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Selection, specification, design and use of various nuclear power plant training simulators

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FOREWORD

Several IAEA publications consider the role of training and particularly the role of simulator training to enhance the safety of NPP operations.

Initially, the focus was on full scope simulators for the training of main control room operators. Experience shows that other types of simulator are also effective tools that allow simulator training for a broader range of target groups and training objectives. This report provides guidance to training centres and suppliers on the proper selection, specification, design and use of various forms of simulators. In addition, it provides examples of their use in several Member States.

This report is the result of a series of advisory and consultants meetings held in the framework of the International Working Group on Nuclear Power Plant Control and Instrumentation (IWG-NPPCI) in 1995–1996. The contributors to this report from participating organizations and Member States are gratefully acknowledged. Special thanks are due to R. Bruno of Exitech Corp., who edited the report. The IAEA officers responsible for preparing this publication were A. Kossilov and V. Neboyan of the Division of Nuclear Power and the Fuel Cycle.

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1. INTRODUCTION

1.1. PURPOSE

Plant reference, full scope simulators have clearly demonstrated their value in the training of nuclear power plant (NPP) personnel. In this regard, many Member States have acquired these simulators for their NPPs and have enhanced their operator training accordingly and provide training 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 operations personnel to receive training on a simulator with operating characteristics similar to their own NPP.

However, the benefits of simulation need not be limited to the special case of plant reference, full scope simulators. Differences in the scope of simulation, methods of simulation, instructor and trainee interfaces, and other features allow simulation as a mode of instruction for a wide audience. Indeed, many training needs can be addressed using various simulation directed toward specific instruction. The application of such simulation can be very effective and relatively inexpensive as well.

While adequate guidance is available for plant reference, full scope simulators, it has been recognized that there is a general lack of information about the selection, specification, and use of other types of simulators. It is the purpose of this publication to provide such guidance.

1.2. TYPES OF SIMULATOR AND THEIR ROLES IN THE TRAINING PROCESS

Various simulators, other than plant reference, full scope simulators, are described below. The list is not intended to be all-inclusive nor definitive, reflective of the current state-of-the-art for an evolving technology.

Part task simulators are designed for training on a specific part of plant operations or for training for special phenomena. Plant systems or phenomena may be simulated more accurately than in a full scope simulator. Such simulators can be beneficial to improve the focus of training in particular areas. Examples of a part task simulators are: a simulator for training of steam generator tube ruptures; and, a simulator for training of Diesel Generator startup and operation.

Basic principle simulators illustrate general concepts, demonstrating and displaying the fundamental physical processes of the plant. This type of simulator can provide an overview of plant behavior or a basic understanding of the main operating modes. The simulation scope focuses on the main systems and auxiliary or support systems may be neglected. Its main goal is to help trainees understand fundamental physical processes, basic operation of complex systems, and the general operating procedures of a nuclear power plant.

Compact simulators provide a means of training on operating procedures in a simplified form. A control desk is often provided to display significant parameters. Although modelling depth and fidelity are equivalent to a full scope simulator, the scope of simulation is typically limited and the full control room is not replicated They are powerful tools for the basic training of new operators, field operators and personnel not working in the control room.

Graphical simulators provide a representation of the control parameters and the operating environment in a graphical form. For example, control room panels may be displayed either in display units or in virtual synthesized images. They provide a low-cost alternative to other simulators requiring the use of control room hardware. The scope and depth of simulation can range up to full scope simulation models.

The term "**multi-functional simulators**" is sometimes used to describe either the compact simulators or the graphical simulators mentioned above. In general, the modelling depth and fidelity are near or the same as those of a full scope simulator, but the human-machine interface is provided graphically through mimics or by a combination of hard and soft panels. This type of simulator can be extended to a full scope simulator.

A **plant analyser** is a training device to study complicated plant transients or accidents in detail. Since the goal is to provide a very detailed description of plant behavior, the simulation provided by Plant Analysers is not required to operate in real-time nor display all actual operating data. Rather, data for complex analysis of plant operating behavior is typically presented in a format conducive to analysis.

1.3. KEY POSITIONS FOR SIMULATOR TRAINING

The use of simulators has proven advantageous in the training and qualification of NPP personnel. In general, simulators have been used 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.

In general, assuming that a systematic approach to training has been selected to manage the training functions at the NPP, the needs analysis and training design will provide the process by which training on a simulator or other alternatives are chosen. the systematic approach to training is fully described in Ref. [1].

1.4. MAIN BENEFITS IN USING A RANGE OF TRAINING SIMULATORS

The main benefits of simulator training in general include, but are not limited to, the following:

- The ability to train on malfunctions, transients, and accidents;

- The reduction of risk to plant equipment and personnel;

- The ability to repeat a scenario as many times as necessary for trainee understanding and retention;

- The ability to experience events in a training mode prior to seeing them for the first time when they happen in the plant;

- The ability to train personnel on actual plant events;

- A cost effective means to master training objectives;

- The opportunity to achieve new training objectives as requirements and training needs change;

- Obtaining excellence in training, especially for cognitive, high level tasks and acquisition and retention of knowledge on plant processes.

Training including a range of simulators, has the additional advantages of:

- Providing a transition for trainees to progress from fundamentals training and initial operations training to the more complex integrated plant operations and team training that are normally performed on a full scope simulator;

- A broader range of personnel can receive effective training when a variety of simulators are available;

- Individualised instruction or self-training can be performed effectively on simulation devices designed with these capabilities in mind;

- Providing training for engineering and management personnel who do not have a need for a thorough familiarity with the control room displays and instrumentation, but who need an understanding of plant processes and specific systems;

- Providing retraining for shift personnel to emphasize comprehension and technical training versus training with an emphasis on teamwork and control room behaviour usually performed on a full scope simulator;

- Achieving cost effective simulator training due to reductions in the scope and complexity of a full scope simulator (for some tasks);

- Ensuring that training appropriate to other simulation devices is not performed on a full scope simulator, supporting training efficiency, and allowing more time for personnel on the full scope simulator when needed;

- Reducing the training demand on the full scope simulator to allow improved preparation by instructors and better simulator maintenance and modifications;

- Providing simulation for processes and actions beyond the ability of control room personnel to respond;

- Training for mitigation of accident consequences, even for accidents beyond the design basis.

