two–phase discharge through the PORV elevates the indicated pressurizer level at a high level. The operator turns off the high pressure injection pumps.
5. Bulk boiling takes place in the reactor core. It is witnessed by diminishing sub–cooling margin and a void in the reactor vessel head.
6. After the core is uncovered, the clad temperature increases rapidly and reacts with steam to generate hydrogen.
7. Hydrogen is released through the stuck-open PORV and ruptured coolant drain tank. Its concentration is observed in the containment.

Students monitor the various indications for this event and view the transient plots for key parameters.

3. CONCLUSIONS

Students participating in the simulator training have given exceptionally positive feedback on use of the simulators and understanding of reinforced concepts by utilizing the simulators. Students have demonstrated improved retention of skills and theory practiced and observed by operating the PC based simulators. The positive feedback given from the simulator training includes allowing the students to learn by doing and teach each other the nuclear theory concepts while operating the simulators. UNEP will continue to implement and seek for new and innovative ways to use PC based simulators in licensed operator training.

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DEVELOPMENT OF A GRAPHICAL RELAP BASED ANALYSIS PLATFORM FOR EDUCATION (GRAPE) FOR FUNDAMENTAL UNDERSTANDING OF NUCLEAR POWER PLANT BEHAVIOURS

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Abstract

A platform for nuclear power plant simulation with graphical user interface using a RELAP5 based best estimate analysis code was developed. It is designed so that users can easily understand how to use the software. It is implemented on top of proven web based technology so that developer can easily maintain and extend the software. The software is available free for evaluation.

1. INTRODUCTION

It is quite important to provide a simulation system that equips realistic simulation models and easy to understand user interface at an affordable price level especially for educational institutions. It is even better to provide a means for users to modify the internal plant models and graphical user interface of the system such as display graphics corresponding to the plant model. In order to accomplish this challenging goal, we developed GRAPE [1][2], Graphical RELAP5 based Analysis platform for Education on the top of RELAP/SCDAPSIM [2] code which is maintained by Innovative Systems Software. It a best estimate code and designed to describe the overall thermal hydraulic response of reactor coolant system and core behaviour under normal operating conditions or under design basis or severe accident conditions. One of the goals in education using GRAPE is to provide an effective learning environment to students. In other words, GRAPE should be an effective tool for students to understand the behaviour of NPPs and its background theory without a struggle to learn how to use the tool itself.

2. DEVELOPMENT

In order to achieve this goal, two key factors were extracted from the viewpoints of user needs when a conceptual design of a new plant simulator was developed, which are (1) extensibility and maintainability, and (2) an easy to understand user interface. Those are realized by a modular architecture of the software and use of the web based technology such as HTML5 and Javascript. GRAPE is designed as flexible as possible in order to decouple among the calculation code, plant models and computer displays. The display graphics can be maintained with associated plant models and easily incorporated into GRAPE. Currently two plant models have been developed which are a four Loop Westinghouse type PWR in Japan (Figure 1) and a General Electric type of BWR–5 in Mexico (Figure 2). Other plant models including CANDU, WWER and research reactors such as TRIGA are also being developed by Innovative Systems Software.

In order to explain behaviours of nuclear power plants under various conditions in a relatively short period of time such as classroom lectures in university or educational institution, simple operation and intuitive display are desired. All the data in a simulation are accumulated into a database which can be saved as a project file. As for a scenario with long simulation run such as SBO (station black out) which normally consider up to several hours in the event, lecturer can distribute pre-calculated project files to students so that they can play back the scenario in their GRAPE environments. Students can understand behaviour of the plant including primary/secondary systems with major parameters in the table, display of water level and status of valves, indication of failure / malfunctions, and widget trend graphs as shown in Figure 3. Playback of simulation can be automated with the play button or manually controlled using the time slide control bar at the bottom of the window.

Trend graphs are also important to understand temporal changes of status of the components in the plant model. In order to grasp the overall behaviour, multiple trend graphs can be easily organized to display the event occurred during the simulation as shown in Figure 4. GRAPE is designed so that users can intuitively understand how to operate the system with the similar manner as the Web browser like the Internet Explorer. The “tab” in the window can be moved outside of the window to have multiple windows at the same time where these windows are all synchronized (Figure 5). This is also quite powerful to manage information as much as possible and encourage students to grasp a whole picture about the behaviour of the plant.

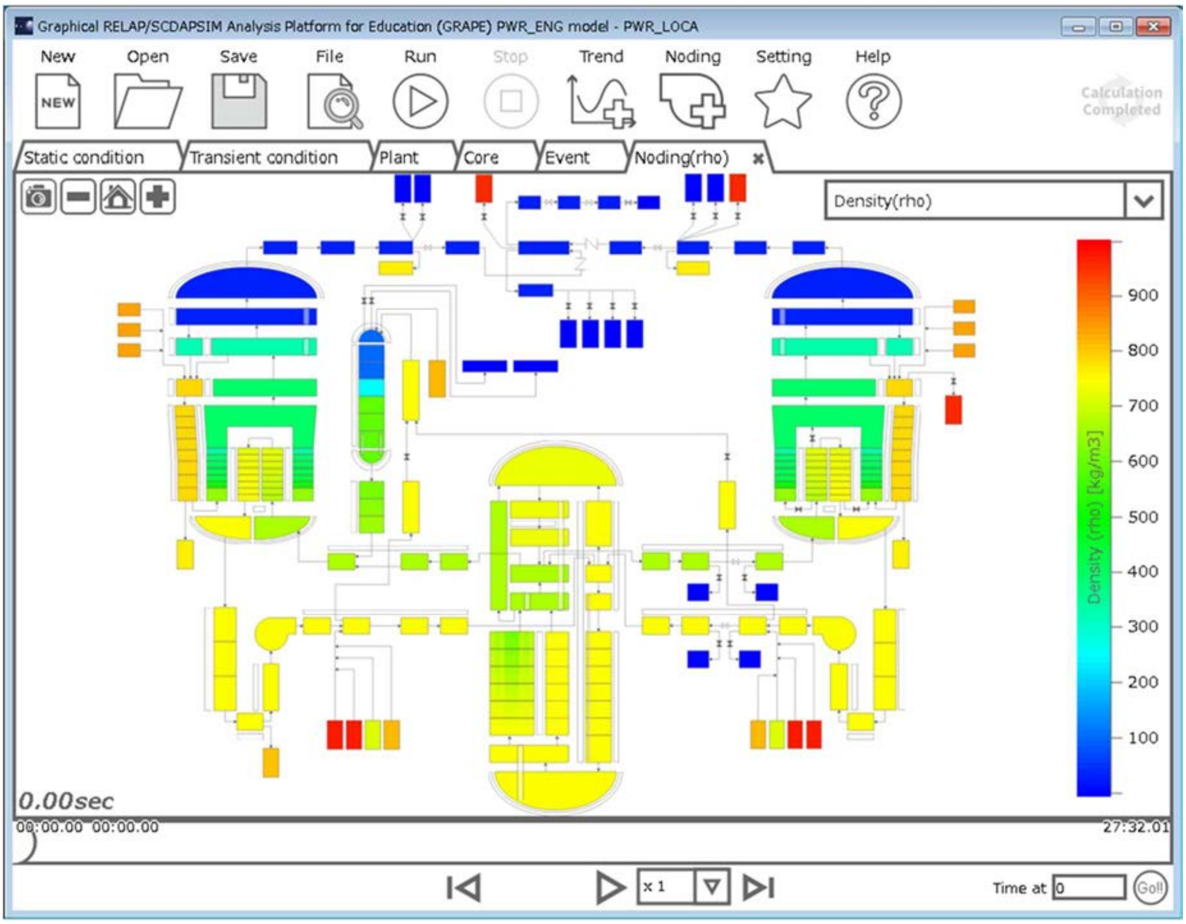

FIG. 1. Example of the noding diagram of PWR.

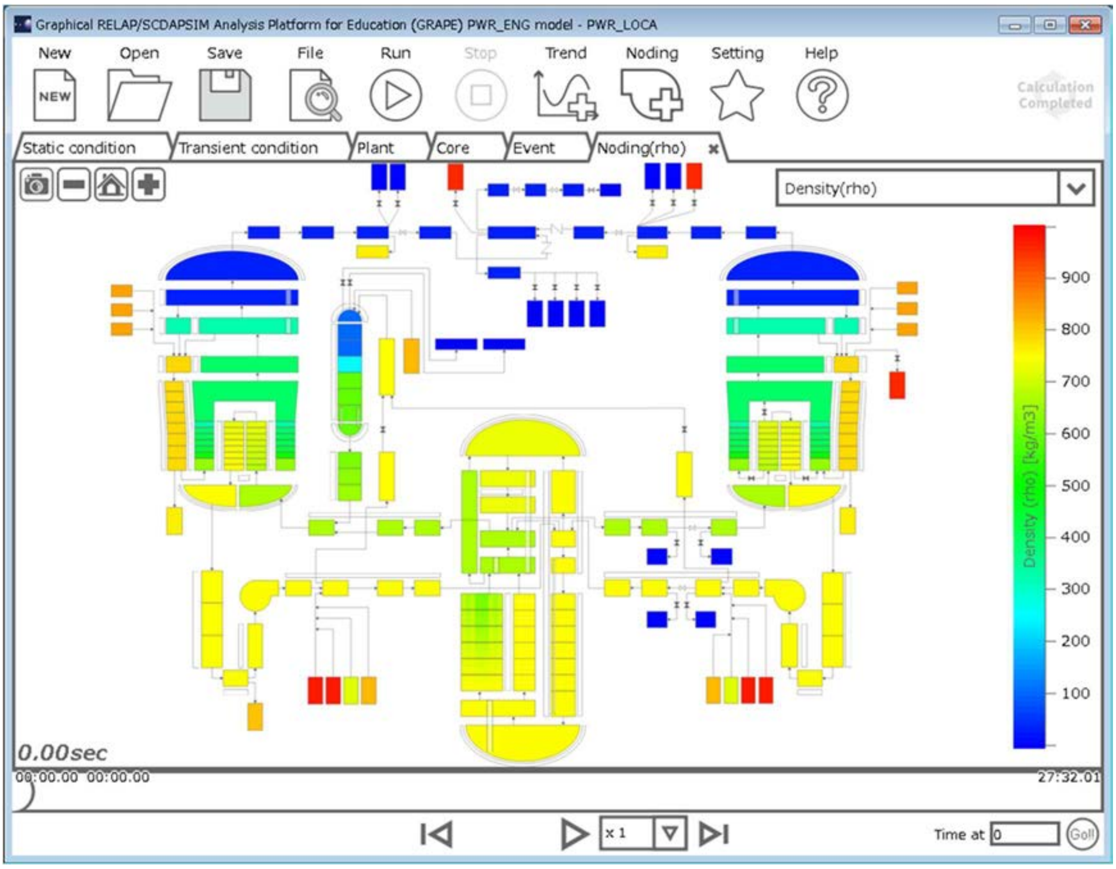

FIG. 2. Example of the noding diagram of BWR.

