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Classification, Selection and Use of Nuclear Power Plant Simulators for Education and Training

IAEA
International Atomic Energy Agency

CLASSIFICATION, SELECTION AND USE OF NUCLEAR POWER PLANT SIMULATORS FOR EDUCATION AND TRAINING

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INTERNATIONAL ATOMIC ENERGY AGENCY
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FOREWORD

Experience has shown that simulators are effective tools that allow education and training for a broad range of target groups with varying needs. Several IAEA publications outline the role of nuclear power plant simulators in education and training for human resource development for sustainable national nuclear power programmes in Member States. Since 1997, the IAEA has provided nuclear power technology education and training with the use of simulators as a core focus of the Nuclear Power Technology Development Section.

This publication provides an update of the IAEA-TECDOC-995, Selection, Specification, Design and Use of Various Nuclear Power Plant Training Simulators, published in 1998, and presents guidance for educational institutions, training centres and suppliers on the proper classification, selection and use of various types of nuclear power plant simulators.

The IAEA acknowledges the efforts and assistance provided by the contributors listed at the end of this publication. The IAEA officer responsible for this publication was T. Jevremovic of the Division of Nuclear Power.

EDITORIAL NOTE

CONTENTS

1. INTRODUCTION

1.1. BACKGROUND

As nuclear power is one promising alternative solution to meet the growing energy demands of countries around the world, educating and enriching the human resource with adequate knowledge on nuclear energy, nuclear reactor technologies, nuclear systems, reactor components and the embedded nuclear safety features are of paramount importance. Education and training which result in the creation of qualified plant personnel are critical in ensuring safe and reliable operation of nuclear power plants (NPPs). Experience shows that education and training NPP simulators are effective tools that allow for a broad range of target groups to meet education and training objectives and needs.

Full-scope simulators have clearly demonstrated their value in the training of NPP personnel. In this regard, many Member States have acquired these simulators for their NPPs and have enhanced their training accordingly on normal and emergency operations for plant operators, engineers, managers, and other appropriate NPP personnel. Even when such simulators are not available, it has become a standard practice for operation personnel to receive training on a simulator with operating characteristics similar to their own NPP [1]. These high fidelity full-scope simulators provide a training environment that emphasizes the control room setting for operators to understand reactor systems and to carry out operational procedures of that plant. Such skill based training is most beneficial when the operators enter with prior knowledge on NPP operations, control, and plant dynamics.

The advances in computer technology have enabled the development of high fidelity simulators on a smaller and simpler scale, applicable for classroom education and training to enhance knowledge based skills. These simpler simulators, as compared to full-scope simulators, allow trainees to more quickly grasp the fundamentals through *learning by doing* without missing the details of complex nuclear technology processes. A combination of lectures on the physics and technology of NPPs, along with hands on learning through *doing*, has proved to be an advanced and effective, yet inexpensive, learning method that strengthens understanding of the fundamentals of nuclear technology principles [2]. Differences in the scope and models of simulation within the simulator package, instructor and trainee interfaces, and other features allow the use of these simulators as a mode of instruction for a wide audience. Many educational and training needs can be addressed by using various types of simulators directed toward specific instructional objectives.

While adequate guidance is available for full-scope simulators, it has been recognized that there is a general lack of information about the classification, selection, and adequate use of other types of simulators in education and training programmes. It is the purpose of this publication to provide such guidance based on the lessons learned from IAEA training courses on reactor technologies with the use of various NPP simulators. Since 1997, the IAEA Nuclear Power Technology Development Section has built a library of basic education and training simulators that are made available to the Member States for access and use in their development of national nuclear power education and training curricula.

1.2. OBJECTIVES

The purposes of this publication are to provide guidance to education institutions, training centres and suppliers on:

- — Classification of various types of NPP simulators for education and training and represents in that respect an update of the IAEA-TECDOC-995 *Selection, specification, design and use of various nuclear power plant training simulators* published in 1998;
- — Suitable selection of simulators according to assessment of education and training needs as well as technical characteristics of the simulators;
- — Integration of simulators into educational and training programmes to enhance knowledge based skills.

1.3. SCOPE

The focus of this publication is to present updated information on classification, selection, and use of simulators for education and training, except for full-scope simulators. Full-scope simulators are discussed in IAEA-TECDOC-1411 [3].

1.4. STRUCTURE

Section 2 provides a classification of NPP simulators for education and training.

Section 3 provides guidelines for the identification of the educational and training objectives and needs for the selection of simulators.

Section 4 provides considerations and assessment for the selection and integration of simulators in educational and training programmes.

The Appendix includes example exercises corresponding to different levels of education and training.

The Annex lists the contents of the attached CD-ROM, which provides a summary of various NPP simulators used for education and training in several Member States based on the presentations provided by the participants at the Technical Meeting to *Develop a New IAEA Nuclear Energy Series Report on Nuclear Power Plant Simulators as Tools for Education and Training* held 23–27 April 2018 in Wuhan, China.

2. CLASSIFICATION OF NUCLEAR POWER PLANT SIMULATORS FOR EDUCATION AND TRAINING

The Technical Meeting to *Develop a New IAEA Nuclear Energy Series Report on Nuclear Power Plant Simulators as Tools for Education and Training* held 23–27 April 2018 in Wuhan, China and the two Consultancy Meetings to *Finalize TECDOC on Specification and Use of Various Nuclear Power Plant Simulators in Education and Training in Support of Human Resource Development* held 10–12 October 2018 and 24–26 April 2019 in Vienna, Austria produced the definitions and classifications for various existing NPP simulators described in this section.

The classification of education and training simulators is based on the following two definitions:

- ***Nuclear education*** understood to represent a knowledge building process enhancing in-depth understanding of nuclear concepts, phenomena and related technologies.
- ***Nuclear training*** understood to represent a capacity building measure to enhance the skill sets, attitude and behaviour within the specific environment of an NPP.