2. TRAINING CENTRE FACILITIES AND SELECTION OF SIMULATORS

2.1. GENERAL OBJECTIVES OF THE TRAINING FUNCTION

Training is an essential component of a safe, economical Nuclear power industry. Typically the training function will underpin a number of the utility's key objectives and business goals. These in turn will usually be linked to the legislative framework governing the activities of the industry; for example, site license requirements where these apply.

Increasingly, however, training is being seen in broader terms as part of the total development of a key resource, namely the workforce. Whilst the focus of this report is on Technical training, it is important to see this in the context of helping to realize the full potential of staff by assisting in the achievement of key competencies.

The training function will seek to develop appropriate training strategies, adopting best practices; for example, the use of simulators and adaptation of new instructional methods.

The essential objectives of the training function can be summarized as:

- support the utility in achieving statutory requirements to ensure safe operation;
- control, assess, and improve staff competence levels;
- enhance safety culture;
- improve productivity and availability.

2.2. ROLE OF THE TRAINING CENTRE

Dedicated, well equipped and well staffed training facilities are an important ingredient in achieving the key business objectives described above. Different approaches have been taken regarding the provision of such facilities. For example, some utilities have provided a multi-purpose training centre designed to meet the needs of a broad range of staff.

The general role of such training centres is to provide a cost effective, quality training service; and:

- assist in achieving company training specifications by the provision and delivery of a range of courses;
- assist in the development of training standards and specifications;
- implement a variety of training devices including simulators;
- provide an effective and comfortable learning environment;
- provide a training advisory service for the utility.

The target audience for technical training can be large and within this there will be a range of requirements. In simple terms, the target groups can be sub-divided into:

- shift operations and support personnel;
- management;
- technical support staff (physics, chemistry, etc.);
- maintenance support (mechanical, electrical, I&C, etc.);
- administrative.

The effective delivery of training depends on several key factors: a high quality teaching environment coupled with good facilities, professional trainers, and suitable methods of delivery are vital.

Each training centre should be equipped for instruction on skill, rule, and knowledge based objectives. This requires investment in classroom equipment and in other instructional media such as simulators, labs, models, mockups, etc.

Of utmost importance for successful training is the co-operation between the Training centre and the operations management in the plant. Formal methods and procedures must be established for common:

- program design;
- definition of learning objectives;
- assessment of the trainees;
- quality assurance of the training.

A constant exchange of information between the plant and training centre is necessary. The approach adopted will reflect the training specification requirements and the target groups of the training. In assembling a training programme, the training function the most effective methods of delivery in terms of training quality and cost. It is important that all available training "tools" are considered in this approach: for example, classroom training, laboratory training, training simulators, mockups, and models.

2.3. SELECTION OF SIMULATORS ACCORDING TO TRAINING NEEDS

If instruction is to be conducted on a simulator, appropriate simulators must be chosen so that training can achieve the desired objectives. After consideration of the training objectives, an appropriate simulator must be chosen. For this reason, it is useful to classify various simulators.

2.3.1. Classification criteria for different simulators

Simulators can be classified according to criteria relating to the software and hardware used. Five levels are identified:

- none: the criteria is not fulfilled or is not applicable;
- low;
- medium;
- high;
- full: the criteria is fully met.

To characterize a simulator in relation to its reference plant by these criteria, the following matrix can be used (see TABLE I).

Below are explanations of classification terms with examples:

Modelling fidelity - unit specificity

Definition: The model simulates the parameters of the reference plant.

TABLE I. CLASSIFICATION MATRIX

Criteria				None	Low	Medium	High	Full
Software	Modelling fidelity		Unit specificity					
			Depth & accuracy					
			Real time					
	Modelling scope		For a given system (list)					
			For a given scenario (list)					
			Operating procedures (list)					
	Instructor system							
	Parameter display system							
Hardware	Plant specific trainee interface	Real panel	Availability					
			Control room layout					
			Instrumentation layout					
			Instrumentation functionality					
	Plant specific trainee interface	Graphic display	Availability					
			Control room layout					
			Instrumentation layout					
			Instrumentation functionality					
Parameter display system								
Instructor Interface								
Computer Configuration								

Example: Isometric data, valve characteristics, pump characteristics, and other reference plant data are used in the calculations performed by the model.

Modelling fidelity - depth and accuracy

Definition: The physical phenomena of the reference plant are able to be simulated. The scope of models, phenomena simulated, and accuracy of calculated parameters are determined by the training objectives.

Examples: Simulation of a cavitation of a pump. Sufficient nodalization of the system allows the simulation of all phenomena having an impact on the selected operating procedure.

Modelling fidelity - real time

Definition: Simulation of physical phenomena occurs in real-time with proper time resolution and in the same sequence when compared to the event sequences in the reference plant.

Example: A safety relief valve reaches its set point after 20 s of isolation, followed by a pressure decrease and re-seating of the valve in 5 s. The simulator demonstrates the same behavior within appropriate accuracy for the training objectives.

Modelling scope - versus a given system

Definition: The specification of system components for a given system to be simulated.

Example: A part task simulator dedicated to electrical distribution will simulate all of the training-relevant components of the electrical distribution system.

Modelling scope - versus a given scenario

Definition: The specification of systems, components, and phenomena concerned with a given scenario to be simulated.

Example: A part task simulator dedicated to the Turbine Control System will simulate the components that will be used to operate the Turbine Control System in all modes of operation.

Modelling scope - versus operating procedures

Definition: The specification of operating procedures to be conducted on the simulator.

Example: Reactor startup procedure.

Plant specific operators' interface - real panel - availability

Definition: The instrumentation and control available in the simulator are the same as in the reference plant.

Example: All channels of nuclear instrumentation are available in the simulator.

Plant specific operators' interface - real panel - control room layout

Definition: The layout of the simulator control room panels is the same as the reference plant.

Plant specific operators' interface - real panel - instrumentation layout

Definition: The layout of the simulator's instrumentation is the same as the reference plant.

Plant specific operators' interface - real panel - instrumentation functionality

Definition: The functionality of the simulator's instrumentation is the same as the reference plant.

Plant specific operators' interface - graphics - availability

Definition: Any data available in the plant reference control room is available in the simulator and all actions that can be performed from the control room can be performed in the simulator.