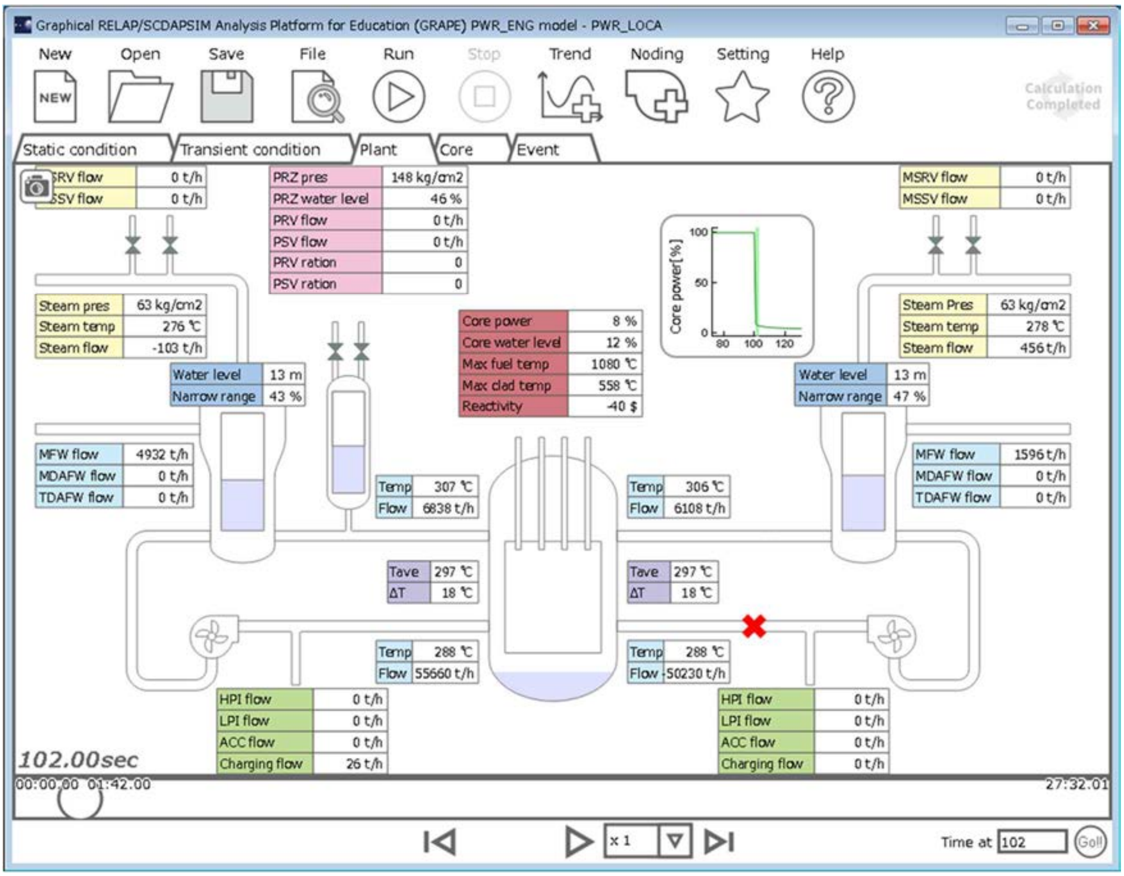

FIG. 3 PWR plant diagram.

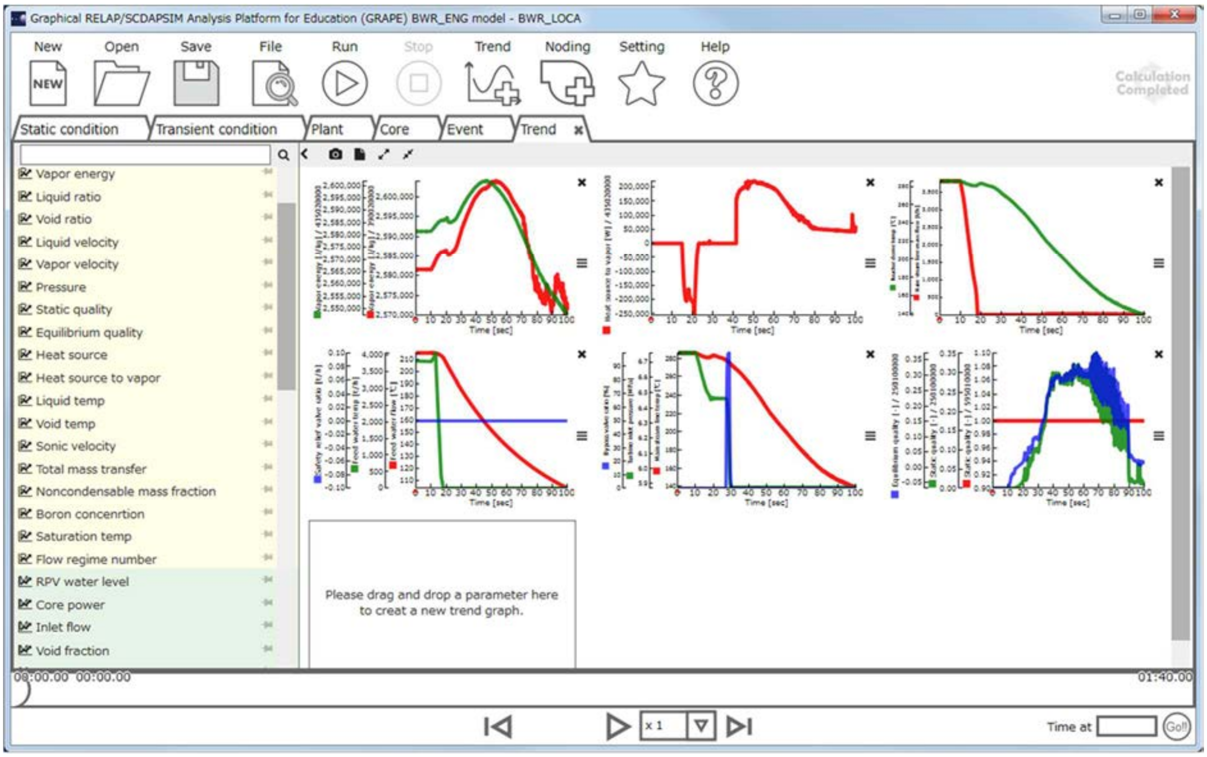

FIG. 4 Multiple trend graphs.

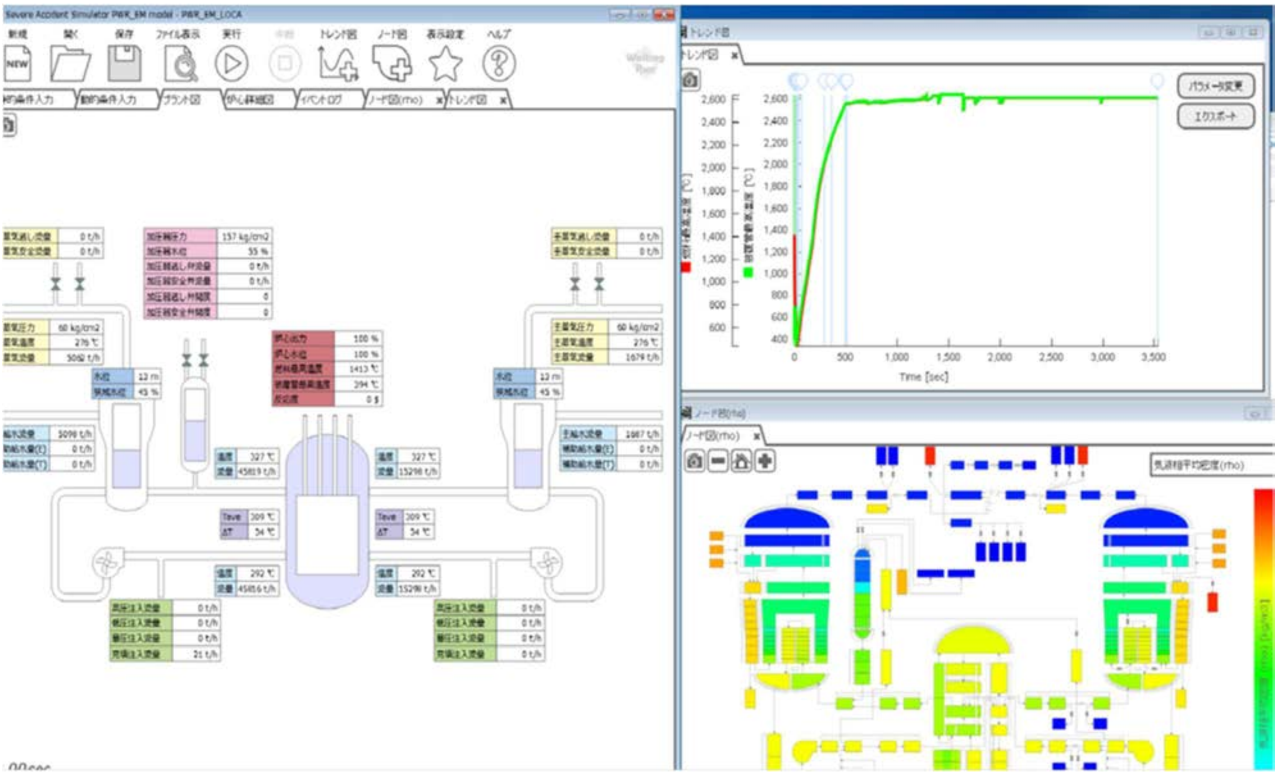

FIG. 5. Multiple windows help student look over simulation results.

3. CONCLUSIONS

GRAPE is developed as an easy to understand plant simulation platform based on RELAP/SCDAPSIM, the best estimate code for overall thermal hydraulic response of reactor coolant system and core behaviour under normal operating conditions or under design basis or severe accident conditions. Through lectures at universities and other educational institutions, effectiveness of its application to education was confirmed. GRAPE is available free for evaluations at the web site [4].

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VUJE NPP PERSONNEL TRAINING CENTER

Using experiences from modernization of FSS for building specific standalone simulation platform

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Abstract

VUJE a.s. is an engineering company that performs design, supply, implementation, research and training activities, particularly in the field of nuclear and conventional power generation. VUJE Training Centre performs both theoretical preparation and training of personnel on simulator. The basis of the training is the educational system for the areas of nuclear industry, conventional power plants, electric grid and for other users. The Training Centre develops and designs hardware and software for education and training including simulator development. It carries out examinations for granting licensees for the execution of functions in nuclear power plants and organizes specialized and international courses. The full scope simulator (FSS), a copy of the 3rd unit of Bohunice NPP control room (CR), has been recently upgraded and new features have been added to provide better, more accurate, reliable and realistic training experience. A new specific standalone simulation platform is under development to be used in classroom training for various target groups.