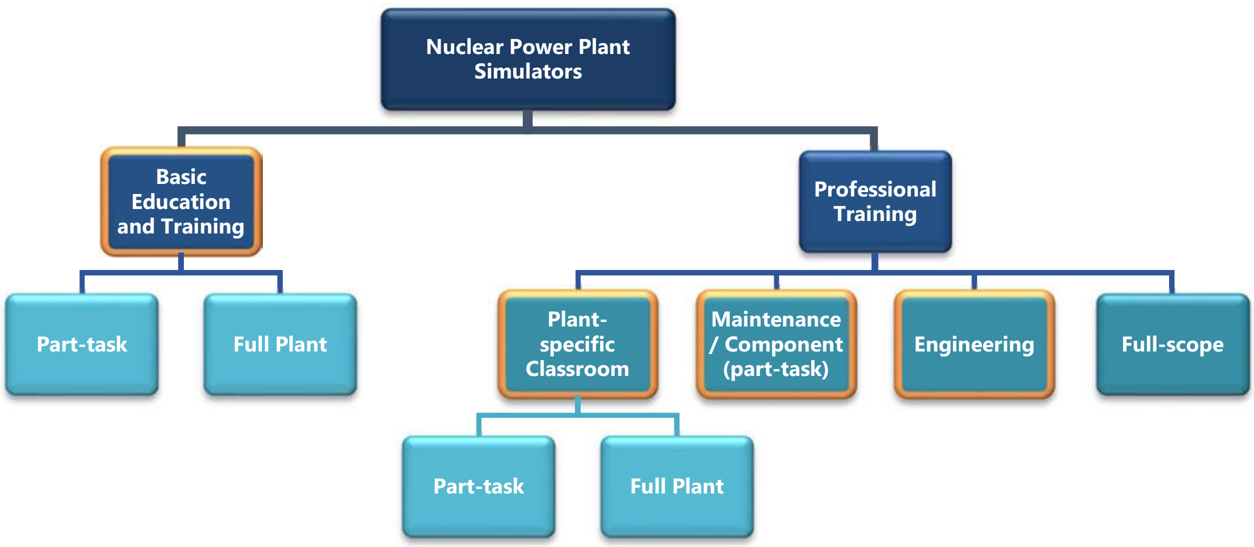

FIG. 1. Classification of NPP simulators.

Based on these definitions, Figure 1 presents a classification of simulators based on their use in education and training as developed during the mentioned Consultancy Meetings:

(a) **Basic education and training simulators** illustrate general concepts, demonstrating and displaying the fundamental physical processes in NPPs. These simulators are sometimes referred to as 'basic principle simulators' and are available for all the main plant design types (e.g. Pressurized Water Reactor (PWR), Boiling Water Reactor (BWR), CANada Deuterium Uranium (CANDU), Advanced Gas Cooled Reactor (AGR)) [3]. Basic education and training simulators are not necessarily plant referenced. The main goal of these simulators is to help users understand fundamental physical processes, basic operation and layout of systems, and NPP general operating procedures. These simulators are highly recommended for use in basic and higher education programmes. They can be the following:

- **Part-task simulators** that address a specific part of plant operations (systems or components) or specific phenomena. Such simulators can be beneficial to improve the focus of education in particular areas (e.g. steam generator tube ruptures, diesel generator startup and operation).
- **Full plant simulators** that describe an overview of NPP behaviour with a focus on main systems, with or without the auxiliary systems. Such simulators can be beneficial for providing overall understanding of the plant behaviour and the main processes (e.g. plant steady state/transient behaviour, main coolant system, steam water system).

(b) **Professional training simulators** represent plant components and systems and their functions, comprehensive operation processes, or the internal effects in various system parameters of the specific NPP during normal, transient, and accident conditions. They are further classified as follows:

(i) **Plant-specific classroom simulators** are simulators with soft (virtual) panels and/or an operator human–machine interface (HMI) as the main operator interface (no hardware panels). The graphics are displayed on standard monitors, touch monitors, or projected screens. The modelling scope of a plant-specific classroom simulator is similar to a full-scope simulator without the physical panels, consoles, and associated instruments. The depth and fidelity of modelling is not necessarily as high as those of a full-scope simulator. For these simulators, modelling of real time processes may not be required. They can be the following:

- **Part-task simulators** which simulate specific components, systems, or phenomena in detail;
- **Full plant simulators** which simulate the whole plant's behaviour in normal operation, transient, or accidents conditions.

(ii) **Maintenance/Component (part-task) simulators** focus on training personnel to perform tasks related to very specific plant component(s) or system(s), such as assembly and disassembly of components or operation of a refuelling machine. For these simulators, modelling of real time processes is not required.

(iii) **Engineering simulators** are real time simulators used to demonstrate an NPP's behaviour with respect to normal operation, transients, or accidents in more detail than basic education and training simulators. They are mainly used for plant design optimization and generating Plant Safety Analysis documents. These simulators may also be used for conducting professional training for NPP personnel on plant dynamics and understanding of severe accident scenarios/conditions with respect to design safety limits.

(iv) **Full-scope Simulators** are plant-referenced training tools which operate in real time and are mainly used for licensing of NPP operators and for training other NPP personnel to develop their skills, reflexes, attitudes, and knowledge needed to demonstrate that they will be able to operate the NPP safely. They consist of a complete replica of a main control room and complete mathematical model of all systems and modes of the NPP's operation. These simulators are not further considered in this publication.

Examples of these simulators are provided within the IAEA NPP education simulators as well as in the attached CD-ROM. However, because the presented classification of simulators is new, the simulators described in the CD-ROM may not always use the same terminology.

3. IDENTIFICATION OF EDUCATION AND TRAINING OBJECTIVES AND NEEDS FOR SELECTION OF THE SIMULATOR

3.1. ADVANTAGES OF USING SIMULATORS IN EDUCATIONAL AND TRAINING PROGRAMMES

Experience confirms that the use of NPP simulators is advantageous in education of university students, and training and qualification of nuclear professionals (e.g. NPP personnel and regulatory bodies). Basic education and training simulators are utilized in IAEA courses supporting human capacity building and sustainability of national nuclear power programmes in Member States. Learning retention rate is more effective with hands on, *active learning by doing* rather than solely lecture teaching. Learning is a process based on an individual's preference toward learning styles such as (a) seeing and hearing, (b) reflecting and acting, (c) memorizing and visualizing or drawing, (d) developing analogies and building models (mathematical), or (e) reasoning logically and intuitively.

Simulators with various scope, level and depth of simulation, instructor and trainee interfaces, and other features are suitable as a knowledge transfer platform in addressing a wide variety of audiences, from the general public to school and university students as well as to NPP personnel. The hands-on experience offered by these simulators is highly essential not only for NPP operators, maintenance technicians, regulators, researchers, and engineers, but also for students enrolled in nuclear power programmes. Simulators play an effective and efficient role in human capacity building.

The major benefits of using simulators in educational and training programmes are enhanced understanding of NPP behaviour under various operating conditions and understanding of fundamental principles of nuclear physics, nuclear technology, and other aspects. Simulators promote increased safety as well-trained personnel are trained in abnormal and stressful situations and therefore decrease the risks of making wrong decisions. They can also play an important role for policymakers in developing a basis for better understanding of technologies. These simulators can bring an increased and positive awareness among the public about the peaceful uses of nuclear energy.