Plant specific operators' interface - graphics (virtual representation) - control room layout

Definition: The layout of the graphical simulator control room is the same as the reference plant.

Plant specific operators' interface - graphics - instrumentation layout

Definition: The layout of the simulator graphic representation of the instrumentation is the same as the reference plant.

Plant specific operators' interface - graphics - instrumentation functionality

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

2.3.2. Human–machine interface (HMI)

The way in which information is given 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 the information will facilitate better understanding. The human–machine interface (HMI) can facilitate understanding and the achievement of training objectives.

Influences regarding the HMI:

– Training presents challenges to trainees. The design of the HMI has to avoid introducing new difficulties to the 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. 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 could be expandable.

- The cost of the HMI is an important consideration in the overall cost of the simulator.

The HMI should take into account also the type of training objectives. For example:

- Training objectives related with abilities of operators should involve a HMI similar to the instrumentation of the panels (replica, or software representation).

- Training objectives related to understanding phenomena could involve other types of HMI where the fidelity of the interactive components are less important than the environment of the graphical representation of outputs and displays. For example, operating personnel and engineering personnel may need simulators with the same models but completely different HMI.

2.3.3. Other considerations

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

- It is important to identify if the simulator requires an instructor or if a trainee could use the simulator by himself. In this last case, special functionality is required to generate guided exercises/scenarios to help the trainee during the training, to track and control the performance of the student, and to record the conclusions of the trainee performance.

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

A list of standard simulation control functions are included in Ref. [2].

2.4. IMPLEMENTATION OF SIMULATORS IN THE TRAINING PROCESS

2.4.1. The training environment

The training environment in which simulators are used has a major impact on the effectiveness of the training. Clearly the choice made will depend on many factors.

From the trainee's point of view, important factors are:

- Comfort of the environment (heating, lighting, ventilation, noise level, etc.);
- Availability and quality of additional visual aids (projectors, video, PCs etc.);
- Space appropriate to the number of trainees.

From the instructor's point of view, important factors are:

- Well designed layout of facilities to ensure effective training;
- Easy access to supporting information/documentation;
- Ease of use and accessibility of additional training material and training aids.

From the simulator maintenance/development engineer's point of view, important factors are:

- Space to work on the simulator;
- Additional space available if further expansion of the simulator is anticipated;
- Adequate and suitably positioned power supplies;
- Suitable humidity/temperature and air quality to suit the electronic equipment;
- Ease of access to support facilities and workshops.

2.4.2. Role of the instructor

The role of the instructor will depend on the type of simulators and the target audience. For certain applications, trainees can use 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 will have a major influence on the effectiveness of simulator training. The instructor must understand the limitations of the simulator and needs to supplement the information provided with further explanations and guidance. The general role and requirements for Instructors are well described in other publications, for example [1].

It is important for instructors to be fully involved in the design, specification and development of a simulator to ensure to ensure that identified objectives will be met.

Because simulators are often used in the early stages of a trainee's development so that the instructor will need to balance the degree of detail and complexity presented with the needs of the learner. Furthermore, he will need to constantly relate what is being taught to the "real world" that the trainee will eventually have to operate in.

2.4.3. Integration of simulators into the training programme

The effective design and use of simulators depends on a careful analysis of the training needs. There are a number of other considerations for the proper integration of simulators into the training programme; for example:

- Availability: will there be a need to have several simulators to service the 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 avoid delays in the overall training programme?
- Adaptability: will the simulators need to be reconfigured for different training applications and if so can this be done easily and quickly?

- Upgrade ability: will it be desirable to enhance the scope in future and if so will this be easy to do?

In addition to these factors, the training needs of the instructors must also be considered. Integration of simulators into the training programme requires careful prior planning and management. A phased approach allows evaluation to proceed as the equipment is increasingly used so that any problems can be sorted out before a major impact on the training programme has arisen.

2.4.4. Evaluation of the effectiveness of the simulators in the training programme

Any simulator is only an aid to training. Rating a simulator purely on factors such as scope, fidelity, or technical sophistication could be misleading. The real criterion should be its overall ability to enhance the training process. This in turn depends on when, how, and by whom the simulator is used. It is clear that the inappropriate use of a simulator can lead to poor training and could even mislead the trainee, i.e., cause so-called negative training. This requires particular care in the case of simulators where the plant/control room and instrumentation is represented in a simplified or idealized way, which bears little relation to the actual plant. So the ways the simulator is going to be used and evaluated need to be carefully considered at the design stage.

The evaluation should be linked to the SAT model. Standard evaluation techniques can be used as detailed in the SAT reference document. For example questionnaires can be designed to obtain feedback from both trainees and instructors. Independent observation and rating of training actually taking place can also be valuable, as can formal or informal interviews with trainees. 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 training methods. Such benefits might be reduced time in training, improved knowledge and skills of the trainees etc. Such management judgments will require the acquisition of suitable data derived from the evaluation process. This evaluation should also address the following questions:

- Is there a need for improvement or modification to the simulators?
- Is there a need to change the way the simulator is used?
- Is there a need for further instructor training?
- Is the environment used suitable?
- Is the documentation satisfactory?

2.5. TRAINING DOCUMENT REQUIREMENTS

The following documents are absolutely necessary for the instructor:

- Simulator operations manual (startup, loading of initial conditions, etc.).
- Malfunctions cause and effects documentation.
- Exercise descriptions and lesson plans, with details about learning objectives, time, appropriate graphics to the training subjects, descriptions of possible malfunction variants, descriptions of the time sequence of exercises in short and long versions, typical captioning of the "pattern plot", and cross references to other information material.
- Description of the simulation models and their limits.

The following training documents are required both for trainee and instructor: Original plant documentation corresponding to the system scope must be available. Depending on the emphasis of the simulation, operation manuals, system diagrams, I&C function charts, operation regulations and shift instructions are relevant.

3. SPECIFICATION

The development of a simulator specification is an important step in the process of making a simulator available for training. Regardless of the scope or purpose of the simulator, such a specification is useful and important because it serves as a focal point for all decisions regarding the simulator and is a significant step in maintaining an historical record of the simulator's development. Depending on which type of simulator is desired, the user can discretely select from the items below those which are applicable to the specific needs being addressed.