1. OVERVIEW

There are three (3) reactors under decommissioning, four (4) in operation and two (2) under construction in Slovakia. Total electrical power production in Slovakia is 25366 GW/h with the nuclear share of 45.86 % [1]. Bohunice Nuclear Power Plant (NPP) (Slovak: Atómové elektrárne Bohunice) is a complex of nuclear reactors situated in Trnava District in western Slovakia. Bohunice comprises two plants: V1 (shutdown in 2006 and 2008, now under decommissioning) and V2. Both plants contain two reactor units. The plant was connected to the national power network in stages in the period between 1978 and 1985. Mochovce NPP (Slovak: Atómové elektrárne Mochovce) is a complex of nuclear reactors situated in the Levice District in western Slovakia. EMO comprises two units: EMO 1,2 (first unit connected to grid in 1999, second unit in 2000) and EMO 3,4 which are now under construction. All above mentioned power reactors in operation and under construction are pressurized water reactors (PWR) of the Russian WWER440, V213 design.

In 2011 a project of modernization of FSS for Bohunice V2 (reference unit 3) and Mochovce 1,2 (reference unit 1) started with the aim to modernize the simulator software ensuring its long term and reliable operation and achievement of required accuracy of simulation. Slovenské Elektrárne (further S.E.) decided to upgrade simulators on both sites in one project due to their similar design and technology used. CORYS T.E.S.S. used the same scope and tools on these two simulators.

Figure 1 shows geographical locations of the NPP full scope simulators in Slovakia: EBO –Bohunice NPP, EMO –Mochovce NPP.

This paper is describing the process of modernization of Bohunice V2 FSS.

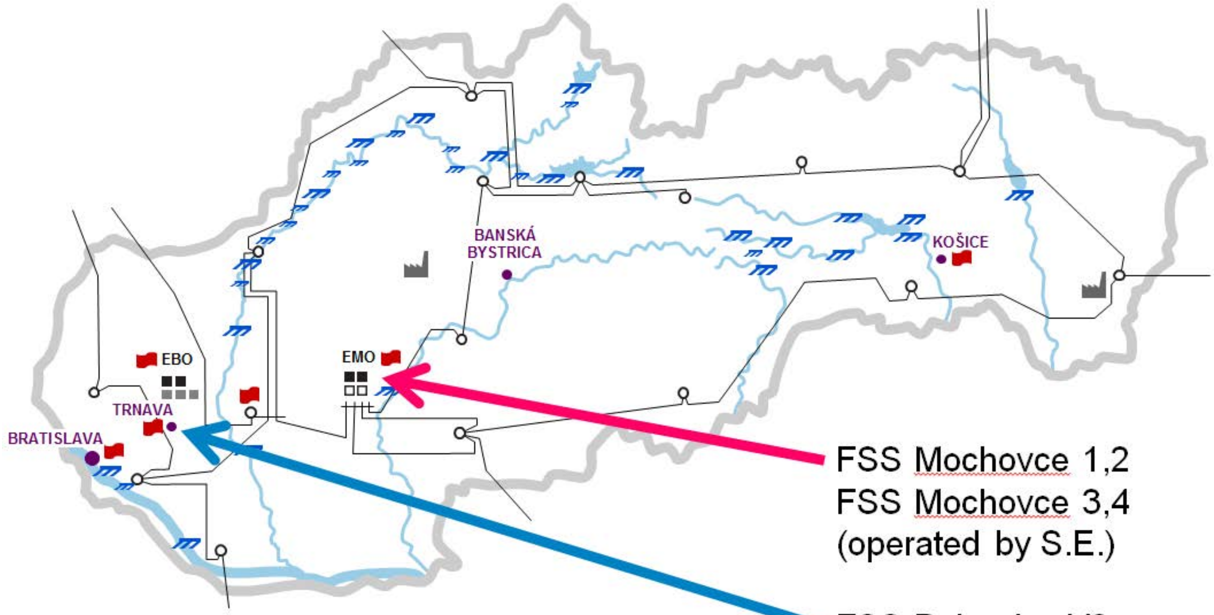

FIG. 1. NPP full scope simulators in Slovakia. Ebo - bohunice NPP, Emo –Mochovce NPP.

2. BOHUNICE V2 FSS MODERNIZATION

Project of modernization Bohunice V2 FSS consisted of two phases. There were five main tasks in phase one, so called **rehost** [2]:

- All documents were ported from SUN to PC environment and encapsulated in ALICES executive software and all existing snapshots have been converted in ALICES environment;
- Exchange communication between systems (I&C) was adapted to work in the new PC environment using ALICES software;
- Code which manages the connection to hard panels was adapted and graphic visualizer is now available;
- Two new T–Rex instructor stations were provided (119 new graphics P&IDs);
- New PCs were delivered and installed on-site.

Phase two, so called **upgrade**, was devoted to replacement of thermohydraulic code of primary and secondary circuit (THOR –two–phase, non–equilibrium, fluid dynamics model for flow networks [3], Fig. 2), neutronic code (KIKO –3D reactor dynamics program for coupled neutron kinetics and thermo-hydraulics calculation of WWER type pressurized water reactor cores [4]) and SCORPIO (Reactor core surveillance system [5]). A new connection of simulator with the Centre of emergency response in Bohunice NPP has been created to allow running emergency scenarios on simulator and in Bohunice NPP at the same time.

Factory acceptance tests, Site acceptance tests and finally License tests for Slovak regulatory authority (ÚJD SR) performed in 2014 proved that simulator upgrade met the goals and can be fully used for training of NPP operational staff [7]. Bohunice V2 FSS has now more accurate and realistic behaviour (tested and compared with real NPP data). All tests were performed according to ANSI/ANS–3.5 standards [8].

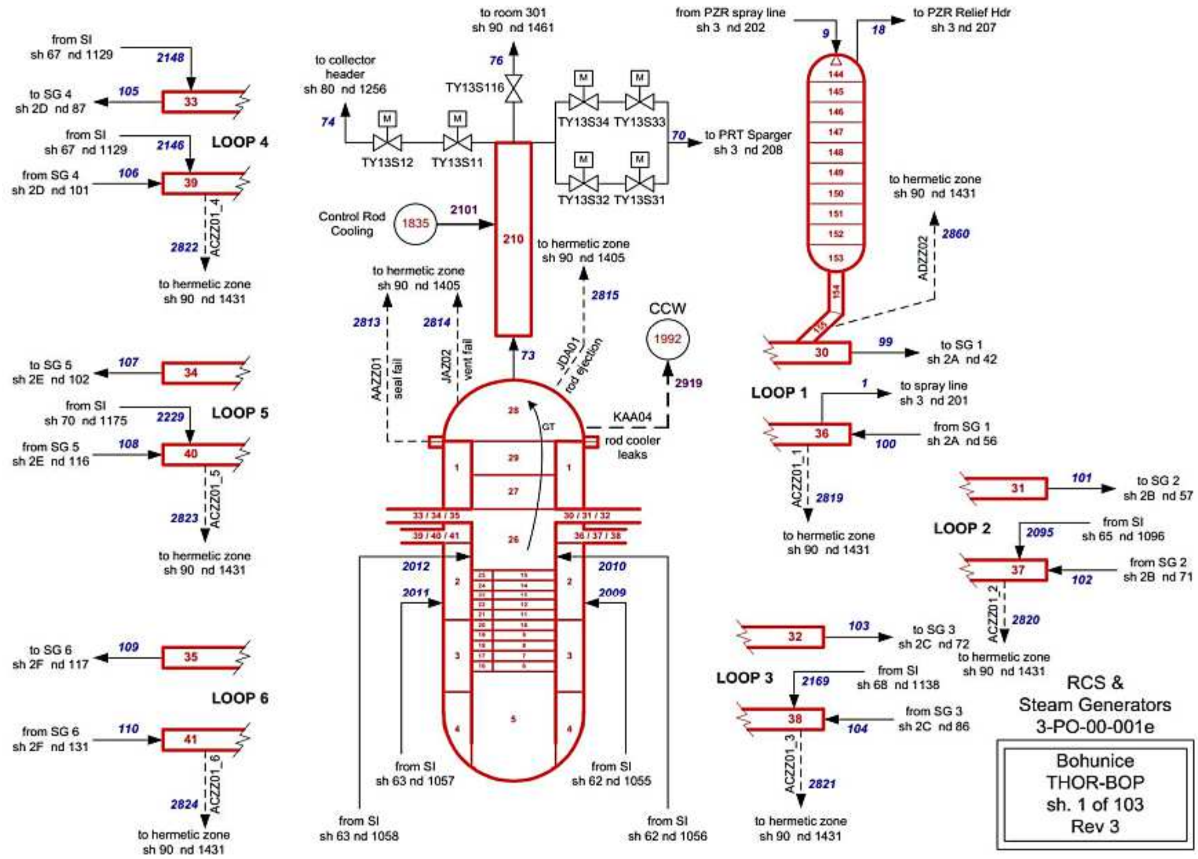

FIG. 2 Example of thor nodalization scheme [6].

3. CONCLUSIONS

Nuclear industry is always challenging. Criteria and demands for the training are getting more complex. There is always need to bring more operational staff to the training to cooperate with the shift, to visualize better, to implement new tools, to involve trainees into the process, to be more realistic or to create new scenarios (e.g. for the management of severe accidents). Therefore, after the main modernization of the FSS, VUJE did tunings and ran several projects to meet above criteria e.g.:

- Development of SAM console (Fig.3), which is now installed at Bohunice V2 NPP control room (CR) and FSS;
- New graphical visualizations (Fig.4.) for FSS instructors and trainees (e.g. during refuelling);
- New HMI (animated P&IDs) (Fig.5.) for the training of the field operator to cooperate with the shift;
- Replacement of the old electrical model of the FSS with the new one based on ThunderElectric (Fig.6.);
- Wireless instructor station;
- Implementation of bug tracking management system for FSS evolution.