The main benefits of using education and training simulators depend on their type and include, but are not limited to, the following:

- Basic education and training simulators:
  - Cost effective means to master education and training objectives and needs;
  - Individualized instruction or self-training can be performed effectively;
  - Easy adaptation for various education and training objectives and needs;
  - Basic understanding of NPP design concepts and operation;
  - Education and training on plant responses and phenomena related to malfunctions, transients, and accidents;
  - Ability to repeat a scenario as many times as necessary for deeper understanding and knowledge retention.
- Professional training simulators:
  - Reduction of risk to plant equipment and personnel by enhancing knowledge-based skills;
  - Providing training for engineering and management personnel, including those who do not have a need for a thorough familiarity with the control room displays and instrumentation, who need an understanding of NPP processes and specific systems;
  - Allowing for flexibility in understanding the impact of plant modifications on plant behaviour;
  - Improving the ability of the trainees to respond rapidly to prevent or mitigate accident consequences;
  - Providing a transition for trainees to progress from fundamentals training and initial operations training, which can be performed with basic education and training simulators, to more complex integrated NPP operations and team training.

3.2. EDUCATIONAL AND TRAINING NEEDS ANALYSIS

Educational and training needs analysis is the process of identifying nuclear education and training needs in an organization, such as a university or NPP, for the purpose of improving student skills or employee job performance.

A successful analysis of educational and training needs will provide the organization with answers to several important questions, such as:

- What education or training is needed and why?
- Is training the right solution for employee job performance?
- Who is the target group for education and training?
- What resources are available for education and training?

A performance analysis and training needs analyses are performed to evaluate potential training needs, to suggest and approve training solutions, and – where it is possible – to suggest other management initiatives to improve facility performance. Currently, the work environment at nuclear facilities requires employees and students as future employees to be skilled for performing complex tasks in a safe, efficient, and cost-effective manner. Education is needed to prepare the students as future employees to perform their jobs to certain standards and training (a performance improvement tool) is also needed when employees are not performing up to a certain standard or at an expected level of performance. The difference between the actual level of job performance and the expected level of job performance indicates either a need for training or other management initiative to improve facility performance.

In order to fully understand who, the target group is, it is important to understand what prior education or training has been received and to define the necessary areas for further education and training. This includes consideration of national NPP programme status. In this way, proper usage of education and training resources, education and training of the correct people or on the correct competencies and using the correct learning method/tools can be accomplished. For example, the use of a professional training simulator for education and training on fundamental concepts would be excessive and unnecessary.

To perform a successful educational and training needs analysis, organizations should determine what resources are available (both financial and personnel) from an early stage. Costs should be considered during the analysis: the time investment, employee salary, or the cost of a simulator; the time needed to learn to use a simulator as well as simulator cost differ greatly between basic education and training simulators and professional training simulators. In order to ensure there is a sufficient need despite these costs, it may be beneficial to perform a cost–benefit analysis. It is also important to consider the availability of capable educators/instructors/trainers and facilities. Senior management should be financially capable and administratively supportive, and managers at all levels have responsibilities to be actively involved throughout the education and training process to ensure its success, including competence development of facility personnel and ensuring that training is used as a tool for continuous performance improvement.

A checklist can help in the process of establishing education and training objectives and needs. The checklist should include all relevant considerations such as, but not limited to, the following:

- Know what the organization is trying to accomplish.
- Know the history of education/training programmes within the organization.
- What ‘needs’ are addressed by the education/training?
- Have there been any recent process or procedure changes?
- What resources and materials are available for education/ training?
- Who needs to be educated/trained?
- Who can serve as subject matter experts?

Once the education and training needs have been established, a suitable simulator may be selected.

3.3. EDUCATION AND TRAINING LEVELS AND ASSOCIATED SIMULATORS

In general, simulator exercises should be adapted to the education and training levels of the individual. To achieve this, the simulator selection must take into account the depth of the physical models employed depending on the education and training level of the target group. Certain simulators are more suitable for basic exercises, while others are more suitable for advanced exercises. Some simulators may be used for various levels of education and training; for example, basic education and training simulators may have some level of customization, allowing for ‘turning off’ of some of the more complex physical effects which will allow students or trainees to learn using basic exercises without spending unnecessary time learning to use complex or advanced simulator features.

Education and training levels and types of simulators provided in Table 1 are defined as follows:

- **Familiarization:** introduction of the general public to nuclear concepts.
- **Basic educational level:** students starting nuclear education at the university level.
- **Intermediate educational level:** students who have a working knowledge of reactor operation and are familiar with simulators.
- **Advanced educational level:** students who have acquired knowledge about normal operation of nuclear power plants, are familiar with the design of the safety systems and with the simulator features.
- **Professional training:** professionals training for related work within nuclear industry.

The Appendix includes examples of NPP simulators pertinent to these education and training levels and the corresponding example topics.

TABLE 1. TYPES OF SIMULATORS AND ASSOCIATED EDUCATION AND TRAINING LEVELS

EDUCATION/ TRAINING LEVEL	NPP SIMULATOR TYPE	SUGGESTED USERS	EXAMPLE TOPICS OF EDUCATION/TRAINING
Familiarization with basic concepts	Basic education and training simulators a. Part-task b. Full plant	Public and NGOs	— Various nuclear installations — Basic concepts/layouts — Various reactor types — NPP systems' safety features — Peaceful uses of nuclear energy
Basic level education	Basic education and training simulators a. Part-task b. Full plant	University students starting nuclear power education programme	— Basic NPP concepts/layouts — Various types of reactors — Overview of NPP behaviour — Main NPP operating modes — Fundamentals of nuclear physics and thermal hydraulics — Basic NPP components and processes involved — Monitoring parameters — Inherent safety features and active/passive safety systems — Reactor containment — Shielding requirements — Importance of decay heat — Basic operation of complex systems: • Reactor power control • Reactivity effects • Turbine load changing • Reactor-lead vs turbine-lead — General operating procedures
Intermediate level education	Basic education and training simulators a. Part-task b. Full plant	Students who have a knowledge of reactor operation and simulator control	— Classification of systems structures components — Overview of primary and secondary circuit main parameters behaviour — Understanding of the NPP operating modes — Waste management and fuel cycle — Xenon poisoning and xenon power distribution oscillations — Transients, e.g. main coolant pump trip, manual reactor trip, house loading, turbine trip without reactor trip — Important operational stages during startup and shutdown condition, e.g. approaching criticality, putting residual heat removal system in and out of service — Types of fuel deployed — Various coolant media
Advanced level education	Basic education and training simulators a. Part-task b. Full plant	Students who have acquired knowledge about plant operations	— NPP start-up conditions, cold startup hot startup requirements, conditions for approaching criticality, steady state operation — Online–offline fuel loading principle — Reactor power control — Basic understanding of design basis accidents and severe accident phenomena — Loss of decay heat removal system — Critical safety function monitoring and restoration

TABLE 1. TYPES OF SIMULATORS AND ASSOCIATED EDUCATION AND TRAINING LEVELS (cont.)