3.1. MODELLING SPECIFICATION

A specification for the simulator's modelling can be divided into two major categories:

- modelling scope;
- modelling fidelity.

These categories were described above.

3.2. CONTENT OF THE SPECIFICATION

The content that is described here is rather detailed. It is included in this detail for two major reasons:

- the information which is provided here is useful as a starting point for the collect of the design data package that must be developed;

- the more precisely the specification is developed, the more a training manager, vendor, or internal developer will be able to accurately determine and predict costs.

It is useful to include an exhaustive naming convention in the specification with graphical symbols descriptions and any other data that would be helpful such as:

- list of simulated control room instrumentation;
- list of simulated plant computer parameters;
- list of stimulated plant equipment;
- simulated P&IDs;
- simulated electrical systems;
- simulated control;
- list of simulated I&C, mechanical and electrical components;
- list of items operated by local operators;
- plant status range;
- initial conditions;
- list of generic malfunctions;
- list of specific malfunctions.

For modelling fidelity, the following should be considered:

- depth of simulation for standard components;
- depth of simulation for special components;
- description of simulated physical phenomena for complex models;
- simulated operating procedures;
- precision and tolerances.

3.2.1. Modelling scope

It is useful to specify the operating modes that are to be simulated. And, in accordance with the simulated modes, to deliver the necessary data to specify the scope of simulation.

List of simulated control room instrumentation

Specify control room instrumentation. For each type of instrumentation, establish a list with:

- a reference code for the type of instrument;
- a reference code for the instrument (ideally the instrument identification used in the plant);
- the system with which it is associated;
- the panel position of the instrumentation;
- a short description of the functions to be simulated;
- the minimum required I/O.

A drawing or a picture of the instrument is useful.

List of simulated plant computer parameters

Specify plant computer parameters. For each parameter, establish a list with:

- a reference code for the type of parameter;
- a reference code for the parameter (ideally the identification used in the plant);
- the system with which it is associated.

Provide layout of the screens.

Simulated P&IDs

Specify plant process (or piping) and instrumentation diagrams or drawings (P&ID) to be simulated. These P&IDs can be flow diagrams and plant logical diagrams, with a clear identification of simulated components and connections to other components or systems. Isometric data should be considered where appropriate.

Simulated electrical systems

Specify the electrical power supply and distribution system:

- the safety relevance of the electrical supply, for example vital busses, non-vital busses, AC and DC distribution systems, diesel generators, external power supplies, and battery power supplies;

- the load carried by each supply;

- include battery chargers, converters, transformers, etc.

Simulated control systems

In addition to control diagrams, it is useful to add a functional description of major controls and provide software for computerized control systems. A list of simulated I&C, mechanical, and electrical components should be included.

For each category and/or sub-category of components, establish a list with:

- a reference code for the components or type of instrument;
- the system with which it is associated;
- indication if it has to be simulated at a remote location.

Note: such information can be extracted from a CAD scheme representing the P&ID, I&C and electrical diagrams.

Plant operating modes

Specify the plant operating modes to be simulated (for example from cold shut-down to full power operation).

Initial conditions (ICs)

Specify the initial conditions to be prepared and validated.

Generic malfunctions

Specify the systems and components on which to apply generic malfunctions. For each, describe the malfunction including the physical malfunction to be simulated, its origin, its consequences, and the limits of simulation.

Specific malfunctions

Specify the specific malfunctions to be simulated. For each, describe the malfunction including the physical malfunction to be simulated, its origin, its consequences, and the limits of simulation. In case of breaks, specify the size and location of the break.

3.2.2. Modelling fidelity

Specify for each parameter the precision and tolerances that can be accepted. Ref. [3] contains the industry standard for precision and tolerances for full scope, plant reference simulators.

3.3. PERFORMANCE AND SPECIFIC FEATURES

The simulator must be specified correctly and include the ability to perform future upgrades as the plant and training needs change. Therefore, a software workshop and a configuration management system can provide:

- documentation;
- maintainability;
- modularity;
- respect of codes and standards;
- portability;
- upgrade possibilities;
- multi-use possibilities.

3.3.1. Software workshop

The implementation of sophisticated simulation models may cause the user to employ a software workshop to maintain and improve the software over time. The scope of simulation addressed by the software workshop is at the discretion of the user, subject to any license agreements with the supplier of the software. Considerations include:

- Availability of documentation for software models.

- Are there automatic code generators that can be used, which types of models can be maintained, what is the software language of the generated codes?

- Other management tools and/or utility programs are available?

- What is the computer language of the code generators and other tools?

- What software packages and ad-hoc licences are available or required?

Emphasis should be placed on the user-friendliness of such workshops

3.3.2. Configuration management system (CMS)

A configuration management system is essential for quality assurance. It can be included in the software workshop if there is one, or dealt with separately. It is a system that helps to facilitate identification of the different versions of simulation configurations, to trace the data package elements contained in it, the changes they undergo, and even a user's aid with regard to the scope of validity. The system should help to identify problems in the configuration and in the associated tools.

3.3.3. Maintainability

The design of simulation models and Human-machine Interfaces must facilitate their maintenance, either by the customer himself, whether or not he has at his disposal an adapted software workshop, or by the models' Supplier. With this purpose, all information about the models and the configuration's constituent images will be detailed either in the instruction manuals or in the source code notes.

3.3.4. Modularity

A modular approach that can permit easy manipulation of the simulator in order to obtain other configurations from an existing one should be considered and encouraged. Modularity concerns the inter-module connection items, and it is recommended that specifications characterizing this modularity be developed to describe the physical variables, their variation range, and units and respect the customer's naming and identification conventions.

3.3.5. Upgrades

Experience has demonstrated the desirability for a simulator to have the ability to increase the scope or depth of simulation. It is therefore prudent to provide considerable spare computing resources in the form of:

- calculation power;
- memory capacity;
- information flow.

The spare computing power should be confirmed at the outset and significant spare computing power should remain available in both the central computer performing the simulation and the distributed HMI stations as changes are performed on the simulator. The spare computing power should be monitored regularly to determine if the simulator is approaching any limits that could adversely affect the simulation. As new functions are added, additional systems or components are modeled, or shortened time steps are implemented, significant upgrades or replacement of computers may be required. Portability of the simulation software then becomes an important consideration.