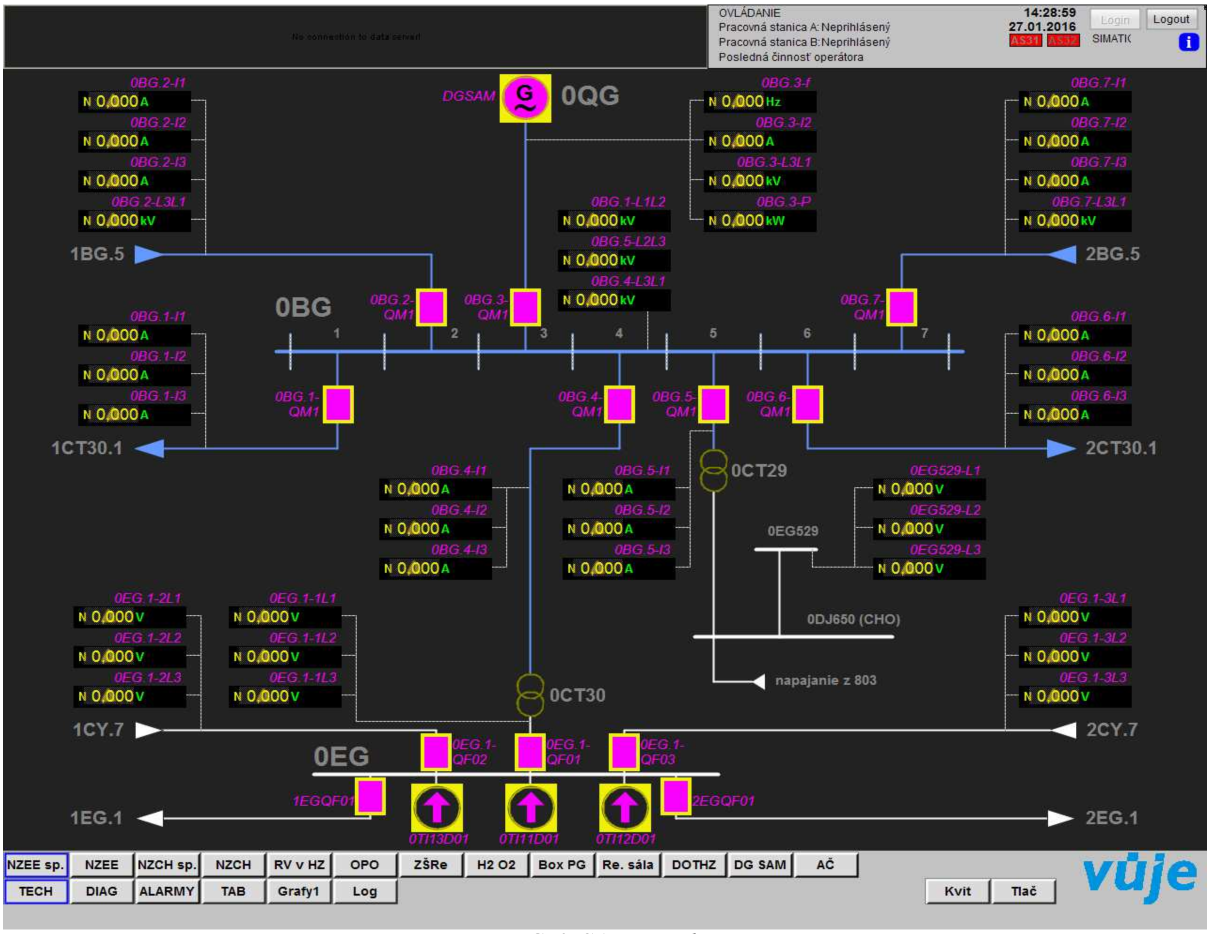

FIG. 3. SAM console.

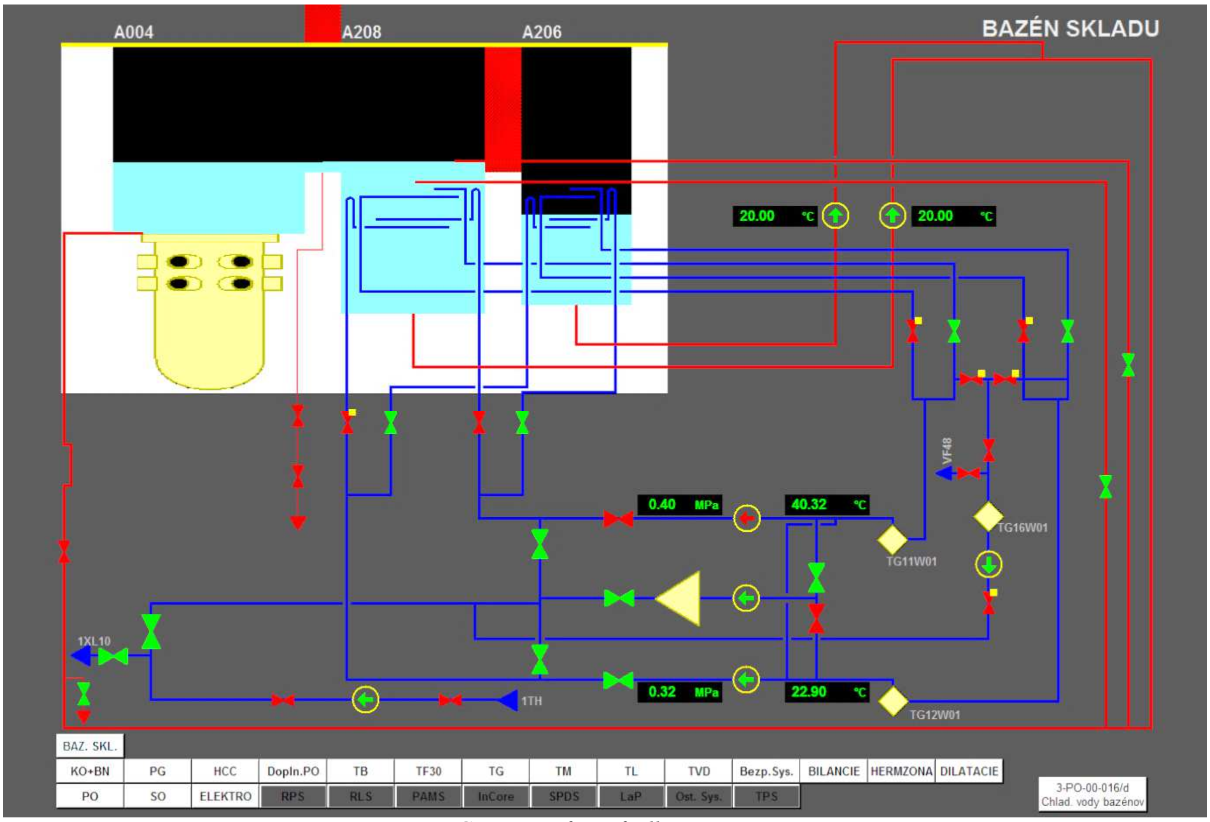

FIG. 4. MMI for refuelling scenario.

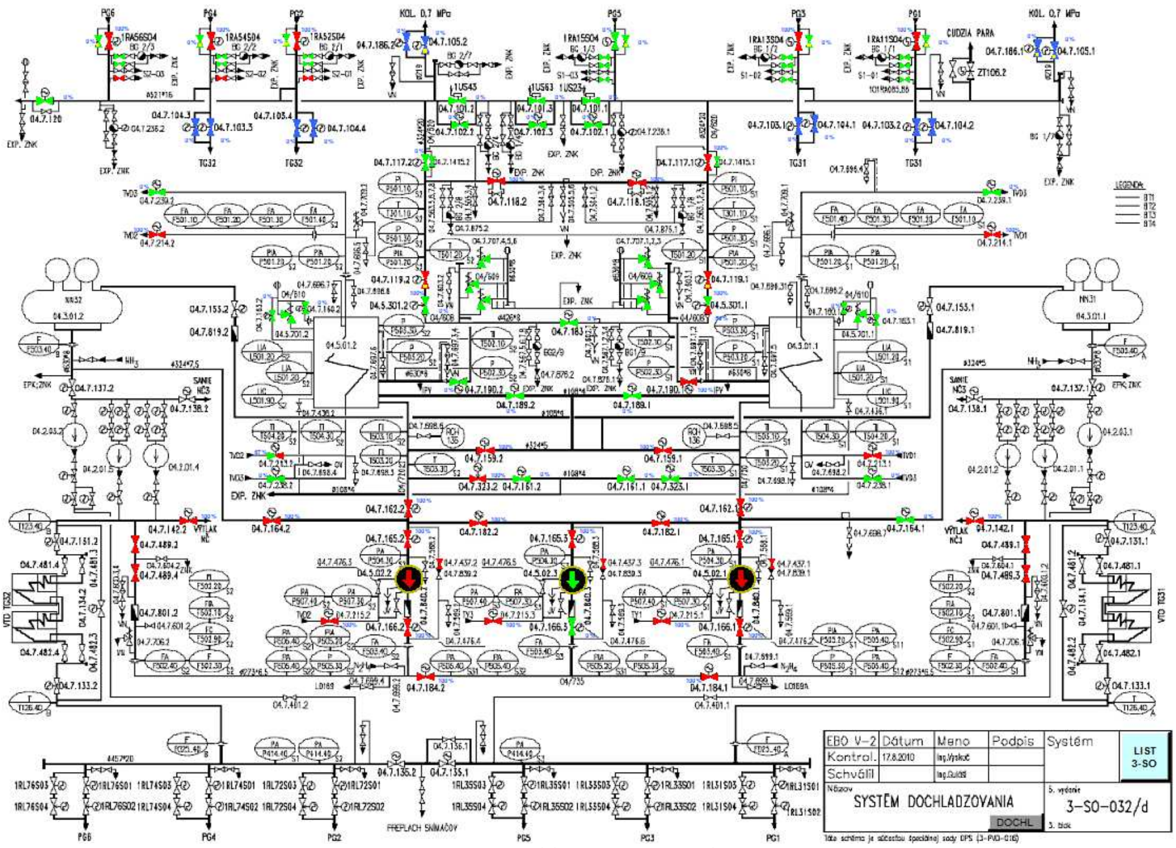

FIG. 5. Field operator console.