EDUCATION/ TRAINING LEVEL	NPP SIMULATOR TYPE	SUGGESTED USERS	EXAMPLE TOPICS OF EDUCATION/TRAINING
Professional training	Professional training a. Maintenance/component (part-task) b. Plant specific classroom c. Engineering d. Full-scope	Plant operators, engineering support staff, maintenance personnel, regulatory body staff	— Technical knowledge: • Safety barriers • Design basics • Safety margins • Safety systems • Operational systems • Control systems and the reactor protection system • Design basis accidents • Design extension conditions • Electrical concept / Emergency Power • Control rod drives / Shutdown system — Abnormal operating or/and environmental conditions: • Various LOCAs • Reactivity events • Abnormal operation (turbine trip, house-load, fire, etc.) • Steam generator tube rupture • Station blackout • Earthquakes, Flooding, Tsunami • Loss of the heat sink • Detailed understanding of severe accident phenomena — Operator fundamentals: • Monitoring plant indications and conditions closely • Controlling plant evolutions precisely • Operating the plant with a conservative bias • Maintaining reactivity control • Having a solid understanding of plant design, engineering principles, and sciences • Team working — Operating experience: • External events • Internal events — Procedures: • Plant diagnostics • Plant startup • Plant shutdown • Hot standby checks • Event based and symptom based emergency operating procedures • Severe accident management guidelines — Soft skills: • Leadership • Human error prevention tools • Safety culture

4. CONSIDERATIONS AND ASSESSMENT FOR SELECTION OF SIMULATORS FOR EDUCATION AND TRAINING

4.1. TECHNICAL CHARACTERISTICS OF EDUCATION AND TRAINING SIMULATORS

Selection of suitable simulators for education and training are applied after identification of education and training objectives and after comprehensive analysis of the education and training needs. As a result, suitable simulators are selected according, but not limited to the following technical characteristics:

- Human–machine interface;
- Modelling scope and simulator components;
- Simulator outputs;
- Simulator developer;
- Other considerations.

These technical characteristics are explained in the following sub-sections.

4.1.1. Human–machine interface

The way in which information is presented to the user is important. Usually, the information can be classified in several levels, from general to detailed. A good structure in the presentation of information facilitates better understanding and the achievement of education and training objectives [1].

Several factors need to be considered during the simulator selection process regarding the HMI, such as:

- The design of the HMI should not introduce new difficulties to the education/training process; for example, through a design which is not user friendly. If the HMI does not correspond with the work environment, the HMI should be as easy as possible to operate.
- The HMI has to be consistent with the scope, detail, and accuracy of the models, as well as with the level of education/training. If the HMI is undersized, it is not taking advantage of the whole power of the simulation, and some information will not be available for the user. It is desirable that the HMI is expandable.

The HMI should also consider the type of education and training objectives. For example:

- Objectives related to understanding physical phenomena could involve types of HMI where the fidelity of interactive components is less important than the environment of the graphical representation of outputs and displays.
- Objectives related to the abilities of the target group, such as operators, should involve an HMI similar to the instrumentation of the actual panels (replica, or software representation).

4.1.2. Modelling scope and simulator components

Simulators can be selected according to the available options relating to the software and hardware used.

4.1.2.1. Modelling fidelity

Specificity: The ability of the simulator model to simulate plant behaviour or the main operating modes of a particular plant. For example, the isometric data, valve characteristics, pump characteristics, and other reference plant data are used in the calculations performed by the model.

This option may not be available in all education and training simulators.

Depth and accuracy: The degree to which the simulator can accurately represent behaviour of a plant or specific components/phenomena. The depth and accuracy depend on the models, phenomena simulated, and accuracy of simulated parameters. For example, simulation of cavitation of a pump can be included among the modelled phenomena in order to increase the modelling accuracy of the behaviour of a pump. Sufficient nodalization of the system allows the simulation of all phenomena having an impact on the selected operating procedure.

The required depth and accuracy are determined by the education and training objectives and needs.

Real time: Simulation of physical phenomena occurs in real time with proper time resolution and in the same sequence as compared to the event sequences in a reference plant. For example, if a safety relief valve reaches its set point after 20 seconds of isolation, followed by a pressure decrease and re-seating of the valve in 5 seconds, the simulator demonstrates the same behaviour with appropriate accuracy.

This option is usually required for the professional training.

4.1.2.2. Modelling scope

For a given system: The specification of system components for a given system to be simulated. For example, a part task simulator dedicated to electrical distribution will simulate all of the training and education relevant components of the electrical distribution system.

For a given scenario: The specification of systems, components, and phenomena concerned with a given scenario to be simulated. For example, a part task simulator dedicated to the turbine control system will simulate the components that are used to operate the turbine control system in all modes of operation.

For a given procedure: The specification of procedure to be conducted on the simulator. For example, a simulator will simulate a reactor start-up procedure.

The required modelling scope is determined by the education and training objectives and needs.

4.1.2.3. Software

Instructor station interface: An interface with the capability to prepare and initiate training exercises, to control the simulation and to monitor and evaluate the trainee's performance.

This option is determined by the education and training objectives and needs.

Parameter display system: A software-based display system to monitor simulator output under various conditions.

This system should be present in all simulators, however its complexity (e.g., number of parameters) is determined by the education and training objectives and needs.

4.1.2.4. Graphic display

Availability: Any data available in the reference control room is available in the simulator and main actions that can be performed from the control room can be performed in the simulator.

Control room layout: The layout of the graphical simulator control room is the same as that of the reference control room.

Instrumentation layout: The layout of the simulator graphic representation of the instrumentation is the same as that of the reference instrumentation.

Instrumentation functionality: The functionality of the simulator's graphic representation of the instrumentation is the same as that of the reference instrumentation.

These options are usually required for the engineering simulators, depending on the education and training objectives and needs.

4.1.2.5. Hardware

Instructor station: A facility with the capability to support training exercises, to control the simulation, and to monitor and evaluate the trainee's performance. Components of an instructor station include, for example, an audio/video recording system, communications systems.

Parameter display system: A hardware and panel-based visualization system to monitor simulator output using various instruments. For example: brush recorders, meters, level indicators.

These options are usually not required for the basic education and training simulators.

4.1.3. Simulator outputs

The result of the simulation is a simulation protocol, which is a text or binary file, containing time dependence of the simulated variables, that were selected for the protocol, as well as all actions of the user (student or trainee) and educator/trainer and all events that happened during the simulation, e.g., alarm signals, control and protection system signals. The simulation reports are based on the simulation protocol, presenting data in some or all of the following ways:

- Text form: selected data from the simulator protocol, presented in a simple text format;
- Graphical form: selected data from the simulator protocol, presented as graphs;
- Directing outputs: selected data from the simulator protocol sent directly to a hardcopy device, e.g., a printer;
- Statistical analysis: selected data from the simulator protocol, processed statistically, e.g., presenting averages, variances;
- Data exchange with other software, e.g., a spreadsheet editor, plotting software.