3.3.6. Documentation

The simulator documentation should permit operation, maintenance and upgrades to be performed on the simulator without difficulty. The documentation database should be able to find documentation and identify relationships to other documents. The following main areas in the documentation may be identified.

Organization and follow-up documentation:

- quality assurance plan;
- development plan;
- progress meeting reports.

Design and development documentation:

- system specification files;
- component specification files;
- I&C specification files;
- P&IDs;
- plant isometric data.

Description of the malfunctions:

- malfunctions cause and effects;
- design transients;
- best-estimate plant response characteristics;
- actual plant transient data.

Control and test documentation:

- testing procedures;
- acceptance procedures;
- filled-in test files for unit testing;
- integration and acceptance testing.

User manuals:

- simulator user manual;
- instructor station user manual;
- manuals provided by third-party vendors.

Maintenance documentation:

- installation specifications;
- software maintenance manuals;

- software manuals;
- documentation provided by third-party vendors.

Document language, document processing requirements, media, and the number of copies of the above should be specified.

3.3.7. Portability

As mentioned above, it may become necessary to upgrade the simulation computer complex after a period of time. In such cases, it is important to consider certain guidelines to minimize costs as follows:

- use of standardized programming languages;

- use of commercial software packages where appropriate (for running graphics, database management, etc.);

- use standard communication protocols;

- if necessary, identify areas in the code that are operating system or hardware dependent.

3.4. DEFINITION OF INSTRUCTOR STATION FEATURES

The instructor station should provide the capability to prepare and initiate training exercises, to control the simulation, and to monitor and evaluate the trainee's performance. The instructor station should also provide the facilities for managing training and maintaining training records. Such functions are usually similar for all training simulators. The basic features related to such functions are, in general terms, described hereafter.

To allow the instructor to focus attention on training, rather than on operating the simulator, an intuitive user friendly graphical interface should be employed. Color and animation should be used to emphasize selected items, equipment, status, thresholds, levels, direction of flows and alarms. The instructor station should display schematic diagrams of plant systems and components, menus, and dialogue boxes that are touch sensitive or mouse sensitive.

The complete or partial implementation of these features depends on the purpose and design of the simulator

3.4.1. Simulation control

Stop, freeze, run

The simulation can be stopped (frozen) and resumed at any time by the instructor.

Slow time

Slow time ability is provided for fast transients. A rate of about 1/10 slower of real-time is usually used.

Fast time

The fast time is provided for demonstration of long-term transients and for fast entering of desired plant conditions without any operator intervention. Different rates can be used depending on the particular process. For example a rate of about 10 times faster should be used during plant heat-up/cool down phase, evacuation of the condenser and decay heat generation. Rates ranging from 2 to 600 times faster are used for build-up/burn-up of xenon-iodine concentration. A rate of about 300 times faster can be used for the hydrogen generation process.

Step by step mode

In this mode the process simulation stops at the end of each simulation time step and the user can initiate the next time step at his will. This operating mode is useful for tutorial, engineering, debugging purposes or for fine tuning.

Snapshot

Temporary initial conditions can be taken either automatically or on instructor's demand. It should be possible to start the simulation from each snapshot initial condition. A snapshot initial condition can be converted into a new initial condition.

Backtrack

The simulator should save initial conditions, automatically, at a user-defined time interval during simulation. Storage space for a high number of backtrack initial conditions should be available. The time interval for recording the backtrack initial conditions can be adjustable between, e.g., 30 s and 600 s. Main plant parameters for identification of the respective plant status should be stored and recallable. The simulation should be restorable from each backtrack initial condition.

Replay

From each backtrack initial condition, the simulation should be able to repeat all the trainee's and instructor's actions and plant reactions. Operator intervention is not possible. The replay process can be, at any time, interrupted and the simulation restarted, from that moment, at normal speed.

3.4.2. Exercise control

Initial conditions

A set of initial conditions can be used to initialize the simulator to any arbitrary plant condition. A high number, or even an unlimited number, of initial conditions should be available to the instructors. In the latter case, the maximum number of initial conditions is only limited by the available disk storage space.

External parameters

External parameters such as external temperatures, river level, etc. should be able to be set or changed by the instructor.

Remote operation

Selected local in-plant operations should be performed from simulated local control stations, if available, or from the instructor station.

Malfunctions

One or more simulated malfunctions/equipment failures can be initiated, on demand by the instructor, triggered at a specified elapsed simulation time, or triggered by a specific event, such as a selected process variable reaching a specified value. The malfunction intensity, when applicable, can occur as either a discrete step, or can be ramped from a minimum value to a specified intensity over a specified period of time.

Trend logs and plots

One or more user-defined simulation variables can be chronologically recorded during any arbitrary period of a training session. Recorded values can be monitored as they are being recorded, or reviewed any time later, in either tabular form or $X = f(\text{time})$, or $X = f(\varepsilon)$ graphic. Hard copies of these curves can be produced for detailed analyses.

Balances

Very important aspect is to show different mass or energy balances during transients. For example during a LOCA transient, the water balance of the primary circuit is of utmost importance. In this perspective, such balances can be required on the base of bar graphs and drawings.

Standard exercises

From the instructor station, standard exercises can be prepared beforehand and activated at any time. These exercises could be, for example, saved as disk files, which could contain simplified commands representing all the available functions including simulation time control. The instructor can activate an exercise file to start a training session with the desired scenario.

3.4.3. Trainee's performance and evaluation tools

Exercise summary

This is a chronological list of the actions performed by the operator and by the instructor during training sessions. It should be permanently saved, but can be reviewed on-line and reported on hard copy.

Trainee assessment

An automated trainee assessment function may be specified. The purpose is to assist the instructor in assessing the trainees' performance against specified criteria and in measuring competence in several areas. This function could, for example, record all the trainees' decisions made during the training session and check their correctness against an appropriate procedure. At the end of the exercise, a concise report should be printed out.

Self- guided exercise

A self-guided exercise mode can be specified. It could be implemented as an expert system, which comprises the rules to be followed, depending on the transient and the trainees' actions. After the analysis the trainee is able, if it is appropriate, to repeat the simulation exercise starting at the point at which he deviated from the correct procedure.