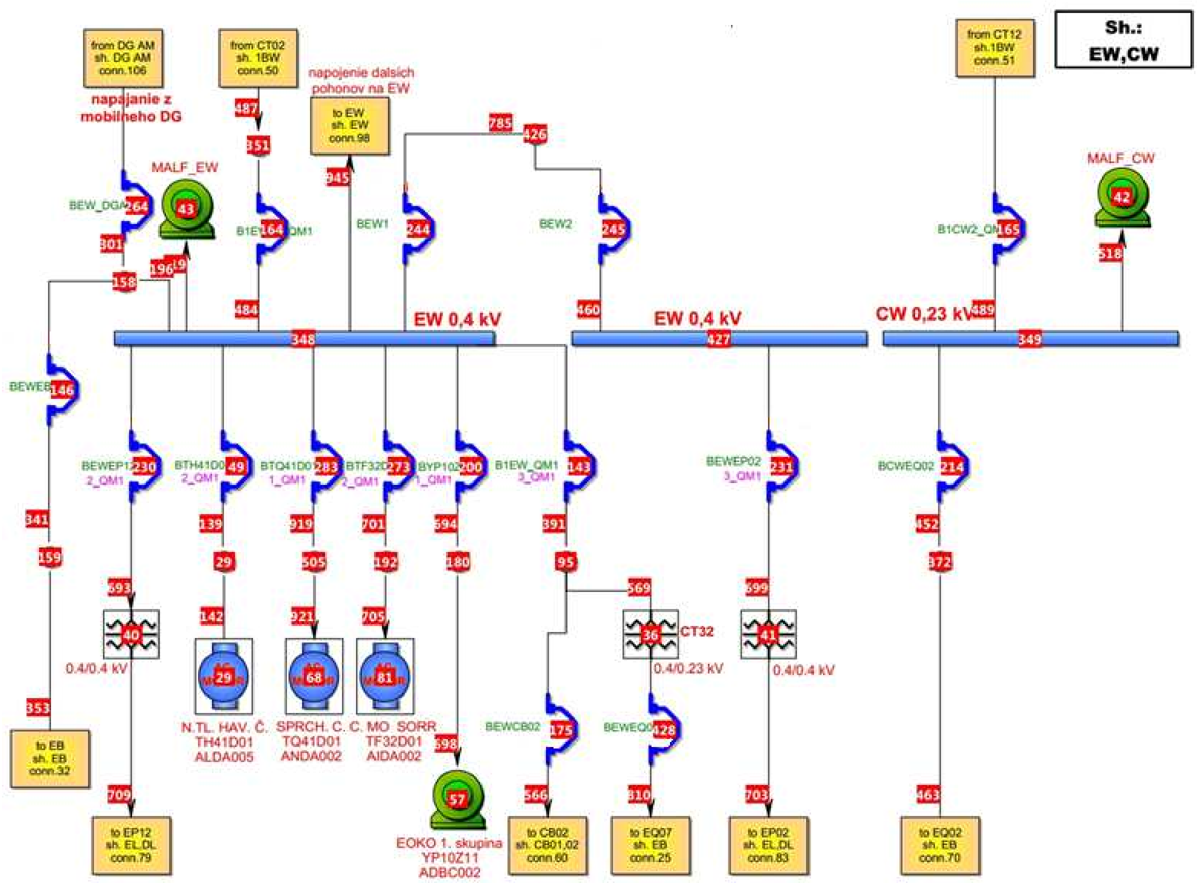

FIG. 6. Thunderelectric model nodalization example.

All above mentioned activities and experiences will be used for building specific Basic principle simulator (BPS) [9] (PC based simulator, standalone simulator, BPS specific). The main purpose to start the process of developing new specific simulation platform at VUJE Training Centre is an intention to make this efficient tool available not only for MCR Personnel or other NPP Personnel (current status with FSS now) but also for technical support Engineers, university students etc. The new platform should be delivered to:

— Validate new power plant procedures;
— Study physical phenomena and their impact on the systems, components and constructions of NPP under particular several accidents;
— Analyse the anticipated transients and accidents;
— Save costs when BSP will be used along the FSS.

Key role in building the specific BPS from FSS is to consider the level of simplification and creation specific and targeted visualizations (HMI) which have to be illustrative and clear so the trainees will have the best possible training experience. Each FSS is different from the point of view of connected external 3rd party systems which are often stimulated. In case of Bohunice V2 FSS a big portion of work will be devoted to building and simulating whole turbine control system, which is now connected as standalone stimulated device (system TVER by Invelt company). After successful integration and testing a new specific MMI will be delivered.

	FSS	**E&RS**	**BPS generic**	**BPS specific**	**Simplified animations**
Relation to specific plant	Plant specific	Plant specific	Not plant specific	Plant specific	Elementary fundamentals for supporting personnel and public
Licensed	Based on plant data	Based on design data, later on plant data	Based on code used (thermo hydraulic, neutron)	Based on plant data	
Training and usage	**Personnel with direct impact on NS** => MCR staff, field operators, physicists, regulatory body staff	Engineers, validation of I&C, validation of design, safety analysis	University students, decision makers, regulatory body staff, suppliers, public	**Personnel with impact on NS** => same as generic + MCR staff, field operators, physicists, regulatory body staff	

FIG. 7. Simplified tab of simulators taxonomy. Red line marks vuje platform under development. Abbreviations: FSS - full scope simulator, E&RS - education&research simulator, BPS - basic principle simulator, NS - nuclear safety, MCR - main control room.

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ANNEX I

OVERVIEW OF RELATED IAEA PUBLICATIONS

I–1. INTRODUCTION

Several IAEA publications provide overviews of training approaches and the used tools specifically the role of simulator training in strengthening the national nuclear power programme development. The lessons learned point at the use of PC based basic principle simulators as effective hands on valuable set of tools in targeting broader ranges of professionals (from students to regulators), and training scopes (physics and fundamentals of reactor technologies, train the trainer and reactor technology assessment). Among the IAEA scientific and technical publications of interest to this publication are the following:

I–2. IAEA–TECDOC-995: SELECTION, SPECIFICATION, DESIGN AND USE OF VARIOUS NUCLEAR POWER PLANT TRAINING SIMULATORS

IAEA–TECDOC-995 was published in January 1998 as a report prepared within the framework of a series of advisory and consultants meetings within the International Working Group on Nuclear Power Plant Control and Instrumentation held 19951996.

The report outlines the types of simulators existent at the time and their roles in the training process:

- **Part task simulators**: designed and used for training on a specific part of plant operations or for training of plant special phenomena, such as but not limited to steam generator tube rupture or diesel generator startup and operation.
- **Basic principle simulators**: illustrate general concepts, demonstrating and displaying the fundamental physical processes of the plant and providing an overview of plant behavior or a basic understanding of the main operating modes.
- **Compact simulators**: provide a means of training on operating procedures in a simplified form. The modelling depth and fidelity are equivalent to a full scope simulator, the scope of provided simulations is limited and the full control room is not replicated.
- **Graphical simulators**: provide a representation of the control parameters and the operating environment in a graphical form. An example is control room panels that can be displayed either in display units or in virtual synthesized images.
- **'Multi-functional' simulators**: describe either the compact simulators or the graphical simulators. In general, the modelling depth and fidelity are near or the same as those of a full scope simulator, but the humanmachine interface is provided graphically through mimics or by a combination of hard and soft panels.
- **Plant analyser**: represents a training device used to study complicated plant transients or accidents in detail. Since the goal is to provide a very detailed description of plant behavior, the simulation is does not run in real time nor display all actual operating data.

The report outlines the use of simulators at the time for the training of personnel with duties in the following areas:

— Overall plant operations and control;
— Individual system operations and control;
— Analysis of plant response to equipment and/or instrumentation failure;
— Instrumentation and control of plant equipment and processes;
— Plant process computer control;
— Emergency plan implementation and/or crisis management;
— Core monitoring and radiation protection;
— Plant maintenance.

A classification of simulators is discussed with respect to their fidelity, modelling scopes, graphic displays and real panel performances. The report also summarizes the practices at the time when using various types of simulators for training and education in Member States.

I–3. IAEA–TECDOC-1411: USE OF CONTROL ROOM SIMULATORS FOR TRAINING OF NUCLEAR POWER PLANT PERSONNEL

The publication states that: "In 1993, the IAEA published IAEA–TECDOC-685, Simulators for Training of Nuclear Power Plant Personnel, and in 1998, IAEA–TECDOC-995, Selection, Specification, Design and Use of Various Nuclear Power Plant Training Simulators. These publications, while providing some information on simulator training, focused primarily upon the characteristics of simulation devices used for training of NPP personnel." Therefore, following the recommendations received from the IAEA Technical Working Group on Training and Qualification of Nuclear Power Plant Personnel, in 2004 this publication was published with the goal to provide information and examples on methods used for training of nuclear power plant personnel using control room simulators, including practical examples of current practices.

The publication provides definitions of various types of simulators such as basic principle simulators, part task simulators, full scope simulators and other–than–full scope control room simulators, overview of historical trends and developments in simulator training, training programmes for nuclear power plant control room personnel, as well as discusses the implementation and evaluation of simulator training programmes. The scope of the publication focuses on nuclear power plant control room personnel training and therefore in respect to training it discusses full scope and other-than-full scope control room simulators.

I–4. IAEA–TECDOC-1502: AUTHORIZATION OF NUCLEAR POWER PLANT CONTROL ROOM PERSONNEL: METHODS AND PRACTICES WITH EMPHASIS ON THE USE OF SIMULATORS

This report was published in 2006 as a response to the IAEA Technical Working Group on Training and Qualification of Nuclear Power Plant Personnel recommendation to prepare an addition to the 2002 IAEA Safety Guide NS–G–2.8, Recruitment, Qualification and Training of Personnel for Nuclear Power Plants. This publication provides a summary of the training practices in Member States with the use of simulators in authorization of control room staff.

The publication highlights the use of simulators in the authorization process. The use of simulators to examine authorized control room staff is as an extension of their use described in the IAEA–TECDOC-1411 (Section I–1.).

ANNEX II

IAEA PC BASED SIMULATORS

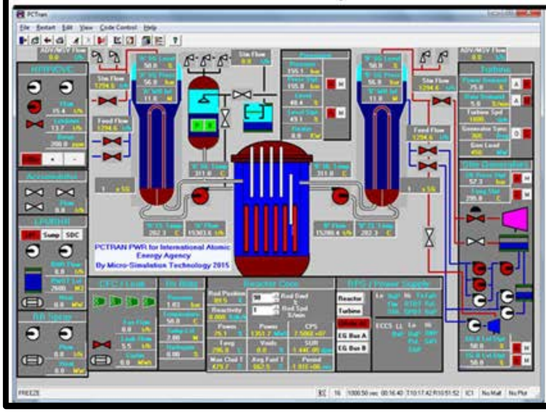
(2017)

II–1. CONVENTIONAL TWO LOOP PWR SIMULATOR (PCTRAN)

II–1.1. INTRODUCTION

PCTRAN is a two loop PWR reactor transient and accident simulator. Since its first release in 1985, Micro–Simulation Technology has been constantly upgrading its performance and expanding its capabilities. The main aspects of PCTRAN simulator are provided in Fig. II-1.

Conventional Two Loop PWR Simulator (PCTRAN)



Reactor type	PWR
Reference plant	Generic 1800 MWth output two loop PWR TRIGA [Research reactor – pool type]
Developer	Micro Simulation Technology (MST)
Developer website	http://www.microsimtech/pctran
Published year	2015
Capabilities	Normal operation; transients; DBA and severe accidents

FIG. II-1. IAEA PCTRAN simulator,
https://www.iaea.org/NuclearPower/Downloads/Simulators/Conventional.PWR.PCTRAN.Manual.2009-10.pdf.