4.1.4. Simulator developer

The selection of the simulator depends on the developer's ability to provide technical support, such as maintenance and updates, documentation in a language suitable for the user, and the availability of education and training courses for future trainers/lecturers.

The simulator developer should provide all documentation related to the simulator. The quality of the documentation should be evaluated, including the user manual, exercise handbook and other provided documents.

4.1.5. Other considerations

Once the simulation models and the HMI have been identified, it is necessary to determine the special functions required for education and training using the suitable simulator. This includes simulation control functions (initial conditions, backtrack, etc.), tutorial capabilities, instructional aides for the assessment of users, and similar.

It is important to identify if the simulator requires an instructor or if users could learn to use the simulator by themselves. In the latter case, special functionality is required to generate guided exercises/scenarios to help the users during the exercise, to track and control the performance of the student, and to record the conclusions of the users' performance.

There are some assessment functions that can be useful for the instructor. For example, to register the student/trainee actions, to warn the instructor when an operational limit has been reached, to assess the reaction of the user as a parameter deviates from its normal range, etc. These functions and others should be evaluated by a cost benefit analysis [1].

4.2. ASSESSMENT OF SIMULATOR SUITABILITY FOR EDUCATION AND TRAINING OBJECTIVES AND NEEDS

Selecting a simulator purely on technical characteristics would be insufficient. There should also be consideration of other factors (such as those included in Table 3) which enhance the overall ability of the candidate simulators to meet the education and training objectives and needs. This in turn depends on when, how, and by whom the simulator is used. Since large costs can be involved in the procurement of simulators, it is important that the users gain and can show real benefits from using such simulators as opposed to other education and training methods. Such benefits might include a reduced time in education and training as well as improved knowledge and skills of students/trainees. Such management judgments will require the acquisition of suitable data derived from the assessment process.

Table 3 [1] outlines the suggested assessment for the suitability of education and training simulators. The assessment therefore heavily depends on the education and training objectives and needs, learning outcomes, and training process.

Table 3 should be filled for each candidate simulator during the assessment process. The determined education and training objectives and needs should dictate what information in Table 3 is pertinent; therefore, some rows in Table 3 may be omitted and others may be added. For example, if the target group consists of university students with a basic or intermediate education level, the other rows under the “Target user group” heading become irrelevant. However, it may be necessary to expand Table 3 to include additional important factors if the target group consists of engineers and technicians of higher education levels who have special or niche objectives and needs. Table 3 will therefore be customized to each specific case. Each row needs to be assessed for whether or not the candidate simulator is satisfactory for the education and training needs and objectives, and an assessor will indicate whether or not it is satisfactory in the “Answer” column of Table 3; additional comments can be made in the “Comments” column, if necessary. An assessor should be qualified enough to be able to check candidate simulators against the pertinent table rows as the subsequent answers will be subjective to the assessor, and each simulator candidate should be assessed in the same manner. After Table 3 has been completed for all candidate simulators, the tables can be used to compare the candidate simulators against each other.

TABLE 3. ASSESSMENT OF SIMULATOR SUITABILITY FOR EDUCATION AND TRAINING OBJECTIVES AND NEEDS

EDUCATION AND TRAINING OBJECTIVES/NEEDS	ANSWER	COMMENT
TARGET USER GROUP		
Initial training		
School students		
University students		
Public		
Engineers and technicians		
LEARNING OBJECTIVES		
Fundamental knowledge		
Integration and application of knowledge		
Skill based practice (knowhow)		
Rule based practice (team work, team projects)		
MODES OF USE		
Self-training / self-learning		
Instructor led training / learning		
Engineering training / learning		
SIMULATOR BASIC RANGE OF PERFORMANCE		
Cold start-up to full power		
Refuelling		
Normal operation conditions		
Limited operating range		
SIMULATOR'S RANGE OF TRANSIENTS		
Design basis accidents		
Severe accidents		
Core melting		
Open vessel accidents		
Malfunctions (listing)		
SIMULATOR'S TIME MODES		
Real time		
Fast time range		
Slow time range		
Time resolution		
SIMULATOR'S MODELS		
Nuclear steam supply system — Thermohydraulics (one or two phase flow) — Non-condensable gases — Neutronics (model, number of energy groups) — Burnup		
Containment — Number of nodes — Radioactive release — Hydrogen combustion modelling		

EDUCATION AND TRAINING OBJECTIVES/NEEDS	ANSWER	COMMENT
Balance of plant — Radioactive releases and transport — Electrical systems — Instrumentation and control systems		
SUPPORT		
Documentation — User manual (instructions and interface description) — Reference manual (scope and model description, verification and validation reports) — Instructor manual (how to create new scenarios and exercises) — Exercise booklet		
Language — Language of simulator interface — Language of documentation		
Developer support — Maintenance — Updates and bug fixes — Training classes/courses		

4.3. INTEGRATION OF SIMULATORS AND ROLE OF EDUCATOR/INSTRUCTOR

The effective use of simulators depends on a careful analysis of the level of educational and training needs. There are many other considerations for the proper integration of simulators into educational and training programmes; for example:

- **Availability**: will there be a need to have several simulators to meet the education and training demand in sensible time scales?
- **Mobility**: will it be necessary or desirable to move the simulators from room to room or even between remote locations?
- **Reliability**: will the simulators be sufficiently reliable to ensure effective training and education and avoid delays in the overall educational and training programmes?
- **Adaptability**: will the simulators need to be reconfigured for different education and training applications and if so, can this be done easily and quickly?
- **Upgradability**: will it be desirable to enhance the scope in the future and if so, will this be easy to do?

In addition to these factors, the education and training needs established by the organization must also be considered. Proper integration of simulators into education and training programmes requires careful planning. While it is important to adjust the integration process on a case-by-case basis, there are several steps which may be included; the following outlines some of the recommended steps for the integration process:

(1) The organization should review its education and training plans to enable selection of the most suitable course to introduce simulators as an educational and training tool. To most effectively utilize available resources, the selected course should ideally allow smooth integration with minimum modification of the course curriculum.

(2) A suitable simulator should be selected which is consistent with the objectives and needs and the education and training level of the course. The simulator selection process should be carried out by those familiar with and knowledgeable of the course curriculum and the relevant characteristics of simulators.

(3) Preparations should be made for the integration of the selected simulator. This includes building instructor competencies (instructor training), development of material for simulator exercises, and preparation of classroom/lab facilities.

(4) A workshop should be held to introduce students/trainees and instructors to the education and training objectives as well as the benefits of simulator use in education and training. This workshop should also be used to demonstrate the selected simulator.

(5) An assessment tool should be used to evaluate the effectiveness of the simulator integration into education and training.