3.5. DATA SPECIFICATION

Data specification is a crucial part of the specification, because the quality of the simulator can not be better than the delivered data. Ideally, all of the data should be assembled at the same time, to ensure its consistency. In practice this is difficult to achieve since it is a time consuming task and performance data is continually produced during a simulator construction project. The usual compromise is to define data sets for each major phase of a project to support the manufacture of the simulator at defined phases. In general the data delivery can be categorized in three different phases as:

- pre-contract phase;
- functional specification phase;
- model development phase.

The same data structure will be used for the three phases and the content will be more and more detailed.

In the pre-contract phase those types of data are needed, which are important to determine the size of the simulator development

In the functional specification phase every piece of information is needed, which specifies the technology for all components (characteristics of the components, detailed 3-D layouts of the main technological parts, etc.).

In the model development phase those types of data are needed, which represent plant behaviour.

It is very important to determine a reference date for the selected plant status and to collect the information for that reference date in order to get a consistent data set.

The data specification should be done in some kinds of tabulated form using a proper database program. Most of the characteristics can be defined in this way, since in most cases only some working points of the components are important and among these points some kinds of interpolation can be used.

At the beginning of the data specification a naming convention should be established. In most cases the naming convention used in the actual plant is not suitable for the data specification, since there will be certain data, which do not exist in the plant. However the naming can be derived from the name convention of the plant. Therefore, it is recommended to derive the necessary new names from the existing names of the plant. Moreover, a description also has to be added to every name in a well defined form; i.e., abbreviations have to be explained in an additional glossary.

As to the measurement specification, it is very important to define the unit of the measurement. It is advisable to provide a reference for every data where it originates from (e.g. drawing number) and the names of the competent persons who have delivered the given data.

3.5.1. Database of the simulated components

General plant data can be used to contribute to the database requirements of the simulator. The databases can be organized as indicated below:

- List of control room instrumentation;
- List of plant computer parameters;
- List of I/O instrumentation;
- List of mechanical component;
- List of electrical components;
- List of remote control components;
- Simulated flow diagrams;
- Simulated electrical systems;
- Simulated logical diagrams and simulated regulations;
- List of the manually controlled devices.

3.5.2. Data for special systems and/or components

Reactor core and vessel

- Nuclear parameters of the reactor, including the Xe-I and Sm dynamics and decay heat generation data at least for the Beginning of Life (BOL) and the End of Life (EOL).

- Dependence of the nuclear data on the thermal hydraulic state of the reactor and boron concentration both for BOL and EOL.

- Axial and radial power distributions with different control rod configurations for BOL and EOL with the corresponding control rod reactivity worth.

- Thermohydraulic data of the reactor, including the thermal parameters of the fuel, cladding and coolant, and their dependence on the operational state of the reactor.

- Differential control rod worth profiles for the regulating control rods.

- Functional description of the control rod drives.

- Description of the reactor control system.

- Description of the reactor safety system.

- Description of the reactor instrumentation.

- Construction drawings of the reactor vessel.

Primary cooling system

- Isometric layout drawings of the primary cooling system components including the main cooling loops, the makeup water system, the residual heat removal system (if it exists in the primary circuit), the emergency boron supply tanks and the pressurized, the pressurizer relief tank showing the locations of the measurements.

- Characteristic of the main gate valves of the cooling loops with opening and closing times if they exist. Pressure behaviour during gate valve opening and closing.

- The metal mass of the main components in the primary cooling system (e.g. main circulating pump, etc.,).

- Construction drawings of the pressurizer with its connection to the safety valves.

- Four quadrant characteristic curves of the primary coolant pumps and of the residual heat removal pumps (if they exist), rotor inertia, pump starting and stopping transient data.

- Characteristic curves of the make-up water pumps with starting and stopping time data.

- Description of the volume control in the primary circuit.

- Description of the auxiliary systems of the main circulating pumps.

Emergency core cooling system and containment

- Description of the operation of the active and passive emergency core cooling.

- Characteristic of the different injection pumps.

- Isometric layout drawings of the emergency core cooling system components with its connections to the primary cooling system, showing the locations of the measurements.

- Description of the containment ventilation system.

- Description of the containment.

Main steam system

- Secondary circuit heat balance diagrams showing the flows, temperatures and other thermodynamic parameters at all important points of the system in different operating states.

- Pressure drop/flow characteristics of all control/safety valves.

- Description of safety system of the secondary circuit (turbine bypass and relief valves to the atmosphere and safety valves of the steam generators).

- Heat transfer and flow characteristics of the residual heat removal system (if it exists in the secondary circuit).

Turbine and main steam condenser

- Construction drawings of the turbine, of the moisture separator and of the condenser.

- Mechanical-, thermodynamic-, metal mass and gas dynamic data of the turbine.

- Functional diagrams and detailed description of the turbine controller.

- Characteristics of the turbine control valves, the stop valves, and the reheater interception valves.

- Control valve characteristic curves and time constants.

- Location of the temperature sensors and temperature profiles during startup.

- Location of the vibration and displacement sensors with their alarm limits.

- Air ejector characteristics.

- Heat transfer data of the main condenser.

Feedwater system

- Heat exchanger data, heat transfer data and flow characteristics of the low pressure and high pressure preheaters.

- Water level/volume relationship for the feedwater tanks.

- control valve characteristic curves and time constants.

- Characteristic curves of the feedwater pumps; starting and stopping times for the feedwater pumps.

- Description of the normal, auxiliary and emergency feedwater systems.

- Isometric layout drawings of the normal, auxiliary and emergency feedwater systems.

Electrical system

- Generator characteristics, including saturation curves and excitation data.

- Description of the excitation controller.
- Electrical data including transformer, generator and line reactance pieces of information.
- Connection of the consumers to the different distributor busses; description of the different safety power supplies.
- Synchronization data.
- The values of the electrical measurements at different operating states.
- Protections and interlocks in the electrical system.
- Diesel generator characteristics; description of the emergency power supply startup program.

Control and instrumentation

- Specification and description of each instrument type, including scale range, format (linear, log, etc.) and measurement ranges.
- Description of each plant measurement: and the purpose of every measurement (e.g. display to the operator, controller input, interlock or protection, etc.)
- Alarm and safety limits.
- Tuning parameters, time constants, set points and response characteristics of the simulated controllers.
- Characteristics of the control valves.