II–1.2. PCTRAN SIMULATOR OPERATIONAL SPECIFICS

The PCTRAN simulator operational specifics are listed as follows and detailed in Table II–1.:

— Graphic User Interface (GUI) adheres strictly to the specifications of the Microsoft Windows environment. Data input/output are in MS Office's Access database format;
— The plant model is a generic two loop PWR with inverted U–bend steam generators and dry containment system, such as the Westinghouse, Framatome or KWU designs with thermal output in the range of 1800 MWt (600 MWe). The examples of these types of reactors are: Point Beach, Kewaunee, Prairie Island and Ginna in the USA, Mihama1 in Japan, Krsko in Slovenia, Angra1 in Brazil and ChinShan2 in China, as found in the IAEA PRIS data base: https://www.iaea.org/pris/;
— A TRIGA model is available for demonstrating the concepts of neutron multiplication, rod control to criticality, feedback, decay heat, and effects of poisoning.

The PCTRAN simulator can address to certain extend the behavior of the plan under severe accidents as follows:

— TMI–2 accident: this accident is simulated by triggering combination of loss of condensate pump, main feedwater pumps and disabling the auxiliary feedwater in thus allowing the users to analyze: steam generator level, peak cladding temperature, system pressure changing over time during the accident;

- Station Blackout (SBO), both off–site AC and on–site diesel power are lost: only DC operated pressurizer and steam generator Pilot Operated Relief Valve (PORV) are operating to relieve pressure. Prolonged SBO may lead to vessel failure as well as core melt;
- Large Break without emergency core cooling system (ECCS): 2000 cm^2 cold leg severe accident is modeled by disabling the accumulators, HPI and LPI pumps. The core is rapidly exposed and starts to melt, then collapses and melts through the vessel bottom. Users may observe corium concrete interaction and aerosol generation in the containment.

TABLE II–1. PCTRAN SIMULATOR APPLICATION DOMAIN.

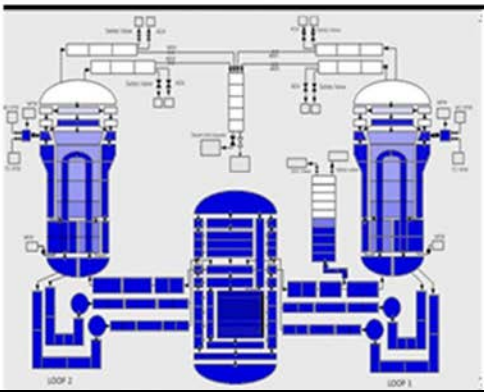
Normal Operation	**Malfunction Transient Events**
o Power Reduction/Increase; o Normal Reactor Trip	o Power Reduction/Increase; o Normal Reactor Trip; o Uncontrolled Rod Bank Withdrawal; o Hot Full Power Rod Drop; o Moderator Dilution; o Startup of an Inactive RCP; o Reduction in Feedwater Enthalpy; o Excessive Load Increase; o Loss of Reactor Coolant Flow; o Turbine Trip; o Loss of Normal Feedwater; o Steam Generator Tube Rupture; o Small/Large Break LOCA

II–2. ADVANCED PWR SIMULATOR (KAERI)

II–2.1. INTRODUCTION

The advanced PWR simulator is developed by Korea Atomic Energy Research Institute (KAERI). It covers transient and accidents and uses the best estimate nuclear system analysis code as its engine to retain the accuracy. The main aspects of this simulator are provided in Fig. II–2.

Advanced PWR Simulator



Reactor type	PWR
Reference plant	OPR1000 (Republic of Korea)
Developer	Korea Atomic Energy research Institute (KAERI)
Developer website	http://www.kaeri.re.kr/english
Published year	2004
Capabilities	Normal operation; transients; DBA

FIG. II–2. IAEA advanced PWR simulator

II–2.2. ADVANCED PWR SIMULATOR OPERATIONAL SPECIFICS

The advanced PWR simulator operational specifics are listed as follows and detailed in Table II–2:

- The simulator is designed to provide an in–depth understanding of transient thermal–hydraulic behavior of nuclear power plants with various on–line graphical displays, especially during the accidents in addressing complicated two–phase flow conditions in the reactor coolant system;
- The simulator is based on the OPR–1000 two loop 1000 MWe PWR nuclear reactor, developed by KHNP and KEPCO. There are OPR–1000 plants currently in operation; they are all in Republic of Korea: Hanbit unit 5/6, Hanul unit 5/6, Shin-Kori unit 1/2, and Shin-Wolsong unit 1/2 (https://www.iaea.org/pris/);
- The simulator can be executed on a personal computer (PC), and it although operates essentially in close to real time with dynamic response and high fidelity during normal operations and accidents, some transient conditions cannot be observed in real time;
- The simulator can easily be adapted for other plants, besides the OPR–1000.

The advanced PWR simulator can address to certain extend the behavior of the plan under severe accidents as follows:

- Station Blackout (SBO): the users can initiate SBO accidents by manually turning off all the components which require the AC power. Even though there are a lot of the engineering safety features, most of them require electrical power source except for the turbine driven auxiliary feedwater system and the relief valves of a safety related class. In a real SBO case, RCP seal leak has to be considered. However, it is neglected in this accident simulation.

TABLE II–2. ADVANCED PWR SIMULATOR APPLICATION DOMAIN.

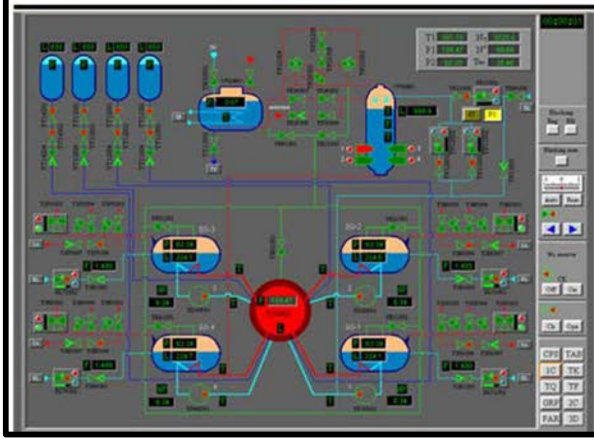
Normal Operation	Malfunction Transient Events
o Power Reduction/Increase; o Normal Reactor Trip	o Turbine Trip; o Loss of Main Feedwater Flow; o Single RCP Trip; o Steam Generator Tube Rupture; o Cold Leg #1 Small/Large Break Loss of Coolant Accident(SBLOCA, LBLOCA)

II–3. WWER (VVER) SIMULATOR

II–3.1. INTRODUCTION

The WWER1000 simulator is was originally developed by Moscow Engineering and Physics Institute for personnel training. It is executed on a personal computer in real time and provides a dynamic response with sufficient fidelity. This version of a simulator is highly suitable for educational and information purposes. The main aspects of this simulator are provided in Fig. II–3.

WWER1000 Simulator



Reactor type	WWER
Reference plant	WWER1000
Developer	Moscow Engineering and Physics Institute
Developer website	http://eng.mephi.ru/
Published year	2003
Capabilities	Normal operation; transients; DBA

FIG. II–3. IAEA WWER1000 simulator, http://www-pub.iaea.org/books/IAEABooks/6686/WWER-1000-Reactor-Simulator

II–3.2. ADVANCED PWR SIMULATOR OPERATIONAL SPECIFICS

The WWER simulator operational specifics are listed as follows and detailed in Table II–3:

- The WWER1000 is a four loop system housed in a containment type structure with a spray steam suppression system developed in the former Soviet Union, and now the Russian Federation, by OKB Gidropress;
- There are a number of PWR plants in the world that belong to this design, such as for example: Balakovo in the Russian Federation, Zaporizhzhia in Ukraine, Kozloduy in Bulgaria (https://www.iaea.org/pris/);
- The present configuration of the simulator is able to respond to operating conditions normally encountered in WWER1000 power plants.The interaction between the user and the simulator is organized through a set of display screens and the use of a mouse. The simulator partially mimics the actual control panel instrumentation as well as provides additional aspects for analysis. Control panel devices (buttons, switches, keys) are represented as simplified pictures and are operated via individual panels in response to the user inputs;
- There are no possibilities to simulate severe accident conditions.

TABLE II–3. WWER SIMULATOR APPLICATION DOMAIN.

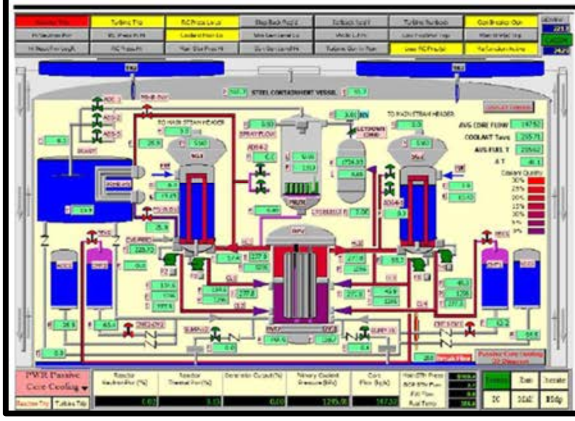
Normal Operation	Malfunction Transient Events
o Power Reduction/Increase; o Normal Reactor Trip	o Reactor Coolant Pump Wheel Jam; o Main steam isolation valve closure; o Reactor Coolant Pump-2 Trip; o Feedwater Pump Trip; o Closure of Turbine Governor Valve; o Reactor SCRAM and Return to Full Power

II–4. ADVANCED PASSIVE PWR SIMULATOR

II–4.1. INTRODUCTION

The purpose of the 600 MWe advanced PWR reactor simulator is educational with the goal to provide a training tool for university professors and engineers involved in teaching topics related to the advanced passive PWR reactor design. It is developed by CTI Simulation International Corporation in 2002. The main aspects of this simulator are provided in Fig. II–4.

Advanced Passive PWR Simulator



Reactor type	PWR
Reference plant	AP600
Developer	CTI Simulation International Corporation
Developer website	http://www.cti-simulation.com
Published year	2002
Capabilities	Normal operation; transients; DBA

FIG. II–4. IAEA advanced passive PWR simulator, https://www.iaea.org/NuclearPower/Downloadable/Simulators/Advanced-PWR-Manual-2011.10.pdf

II–4.2. ADVANCED PASSIVE PWR SIMULATOR OPERATIONAL SPECIFICS

The advanced passive PWR simulator operational specifics are listed as follows and detailed in Table II–4:

- The passive safety features implemented in the simulator include:
  - Passive Residual Heat Removal System;
  - Two Core Make-up Tanks (CMTs);
  - Four Stage Automatic Depressurization System (ADS);
  - Two Accumulator Tanks (ACC);
  - In-containment Refuelling Water Storage Tank (IRWST);
  - Lower Containment Sump (CS);
  - Passive Containment Cooling System (PCS).
- Parameter monitoring and plant operator controls, implemented via the plant display system at the generating station, are represented in a virtually identical manner in the simulator. Control panel instruments and control devices, such as push–buttons and hand–switches, are shown as stylized pictures, and are operated via special pop–up menus and dialog boxes in response to user inputs;
- More information about AP600 are available in the IAEA ARIS data base, https://aris.iaea.org/sites/PWR.html;
- There is no possibility to model severe accidents.