The role of the instructor depends on the type of simulator(s) and the target audience. For certain applications, users can utilize simulators without an instructor; for others, an instructor is necessary to design complex scenarios and explain how seemingly unrelated effects are, indeed, related. The instructor has a major influence on the effectiveness of simulator education and training. The instructor must understand the limitations of the simulator and needs to supplement the information provided with further explanations and guidance [1].

Learning by doing in education and training sessions with an instructor is preferably structured around carefully organized learning outcomes with opportunities for reflection, application and assessment of learned materials. Briefing sessions and/or handouts are part of such education and training sessions. Experience shows that the organization of education and training courses with simulators is most efficient if containing the elements of a conceptual course structure as outlined in Figure 2 with an early established feedback that could become ongoing evaluation/feedback (formative vs summative evaluation).

Instructors are expected to provide a sense of closure when bringing the experiential process to an end by helping students and trainees to understand the learning outputs over the learning objectives. Specifically, this is of importance to their newly acquired skills to suggest future applications and demonstrate integration of the learned knowledge.

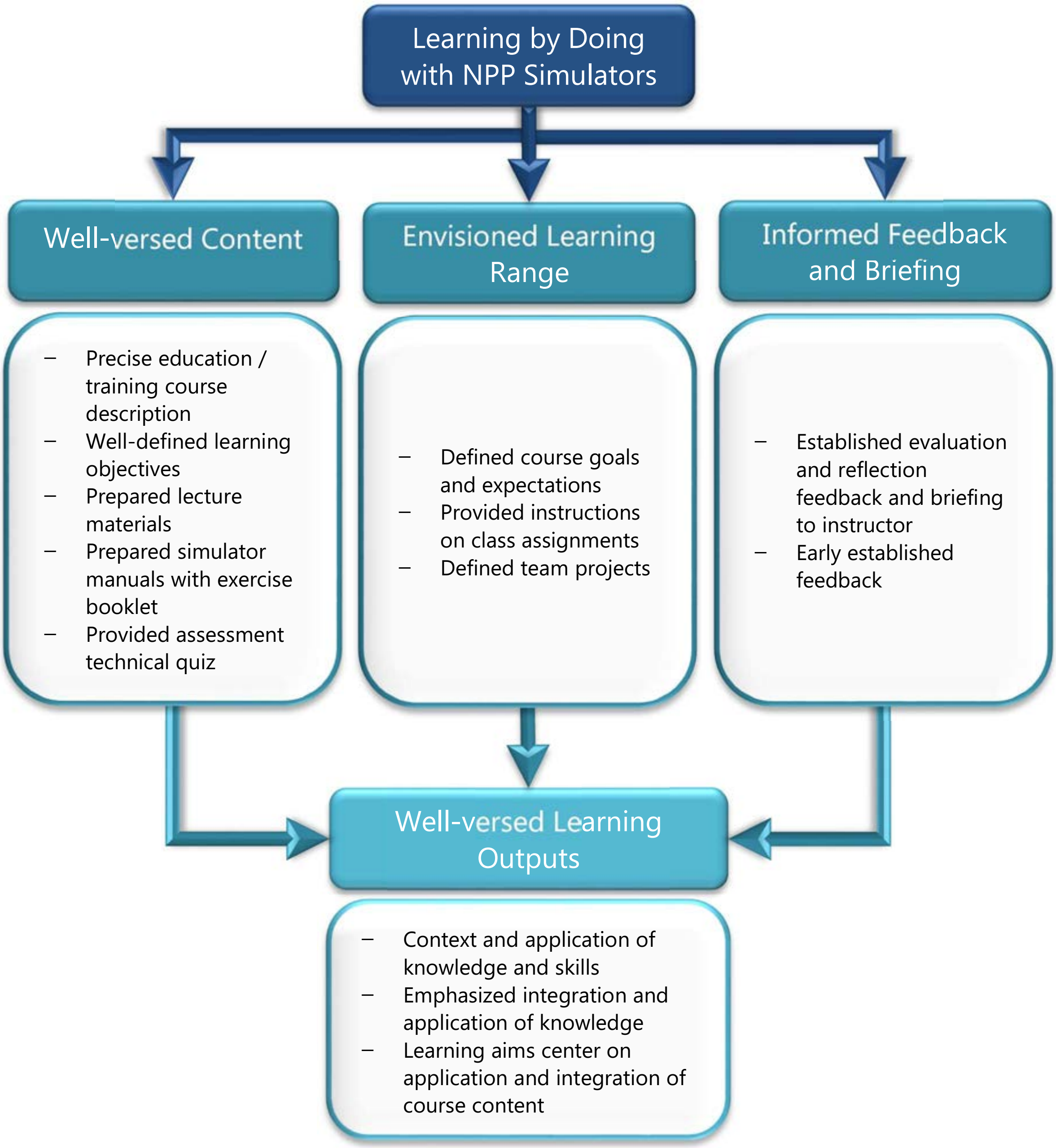

FIG. 2. Conceptual course structure emphasizing importance of learning by doing approach.

5. CONCLUDING REMARKS

The IAEA has established a programme in nuclear reactor simulation computer programs to assist Member States in educating and training their nuclear professionals. More than twenty years of IAEA experience in the distribution and application of basic education and training simulators shows that education and training simulators are an effective medium for knowledge transfer. Presently, there are more than 10 basic education and training simulators available from the IAEA simulator suite. The IAEA regularly arranges for the development of simulation software and corresponding training materials, sponsors training courses and workshops, and distributes computer programs and documentation.

Education and training simulators can be of great value for students and professionals of stakeholder organizations of NPP projects in IAEA Member States, including utilities, regulatory bodies, and universities. Education and training simulators manifest theoretical knowledge gained by students by transferring this knowledge to real practices. In this context, integration of these simulators into educational and training programmes is an advantageous step to enhance knowledge based skills. The integration of such tools in educational and training programmes is very critical at an early stage of the nuclear energy development programme in embarking countries. The utilization of basic education and training simulators, such as those available from the IAEA, is an important step in moving forward to professional training simulators.

Since the publication of IAEA-TECDOC-995, significant changes have occurred in the variety, complexity, and capability of software and hardware reflecting on increased complexity and widened applications of education and training simulators. Accordingly, this publication presents updated information and is intended as a guideline for classification, selection, and use of education and training simulators.

APPENDIX
EXAMPLE EXERCISES FOR DIFFERENT EDUCATION/TRAINING LEVELS

The IAEA collection of NPP simulators contains basic education and training simulators [4–17]. These simulators can be used to perform various exercises of various complexity (belonging to basic, intermediate, and advanced education levels), examples of which are included below. It is important to emphasize the following facts:

— All of the simulators found in the IAEA collection can be used to teach several different exercises (see examples below).
— Most of the simulators in the collection are full-plant simulators. Accordingly, they refer to a particular NPP technology, such as PWR, BWR, VVER, or PHWR. Presently, the only exception is the Micro-Physics Nuclear Reactor Simulator, which is a part-task simulator.