3.5.3. Steady state data

A simulator has to have a minimum of two sets of steady state, although it is normally observed that there are many sets often used, which include the plant at 25%, 50%, 75% and 100% power conditions of the plant. In general, other steady states are also provided, very often a cold state and some other states between these two limits. The simulator has to maintain the specified steady state for a long time, for this reason this specification is very important. For each steady state, the following information is needed:

- Measured core performance data at BOL and EOL as a minimum,
- The values of every simulated main parameter with at least $\pm$ 1 % accuracy,
- The state of all controllers and switches in the control room within the simulation scope.

3.5.4. Transient data

The available transient data determines the quality of the dynamic behaviour of the simulated processes. The transient data can be classified into two groups as:

- Transient data,
- Accident data.

The requested information is the transient recordings of the main parameters during a plant perturbation.

Transient data are recordings of the main parameters during such major plant transients as:

- Complete start up,
- Reactor and turbine trips.
- Turbine load change,
- Main circulating pump trip,
- Loss of external load (house load remains),
- Complete shutdown (black-out).

It is extremely important to stress that the measurement of the transient recordings has to be clearly specified, that is:

- The initial state must be steady and its power is well defined,
- The operating controllers have to be stated,
- The initial event, which results in the given transient, has to be clearly defined.

Accident data are, fortunately, rarely available, thus they are replaced by analytical data. It is very important to clarify the initial condition, the boundary conditions of the calculation and to specify the used computing codes.

However, if a safety analysis provides the accident data, additional problems are caused by the following facts:

- Safety analysis aims to determine a transient in a conservative situation, thus the parameters of the initial condition in general differ from the initial conditions of a training simulator, having best estimate parameter values.

- Very often safety calculations omit parts of the plant having small effects on safety, but in the simulator different boundary conditions can cause serious problems.

3.6. SCOPE OF SUPPLY

The two parties (suppliers on one hand, purchasers on the other) may find the following arrangement acceptable:

- The software tools (or other utilities) remain the Supplier's exclusive property and are supplied to the Customer only in run-time form on completion of maintenance of its application software.

- The application software is supplied to the Customer, who has entire ownership of them (provided that other Manufacturers do not at least partially own such or such a part of the data package).

- The simulator structure global architecture software is supplied to the Customer, with whom the Supplier own them jointly, and who can have them modified or added to by a third party for his strict needs as operator of the purchased simulator.

4. QUALITY ASSURANCE ASPECTS/REQUIREMENTS

A quality assurance System is essential to ensure the effective procurement and use of simulators. This section specifies Quality assurance Requirements for the development and continued maintenance of simulators. Depending on which type of simulator is desired, the user can discretely select from the items below those which are applicable to the specific needs being addressed.

If using an external vendor, a Quality assurance system should be provided which can be integrated with the customer's QA system. The supplier QA system should be reviewed prior to and during the project.

The supplier should designate a responsible person for the Quality assurance system, and should include routines for:

- Document control,
- Configuration management,
- Software structure,
- Hardware quality,
- Acceptance tests,
- Discrepancy Report system,
- Corrective actions,
- Post-delivery assistance,
- Warranty management.

4.1. DOCUMENT CONTROL

During the design phase of the simulator all documents should be registered as they are delivered to the supplier.

Documents used for the simulator design should have revision levels and/or revision dates that are maintained. Use of a computer based system is recommended to keep track of all documents.

4.2. CONFIGURATION MANAGEMENT SYSTEM (CMS)

The system for configuration control of the simulator must be initiated early in the project. The software should be base-lined prior to the end of acceptance testing or at earlier stages as defined by the project procedures. After integration, the software should be placed under the control of the CMS.

The CMS should enable the user to recover previous versions and obtain the history of changes to the simulator software and hardware configuration. All changes should be tracked and related to the reason for change; e.g., errors discovered in the design database or changes due to plant modifications after data freeze. Provisions should exist to backup of the software during periods when the software is undergoing change.

4.3. SOFTWARE STRUCTURE

All software written by the supplier or its subcontractors should use standard coding practices. These practices should be specified in a handbook used by all programmers.

The code should be written so it is easy to understand using agreed standards. Comments should be used extensively. Modular structure, standard models, models generated by the software workshop, and subroutines should be used as appropriate to the simulator under construction. The following items should be considered:

- Variables and constants must follow the naming convention.

- Variables and constants are appropriately defined with correct units.

- Derived or empirical values generated during development must be identified as such in the database.

- Data delivered by the customer must be identified.

4.4. HARDWARE QUALITY

The hardware for the simulator should be defined by the customer so it will fit in the existing environment at the training centre. It is important that the hardware is, if possible, standard equipment and easy to expand, if the scope of the simulator should increase.

4.5. VERIFICATION AND TESTING

A plan for verification and testing of the simulator should be created to enable the customer to check the progress of the simulator. Verification and testing should be conducted during different phases of the project and should be indicated in the project plan.

The following actions should be taken during the development phase of the simulator:

- Design specification review,
- Integrated testing,
- Acceptance tests.

Design specification review

The design specification (DS) should be reviewed and approved by the customer prior to the start of the construction of the simulator models.

The DS should be updated and approved at the start of the acceptance test procedure (ATP) and at the end of the project.

Integrated testing

During software integration, the supplier can use the ATP to conduct internal tests prior to the formal Acceptance Test. It is important that all discrepancies are recorded and tracked during the internal tests. All important and critical discrepancies should be corrected before the start of the formal acceptance test.

Acceptance test

During the design phase of the simulator the ATP should be developed. The ATP is based on customer data and analytic requirements. The ATP should be produced jointly by the customer and the supplier. The ATP should include tests for:

- Hardware,
- Software,
- Instructor facility,
- Simulator Performance.

The ATP is normally prepared and approved by the customer and supplier, and should be written with the following in mind:

- The simulator performance should be based on the reference plant design and operations data.

- Where no plant data is available, the ATP should be based on "best estimate" engineering codes, or evaluation by subject matter experts (SMEs). This applies mostly to transients.

- The personnel writing the ATP should be SMEs from the customer.

- A system for tracking discrepancy reports should be established.

Test procedures for the performance part should be written to exercise the simulator over the range of its intended operation. For example, for a full scope simulator, the test procedures would include normal operations such as:

- Startup from cold shutdown to full power,
- Shutdown from full power to cold shutdown,
- Change of power.