TABLE II–4. ADVANCED PASSIVE PWR SIMULATOR APPLICATION DOMAIN.

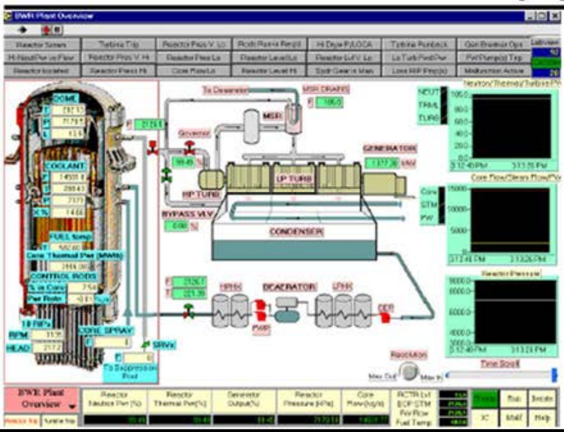
Normal Operation	Malfunction Transient Events
o Power Reduction/Increase; o Normal Reactor Trip	o Reactor Setback and Stepback Fail; o One Bank of Dark Control Rods Drop into the Reactor Core; o Pressurizer Pressure Relief Valve Fails Open; o Charging/Letdown Valve Fails Open; o Pressurizer Heaters Turned on by Malfunction; o Reactor Header Break; o All Level Control Isolation Valves Fail Closed; o One Level Control Valve Fails Open/Closed; o Main Feedwater Pump Trips; o All Main Steam Safety Relief Valves Open; o Steam Header Break; o Steam Flow Transmitter Failure; o Turbine Spurious Trip /Runback; o Condenser Steam Discharge Valves Failed Closed; o Reactor Inlet Header Break

II–5. CONVENTIONAL BWR WITH ACTIVE SAFETY SYSTEMS SIMULATOR

II–5.1. INTRODUCTION

The purpose of this 1300 MWe boiling water reactor simulator is educational; a teaching tool for university professors and engineers involved in teaching various topics related to nuclear power. It is developed by CTI Simulation International Corporation in 2008.The main aspects of this simulator are provided in Fig. II–5.

Conventional BWR with Active Safety Systems Simulator



Reactor type	BWR
Reference plant	Conventional 1300 MWe BWR
Developer	CTI Simulation International Corporation
Developer website	http://www.cti-simulation.com
Published year	2008
Capabilities	Normal operation; transients; DBA

FIG. II–5. IAEA conventional BWR simulator,
https://www.iaea.org/NuclearPower/Downloads/Simulators/Conventional.BWR.Manual.2009-10-05.pdf

The conventional BWR simulator operational specifics are listed as follows and detailed in Table II–5:

— The plant model is a typical 1300 MWe BWR with internal recirculation pumps and fine motion control rod drives;
— There is a number of BWR plants in the world that belong to this category, such as for example: Susquehanna in the USA, Gundremmingen in Germany, Shika in Japan (https://www.iaea.org/pris/);
— The simulator can be executed on a personal computer, to operate essentially in real time, and have a dynamic response with sufficient fidelity;
— The simulator provides a user–machine interface that mimics the actual control panel instrumentation, including the plant display system, and more importantly, allows user interaction with the simulator during the operation of the plant events;
— The emphasis in developing the simulation models was on giving the desired level of realism to the user in being able to display all plant parameters that are critical to operation, including the ones that characterize the main process, control and protective systems;
— The appropriate parameters and input–output relationships are assigned to each model as demanded by a particular system application;
— Parameter monitoring and plant operator controls are represented in a virtually identical manner on the simulator. Control panel instruments and control devices, such as push–buttons and hand–switches, are shown as stylized pictures, and are operated via special pop–up menus and dialog boxes in response to user inputs.
— There is no possibility to model severe accidents.

TABLE II–5. IAEA CONVENTIONAL BWR SIMULATOR APPLICATION DOMAIN.

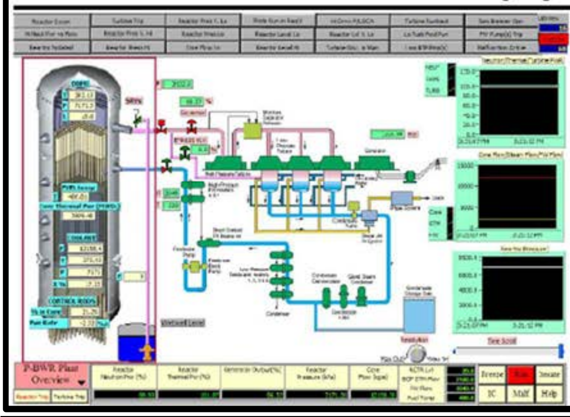
Normal Operation	Malfunction Transient Events
o Power Reduction/Increase; o Normal Reactor Trip	o Increasing and Decreasing Core Flow Due to Flow Control Malfunctions; o Inadvertent Withdrawal of One Bank of Control Rods; o Inadvertent Insertion of One Bank of Control Rods; o Inadvertent Reactor Isolation; o Power Loss to 3 Reactor Internal Pumps (RIPs); o Reactor Bottom Break; o Loss of Both Feedwater Pumps; o Loss of Feedwater Heating; o Reactor Feedwater Level Control Valve Fails Open; o Safety Valves on One Main Steam Line Fail Open; o Steam Line Break Inside Drywell; o Feedwater Line Break Inside Drywel

II–6. ADVANCED BWR WITH PASSIVE SAFETY SYSTEMS SIMULATOR

II–6.1. INTRODUCTION

This simulator is based on the Economic Simplified Boiling Water Reactor (ESBWR), designed by General Electric. It was developed by CTI Simulation International Corporation in 2008. The main aspects of the simulator are provided in Fig. II–6.

Advanced BWR with Passive Safety Systems Simulator



Reactor type	BWR
Reference plant	Economic Simplified BWR [ESBWR]
Developer	CTI Simulation International Corporation
Developer website	http://www.cti-simulation.com
Published year	2008
Capabilities	Normal operation; transients; DBA

FIG. II–6. IAEA advanced BWR simulator, https://www.iaea.org/NuclearPower/Downloads/Simulators/Advanced.BWR.Manual.2009-10.pdf

The advanced BWR simulator operational specifics are listed as follows and detailed in Table II–6:

— The ESBWR uses natural circulation that provides major simplifications of the plant by removal of the recirculation pumps and associated piping, head exchangers and controls. It also ensures large safety margins with reliable passive emergency core cooling system (ECCS), a requirement that GE considered to be important in the design of Gen III+ reactors. Details of the ESBWR design are found in the IAEA ARIS data base, https://aris.iaea.org/sites/BWR.html;

— The ESBWR safety systems design incorporates four redundant and independent divisions of the passive ECCS. The passive BWR ECCS features implemented in the simulator include the following systems:
  - o Gravity Driven Cooling System (GDCS);
  - o Automatic Depressurization System (ADS);
  - o Isolation Condenser System (ICS);
  - o Standby Liquid Control System (SLCS).

— The simulator has a user–machine interface that mimics the actual control panel instrumentation;

— There is no possibility to model severe accidents.

TABLE II–6. IAEA ADVANCED BWR SIMULATOR APPLICATION DOMAIN.

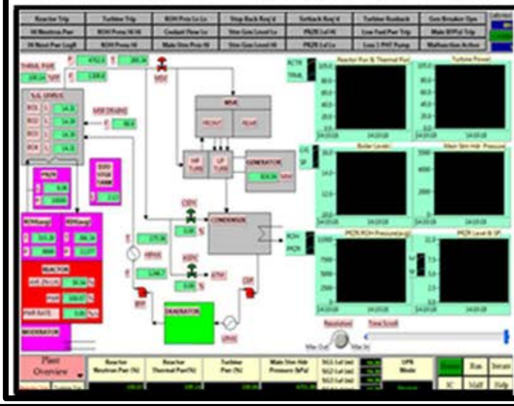
Normal Operation	Malfunction Transient Events
o Power Reduction/Increase; o Normal Reactor Trip	o Both FW Pumps Trip; o Inadvertent Isolation Condenser Initiation; o Inadvertent Opening of Bypass Valve; o Decreasing/Increasing Steam Flow from Dome Due to Pressure Control Failure; o Turbine Throttle PT Fails Low; o Safety Relief Valve (SRV) on One Main Steam Line Fails Open; o Feedwater Level Control Valve Fails Open; o Turbine Trip with Bypass Valve Failed Closed; o Inadvertent Withdrawal/Insertion of One Bank of Rods; o Inadvertent Reactor Isolation; o Loss of Feedwater Heating; o Loss of Condenser Vacuum; o Steam/Feedwater Line Break Inside Drywell; o Reactor Vessel Bottom Break - 1660 kg/sec LOCA

II–7. CONVENTIONAL PHWR SIMULATOR

II–7.1. INTRODUCTION

The conventional PHWR simulator was originally developed to assist Atomic Energy of Canada Limited (AECL) in the design of the plant display system. It was developed by CTI Simulation International Corporation in 2005. The main aspects of the simulator are provided in Fig. II–7.

Conventional Pressurized Water Reactor (PHWR) Simulator



Reactor type	PHWR
Reference plant	Generic 900 MWe CANDU
Developer	CTI Simulation International Corporation
Developer website	http://www.cti-simulation.com
Published year	2005
Capabilities	Normal operation; transients; DBA

FIG. II–7. IAEA conventional PHWR simulator.

The conventional PHWR simulator operational specifics are listed as follows and detailed in Table II–7:

- The simulator operates essentially in real time, and has a dynamic response with sufficient fidelity to provide realistic signals to the plant display system.
- It has a user–machine interface that mimics the actual control panel instrumentation, including the plant display system, to a degree that permits operation of the simulator in a standalone mode, i.e. in the absence of the plant display system equipment. These features also made the simulator suitable as an educational and training tool;
- The plant model is CANDU, the Canadian designed PHWR with electrical output of 900 MWe;
- There are a number of PHWR plants in the world that belong to this category, such as: Darlington in Canada, Cernavoda in Romania, Qinshan3 in China. More information about these reactors can be found in the IAEA PRIS data base, https://www.iaea.org/pris/;
- The emphasis in developing the simulation models was on giving the desired level of realism to the user in displaying those plant parameters that are most critical to the plant, including the ones that characterize the main processes, control and protective systems;
- The interaction between the user and the simulator is via a combination of monitor displays, mouse and keyboard. Parameter monitoring and operator controls implemented via the plant display system at the generating station are represented in a virtually identical manner. Control panel instruments and control devices, such as push–buttons and hand–switches, are shown as stylized pictures, and are operated via special pop–up menus and dialog boxes in response to user inputs;
- There is no possibility to model severe accidents.