This Appendix also includes example exercises pertaining to the professional training level, and the IAEA collection of basic education and training simulators are not suitable for this level.

A.1. BASIC EDUCATIONAL LEVEL EXAMPLE EXERCISES

It is essential to start with simple exercises using education and training simulators to benefit students starting their nuclear engineering education. The following are some examples of simulator exercises where students can learn by participation, observation and understanding.

Exercise 1: Reactor power control

A simulator which supports reactor power change using control rods in an intuitive way should be selected. For example, the IAEA basic principle simulators 'PCTRAN: Conventional Two-Loop Pressurized Water Reactor' and 'Russian-type PWR (VVER-1000)' support this type of exercise.

Student should be instructed to:

— Note the position of control rods and power level of reactor (instructor may select some other additional parameters for students to observe, e.g., neutron flux, fuel temperature, etc.);
— Insert an instructor defined number of rods by the instructor defined steps into the reactor core;
— Note the changed position of control rods and new power level of reactor;
— Two latter points could be repeated;
— Student should compare noted rod positions and corresponding power levels.

Expected output is understanding of:

- Nuclear reactor power control principle;
- Relationship between control rod positions and power level;
- If they were selected by the instructor, additional parameter behaviour during reactor power changing.

Exercise 2: Reactor–lead vs turbine–lead

A simulator which supports load manoeuvring methods from both reactor and turbine sides should be selected. For example, the IAEA basic principle simulator 'PCTRAN: Conventional Two-Loop Pressurized Water Reactor' supports this type of exercise.

Student should be instructed to:

- Note the reactor power, steam generator pressure, primary coolant pressure, average coolant temperature, and control rods positions;
- Reduce reactor power in reactor–lead mode;
- Observe parameter changes during transient and record comments;
- Reset the simulation at nominal power;
- Reduce reactor power in turbine–lead mode;
- Observe parameter changes during transient and record comments.

Expected output is understanding of:

- Differences between two methods of load manoeuvring;
- Working of the automatic power control system, including reactor power and turbine load.

A.2. INTERMEDIATE EDUCATIONAL LEVEL EXAMPLE EXERCISES

As students at this level already have the working knowledge of reactor operation and are familiar with simulators, the following example exercises help them to learn and understand integrated operation of a plant by participation and observation.

Exercise 1: Turbine trip

A simulator which can simulate a turbine trip and system response should be selected. For example, the IAEA basic principle simulators 'PCTRAN: Conventional Two-Loop Pressurized Water Reactor' and 'Advanced PWR: Two-Loop Large PWR (Korean-OPR 1000)' support this type of exercise.

Student should be instructed to:

- Note the position of the main steam stop valve, turbine valves, control rods, reactivity indicators, xenon concentration and power level of reactor (instructor may select some other additional parameters for student to observe, e.g., neutron flux, fuel temperature, etc.);
- Actuate the turbine trip;
- Note the positions of the main steam stop valve and turbine valves, observe position of control rods and values of reactivity indicators, xenon concentration and power level of reactor;
- Observe functioning of the turbine bypass system.

Expected output is understanding of:

- Changes of the parameters in the secondary loop due to turbine trip;
- Response of the primary side and reactor to the turbine trip;
- Function of the turbine bypass system.

Exercise 2: Pressurizer heater activation by malfunction

A simulator which can simulate pressurizer phenomena and system response to it should be selected. For example, the IAEA basic principle simulator 'Advanced Passive PWR (AP-600)' supports this type of exercise.

Student should be instructed to:

- Note the reactor coolant pressure and temperature, pressurizer level and status of pressurizer heaters and sprays;
- Actuate pressurizer heaters;
- Note the changes of the reactor coolant pressure and temperature, pressurizer level and status of pressurizer heaters and sprays.

Expected output is understanding of:

- Functioning of the pressurizer heating and spray system;
- Response of the primary coolant system.

Exercise 3: Xenon poisoning

A simulator which supports reactor power change using control rods in an intuitive way and is able to simulate xenon poisoning effect should be chosen. For example, the IAEA basic principle simulator 'PCTRAN: Conventional Two-Loop Pressurized Water Reactor' supports this type of exercise.

Student should be instructed to:

- Note the position of control rods, reactivity indicators, xenon concentration and power level of reactor (instructor may select some other additional parameters for student to observe, e.g., neutron flux, fuel temperature, etc.);
- Insert an instructor defined number of rods by the instructor defined steps into the reactor;
- Note the changed position of control rods and values of reactivity indicators, xenon concentration and power level of reactor;
- Withdraw an instructor defined number of rods by the instructor-defined steps from the reactor core;
- Note the changed position of control rods and values of reactivity indicators, xenon concentration and power level of reactor.

Expected output is understanding of:

- Xenon concentration response to the reactor power changes;
- Impact xenon concentration has on neutron flux and reactivity.

A.3. ADVANCED EDUCATIONAL LEVEL EXAMPLE EXERCISES

As the students at this level already have adequate knowledge about normal operation of nuclear power plants and are familiar with the design of the safety systems and simulator features, the following example exercises help them to learn and understand more complex systems functioning with respect to safety of the plant on occurrence of an event/accident by participation and observation.

Exercise 1: Drop of one bank of control rods

A simulator, which supports simulation of the control rod effects on the reactor power, should be selected. For example, the IAEA basic principle simulator 'Conventional Boiling Water Reactor with Active Safety Systems' supports this type of exercise.

Student should be instructed to:

- Observe the reactor power, flux and reactivity parameters;
- Using the appropriate simulator feature, actuate the control rod bank drop;
- Note the automatic system response to the malfunction;
- Observe changes in the reactor power, coolant pressure, main steam pressure.

Expected output is as follows:

- Knowledge of the event sequence of the transient;
- Phenomenological understanding of the different stages occurring during transient progression;

— Ability of the student to explain observed parameter changes;
— Understanding of the actuated safety system functions.

Exercise 2: Accident — loss of coolant accident (LOCA)

A simulator, which supports simulation of LOCA should be selected for the exercise. For example, the IAEA basic principle simulators 'PCTRAN: Conventional Two-Loop Pressurized Water Reactor' and 'Advanced PWR: Two-Loop Large PWR (Korean-OPR 1000)' supports this type of exercise.

Student should be instructed to:

— Observe the major parameters of primary, secondary circuits and containment;
— Using the appropriate simulator feature, actuate the simulated accident and observe its parameters (e.g., break flow);
— Note the major parameter values during different accident stages;
— Note the functions of safety systems.

Expected output is as follows:

— Knowledge of the event sequence of the accident;
— Phenomenological understanding of the different stages occurring during accident progression;
— Ability of the student to explain observed parameter changes;
— Understanding of the actuated safety system functions.

A.4. PROFESSIONAL TRAINING EXAMPLE EXERCISES

Note that the examples below present a general idea of components of a simulator training scenario for nuclear professionals.