TABLE II–7. IAEA CONVENTIONAL PHWR SIMULATOR APPLICATION DOMAIN.

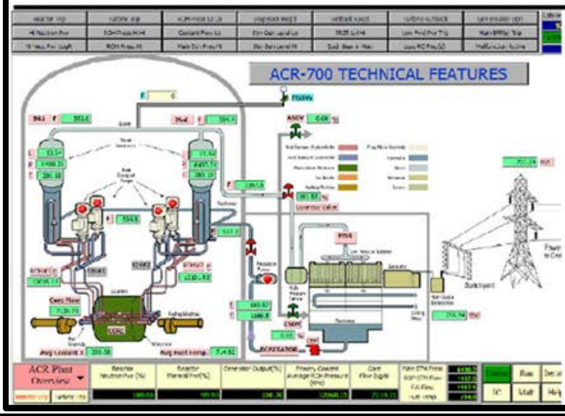
Normal Operation	Malfunction Transient Events
o Power Reduction/Increase; o Normal Reactor Trip	o Reactor Setback and Stepback Fail; o One Bank of Control Rods Drop into the Reactor; o Main Circuit Relief Valve Fails Open; o Pressurizer Relief Valve Fails Open; o Pressurizer Isolation Valve Fails Closed; o Feed Valve Fails Open; o Bleed Valve Fails Open; o Reactor Header Break; o All Level Control Isolation Valves Fail Closed; o One Level Control Valve Fails Open/Closed; o All Feedwater Pumps Trip; o All Safety Valves Open; o Steam Header Break; o Flow Transmitter Fails

II–8. ADVANCED PHWR SIMULATOR

II–8.1. INTRODUCTION

The Atomic Energy of Canada Limited (AECL) has developed the ACR700 (Advanced CANDU Reactor 700) as the next generation CANDU with goals of reduced capital cost, shorter construction schedule, higher capacity factor, lower operating cost, increased operating life, simpler components, replacement and enhanced safety features. Passive safety features drawn from those of the existing CANDU plants (e.g., the two independent shutdown systems), and other passive features are added to strengthen the safety of the plant –these safety features are implemented in the simulator. The simulator is developed by CTI Simulation International Corporation in 2005. The main aspects of the simulator are provided in Fig. II–8.

Advanced Pressurized Water Reactor (PHWR) Simulator



Reactor type	PHWR
Reference plant	ACR700 [Advanced CANDU reactor 700]
Developer	CTI Simulation International Corporation
Developer website	http://www.cti-simulation.com
Published year	2005
Capabilities	Normal operation; transients; DBA

FIG. II–8. IAEA advanced PHWR simulator, https://www.iaea.org/NuclearPower/Downloads/Simulators/ACR700.Simulator.Manual.2009-10.pdf

The advanced PHWR simulator operational specifics are listed as follows and detailed in Table II–8:

- The emphasis in developing the simulation models was on giving the desired level of realism to the user in displaying those plant parameters that are most critical to plant operation, including the ones that characterize the main operational processes, control and protective systems;
- Details of the AECL HWR designs can be found in the IAEA ARIS data base, https://aris.iaea.org/sites/HWR.html;
- The interaction between the user and the simulator is via a combination of monitor displays, mouse and keyboard. Parameter monitoring and operator controls implemented via the plant display system at the generating station are represented in a virtually identical manner on the simulator’s screens. Control panel instruments and control devices, such as push–buttons and hand–switches, are shown as stylized pictures, and are operated via special pop–up menus and dialog boxes in response to user inputs;
- There is no possibility to model severe accidents.

TABLE II–8. IAEA ADVANCED PHWR SIMULATOR APPLICATION DOMAIN.

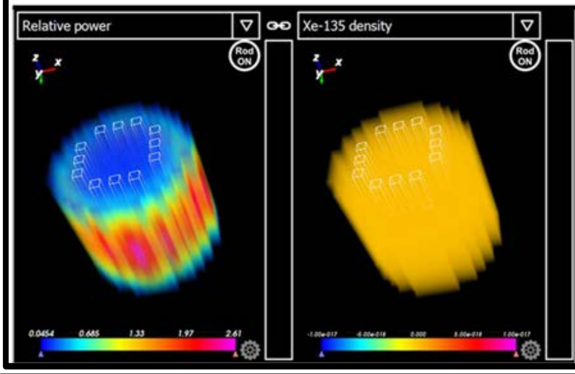
Normal Operation	Malfunction Transient Events
o Power Reduction/Increase; o Normal Reactor Trip	o Reactor Setback and Stepback Fail; o One Bank of MCA Rods Drop into the Reactor Core; o All MCA Rods “Stuck”‖to Manual; o Pressurizer Pressure Relief Valve Fails Open; o Coolant Feed Valve Fails Open; o Coolant Bleed Valve Fails Open; o Pressurizer Heaters #2 to # 6 Turned "ON" by Malfunction; o Reactor Inlet Header Break; o Loss of One HTS Pump; o Loss of Two HTS Pumps in One Loop; o All Level Control Isolation Valves Fail Closed; o One Level Control Valve Fails Open/Closed; o Main Feedwater Pump Trips; o All Main Steam Safety Relief Valves Open; o Steam Header Break; o Steam Flow Transmitter Failure; o Turbine Spurious Trip; o Condenser Steam Discharge Valves Failed Closed; o Reactor Inlet Header Break

II–9. MICRO–PHYSICS NUCLEAR REACTOR SIMULATOR

II–9.1. INTRODUCTION

The Micro–Physics Nuclear Reactor Simulator was developed by Nuclear Engineering, Ltd. (NEL), Japan, in 2014, as a platform for analysis and visualization of behaviour of the nuclear reactor core from the viewpoint of reactor physics, fuel performance and thermal–hydraulics. The simulator is mainly used as an educational tool. The main aspects of the simulator are provided in Fig. II–9.

Micro-Physics Nuclear Reactor Simulator



Reactor type	PWR
Reference plant	Generic two loop PWR core
Developer	Nuclear Engineering Ltd. (NEL)
Developer website	http://www.neltd.co.jp/index_eng.html
Published year	2014
Capabilities	Depletion; transients

FIG. II–9. IAEA Micro–Physics nuclear reactor simulator

The Micro–Physics simulator operational specifics are listed as follows:

— The simulator provides visualizations of calculations performed with the neutronics code, RAMBO–T, developed by NEL that is built in the simulator. The RAMBO–T solves two group neutron diffusion equation in 3D for analysis of a generic two loop type PWR core in stationary and transient conditions;

— Visualization of depletion calculations of the core and transient calculations are available;

— The transient conditions that can be simulated include:

  - Abnormal Control Rods Withdraw at Hot Zero Power;
  - Control Rods Withdrawal at Hot Full Power;
  - Loss of Flow Accident (LOFA);
  - Main Steam Line Break (MSLB).

— The well designed Graphical User Interface (GUI) allows for ease use of the simulator.

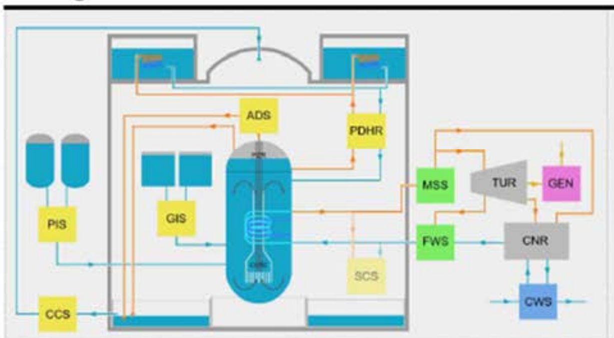
— Severe accidents modeling is not available in this simulator.

II–10. INTEGRAL PRESSURIZED WATER REACTOR SIMULATOR

II–10.1. INTRODUCTION

There is continuing global interest in the development of Small Modular Reactors (SMR). One type of SMRs currently under the development in a number of countries is the integral Pressurized Water Reactor (iPWR). In this design, primary circuit components are placed within the reactor pressure vessel, eliminating the need for primary circuit pipework, with the intention of enhancing safety and reliability. This simulator is developed by Tecnatom in 2017. The main aspects of the simulator are provided in Fig. II–10. Details on the currently available SMR designs can be found in the IAEA ARIS data base, https://aris.iaea.org/sites/SMR.html.

Integral Pressurized Water Reactor Simulator



Reactor type	iPWR
Reference plant	Generic 150 MWth output SMR
Developer	Tecnatom
Developer website	http://www.tecnatom.es/en/
Published year	2017
Capabilities	Normal operation; transients; DBA and severe accidents

FIG. II–10. IAEA iPWR simulator, http://www-pub.iaea.org/MTCD/Publications/PDF/TCS-65_web.pdf

The iPWR simulator operational specifics are listed as follows and detailed in Table II–9:

- The simulator is designed to examine the primary and balance of plant (BOP) behaviors of the iPWR;
- In order to simulate the operation under accident conditions, a variety of safety systems are implemented including Gravity Driven Water Injection System, Pressure Injection System, Passive Decay Heat Removal system (PDHR), and Protection and Control System;
- Severe accidents include a station blackout (SBO): the users can initiate the SBO accident by loading SBO malfunction. It will automatically trip both the reactor and the reactor turbine, and subsequently, actuate Passive Decay Heat Removal System (PDHR). The reactor behavior can be observed during SBO until the reactor becomes stable.

TABLE II–9. IAEA iPWR SIMULATOR APPLICATION DOMAIN.

Normal Operation	Malfunction Transient Events
o Power Reduction/Increase; o Normal Reactor Trip	o Loss of Feedwater Flow; o Turbine Runback; o Large Steam Generator Tube Rupture (SGTR); o Large Main Steam Line Break (MSLB); o Steam Line Isolation; o Reactor Pressure Vessel Safety Valve Opening; o Reactor Coolant Pumps Trip; o Loss of Condenser Vacuum; o Condenser Coolant Pumps Trip; o Inadvertent Initiation of Decay Heat Removal System; o Reduction in Feedwater Temperature (Loss of FW Heating); o Abnormal Increase in FW Flow; o Steam Header Break; o Major Steam System Piping Failure within Containment; o Reactor Setback Fail; o One Bank of Shutdown Control Rods Drop into the Core; o Charging (Feed) Valve Fails Open; o Inadvertent Operation of Pressurizer Heaters; o Uncontrolled Control Rod Assembly Withdrawal; o Fail of Pressurizer Control System; o Failure of Main Coolant Pumps; o Reactor Stepback Fail; o Seismic Event

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