Exercise 1 (emergency mode): Steam generator tube rupture, opening and not closing of the steam generator safety valve

An engineering simulator that supports simulation of a steam generator tube rupture and related safety valves operation should be selected for the exercise.

The trainees should be instructed to:

— Apply a conservative approach to making any decision.
— Determine the entry conditions in the symptom based emergency operating procedures (SB EOPs) package.
— Track the execution of the immediate action steps.
— Inform the team about the conditions and actions, described in the page for permanent control.

— Follow the instructions in the step by step procedure by marking the path and the transitions.
— Distribute the actions of the team when following procedures and taking actions.
— Control the critical safety functions in accordance with the ‘instructions for using of SB EOPs’.
— Control the correct state of the unit according to a thermodynamic chart.
— Identify the availability of criteria for implementation of the emergency plan and notify the responsible person.
— Control communication amongst the team members.
— Control place keeping and filling in of operating logs.

Expected output is knowledge and correct actions as follow:

— The ‘procedure for actions in case of primary to secondary circuit leakage, compensated by makeup system’ is implemented.
— Symptom based emergency operating procedures are implemented.
— Emergency plan is activated.
— The reactor is settled in a stable and safe condition.

Exercise 2 (transient mode): Reactor startup and reaching criticality

An engineering simulator that supports simulation of reactor startup and reaching criticality should be selected for the exercise.

The trainees should be instructed to:

— Withdraw control rods.
— Decrease boron concentration.
— Monitor reactor control and protection instrumentation: digital neutron flux monitors and boron meters to measure the reactor's boron concentrations in the primary circuit.
— Control the state of reactor and primary circuit parameters:
  - Reactor power N;
  - Reactor period T;
  - Neutron flux;
  - Boron concentration;
  - Coolant pressure;
  - Coolant temperature Determine correctly the entry conditions in the Symptom Based Emergency Operating Procedures (SB EOPs) package.

Expected output is knowledge and correct actions as follow:

— The minimal controlled level of reactor criticality is reached.
— The reactor is settled in stable and safe condition.

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DEFINITION OF TERMS

Education, Nuclear. Knowledge building process enhancing in-depth understanding of nuclear concepts, phenomena and related technologies.

Training, Nuclear. Capacity building measure to enhance the skill sets, attitude and behaviour within the nuclear installation environment.

Part-task simulators. Simulators that address a specific part of plant operations (systems or components) or specific phenomena.

Full plant simulators. Simulators that describe an overview of NPP behaviour with a focus on main systems, with or without the auxiliary systems.

Basic education and training simulators. Simulators that illustrate general concepts, demonstrating and displaying the fundamental physical processes in an NPP

Professional training simulators. Simulators that represent plant components and systems and their functions, comprehensive operation processes, or the internal effects in various system parameters of the specific NPP during normal, transient, and accident conditions.

Maintenance/Component (part-task) simulators. Simulators that focus on training personnel to perform tasks related to very specific plant component(s) or system(s), such as assembly and disassembly of components or operation of a refuelling machine.

Engineering simulators. Real time simulators used to demonstrate an NPP's behaviour with respect to normal operation, transients, or accidents in more detail than basic education and training simulators.

Full-scope simulators. Simulators that are plant-referenced training tools which operate in real time and are mainly used for licensing of NPP operators and for training other NPP personnel.

ABBREVIATIONS

APROS	Advance Process Simulator Software
CNPO	China Nuclear Power Operations & Technology Corporation Ltd.
CRDM	Control rod drive mechanism
DACS	Data acquisition and control system
DCS	Digital control system
DTB	Dynamic test bed
ETSON	European Technical Safety Organisation Network
FSTS	Full-scope training simulator
HMI	Human–machine interface
I&C	Instrumentation and control
IAEA	International Atomic Energy Agency
ICCC	Instrumentation Control and Computer Complex, Pakistan
INSTN	Institut National des Sciences et techniques Nucléaires, Madagascar
IS	Instructor station
ISAG	Ignalina Safety Analysis Group, Lithuania
JAEC	Jordan Atomic Energy Commission
JRTR	Jordan Research and Training Reactor
JSA	Jordan Subcritical Assembly
JSP	Junior Staff Program, ETSON
JUST	Jordan University of Science and Technology
KAERI	Korea Atomic Energy Research Institute
KALBR-SIM	Kalpakkam Breeder Reactor Simulator
KANNUP	Karachi Nuclear Power Plant, Pakistan
KINPOE	KANUPP Institute of Nuclear Power Engineering, Pakistan
KTU	Kaunas University of Technology, Lithuania
LCC	Local control centres
LDP	Large display panel
LEI	Lithuanian Energy Institute
LOCA	Loss of coolant accident
NPP	Nuclear power plant
OWS	Operator work station
PAEC	Pakistan Atomic Energy Commission
PFBR	Prototype Fast Breeder Reactor, India
PIEAS	Pakistan Institute of Engineering and Applied Sciences
PLC	Programmable logic controller
RPS	Reactor protection system
RRS	Reactor regulating system
RTP	Reactor PUSPATI TRIGA Mark II, Malaysia
SB EOPs	Symptom based emergency operating procedures
SBO	Station blackout
SNERDI	Shanghai Nuclear Engineering Research and Design Institute, China
TSO	Technical and scientific support organizations

VATESI	State Nuclear Power Safety Inspectorate, Lithuania
VINSAP	Visualization of Nuclear Power Plant Severe Accident Progression for Training on Severe Accident Management
VU	Vilnius University

ANNEX
CONTENTS OF THE ATTACHED CD-ROM

Papers Submitted to the Technical Meeting to *Develop a New IAEA Nuclear Energy Series Report on Nuclear Power Plant Simulators as Tools for Education and Training*

23–27 April 2018, Wuhan, China

MEMBER STATE	TITLE
Armenia	DESIGN AND DEVELOPMENT OF MAINTENANCE SIMULATOR FOR ARMENIAN NUCLEAR POWER PLANT TECHNOLOGICAL EQUIPMENT
Bulgaria	APPLICATION OF VVER-440 MULTIFUNCTIONAL SIMULATOR FOR UNIVERSITY EDUCATION IN TECHNICAL UNIVERSITY OF SOFIA, BULGARIA
China	PRACTICE AND EXPERIENCE IN THE USE OF VARIOUS OF SIMULATORS FOR NPP TRAINING AND UNIVERSITY EDUCATION
Czech Republic	VINSAP (Visualization of Nuclear Power Plant Severe Accident Progression for Training on Severe Accident Management): Tool for nuclear power plant staff education and training on severe accident management decision making –
Hungary	APPLICATION OF PC^2+, REMEG, STEGENA, AND SSIM BASIC PRINCIPLE SIMULATORS IN HIGHER EDUCATION IN HUNGARY
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