Similarly, tests should be written for abnormal operations. For the above example, the test procedure could include:

- Reactor trip,
- Turbine trip,
- Main circulation pump trip,
- Loss of feedwater,
- Loss of electrical power, sub and total,
- Steam leakage,
- Feedwater leakage,
- Other transients that are specified in the requirements for the simulator.

A critical part of the project for the customer is to perform the acceptance test. The test operators should be SMEs, experienced in the reference plant operation and transient behavior.

During the test period, discrepancy reports (DRs) should be written.

4.6. DATABASE

A database should be used to monitor the configuration of the simulator and to keep track of all discrepancy reports written during the project. Most of the suppliers of simulators can offer such a system.

4.7. POST-DELIVERY ASSISTANCE

It is important to determine a scope of assistance after the project. The customer should be able to get assistance from specialists in specified areas, such as:

- Core modelling,
- Instructor system,
- I/O-system,
- Special hardware,
- Hardware Maintenance and Support Agreements,
- Warranty Management.

5. CONCLUDING REMARKS

The benefits of using plant reference full scope simulators for training NPP personnel have long been recognized and their use is widespread and well documented. More recently a diverse range of simulators has evolved with varying scope, fidelity and application. This document describes such simulators and shows how using a range of these can provide cost effective training solutions for NPP utilities. Guidance is provided on the classification, selection and specification of these simulators.

Developments in technology allow new methods for training delivery providing instructors with improved simulator facilities.

The selection of simulators should be based on training needs and fulfillment of the criteria in Section 2, and not just on the technology available. The need of a proper training infrastructure is emphasized in order to get the best training result from the simulator. The training centres normally include several types of simulator, and the training environment is important for effective training delivery.

Careful specification and a good quality assurance program are essential, however some discretion can be used depending on the nature of the simulator. Regardless of the type of simulator, the verification and validation process is important.

The examples in the Appendix indicate the range of technology and the types of application that already exist. No doubt as technology advances, the potential of such devices in providing low-cost, high quality simulation can only increase.

Appendix

EXISTING PRACTICES OF USING VARIOUS TYPES OF SIMULATOR

Depending on the actual training objectives and on the audience, different types of simulators can be used for training. Examples are provided to illustrate how different types of simulators are used in different training organizations. Sample Data Sheets are provided to give detailed information for these devices.

Magnox Electric plc, and Nuclear Electric, Ltd (United Kingdom)

Magnox Electric plc., and Nuclear Electric, Ltd are using and developing portable basic principle simulators to train a wide range of personnel. Such simulators give the opportunity of cost effective access to real-time simulation in an appropriate environment for new operational staff and those not directly involved in operations. Basic simulation can be incorporated into lessons to demonstrate transient reactor behavior or to give students the opportunity to "learn by doing."

Paks (Hungary)

At the Paks training centre a WWER-440 compact simulator relieves the load on the full scope simulator. This simulator is used for training operator candidates before starting their training on the full-scale simulator, it is used by the operators for self-training, and also university students get a possibility to learn the operation of the plant. Similar simulators have been used since 1990 at Kola NPP (Russia) and since 1991 at Rovno NPP (Ukraine).

Forsmark Kraft AB (Sweden)

At Forsmark 3, a graphical simulator is used for training. This simulator covers the full scope of the plant, as a full scope simulator, but instead of a very expensive control room, the control and instrumentation are represented graphically. Graphical displays are very useful to present information never available in a control room but valuable to extend knowledge and cognitive operator skills.

Zaporozhe (Ukraine)

At Zaporozhe NPP a WWER-1000 multifunctional simulator serves for training in addition to a full scope simulator. Using the multifunctional simulator gives the opportunity of cost effective training for a wide range of NPP personnel. Its modelling depth and fidelity are practically the same as those of a full scope simulator, but the representation and control are provided through mimic diagrams of the plant. Similar simulators are used at Kalinin NPP (Russia) and at VNIIAES, Moscow.

Kursk (Russia)

A number of different part task functional simulators are used at the Kursk NPP training centre to train various NPP personnel. As an example, at Kursk NPP a turbine part task simulator has been in service to train turbine operators, turbine department managers, and shift supervisors.

Konvoi (Germany)

Konvoi and pre-Konvoi power plants in Germany use a functional simulator with a part of the control room to simulate safety relevant systems and complex reactor control. This simulator has been used since 1990. The main emphasis of training is put on the understanding of the interactions between the physical phenomena and the I&C. To reduce cost a graphic interface with detailed system diagrams has been developed. The result of this development is the plant analyser ASN which is used for comprehension training and plant analysis purposes.

Common Tendencies

In addition to the specific experience of each Member State, some common tendencies can be observed.

- The use of graphic interfaces has increased.

  By using powerful graphic features of modern computer systems, many utilities have developed tools that can better address training needs related to physical phenomena observed during plant transients and accidents. For training purposes, these systems are capable of displaying physical variables beyond the variables displayed in the real plant.

- There is better selection of appropriate tools for a given training objective.

  For example, before going through a full scope simulator training session and to make this training session as effective as possible, it may be useful to introduce some of the more complex matters by computer based training (CBT) or training on a compact simulators. In some cases, it is clear that training operators in diagnosis and recovery actions tasks on a graphic based simulator can be more effective than classical full scope simulators. Graphic based simulators are an appropriate solution for the training of a wide range of reactor plant personnel for the well directed consolidation of the theoretical understanding of the plant with regard to its safety-engineering design, physical phenomena in the malfunction area, rare operational procedures and complex I&C interrelations of the reactor, even if reference plant, full scope simulators are available.

  Shift personnel who normally are trained on full scope simulators with an emphasis on teamwork, communications, and the operators role in the control room, find training on various simulator devices an opportunity to focus on the technical and physical aspects of plant behaviour. Graphic simulators, in particular, which present a clearly different environment than the control room, provide an opportunity to enhance the operator's knowledge regarding theory and understanding of plant design limits.

- The tendency to use the appropriate tool for a given target group. Many utilities and engineering companies have developed specifically adapted simulators according to their target population. For management and technical support personnel, both non-control-room based, a transition to a mere screen operator environment (e.g. graphical simulator or Plant analyser) is likewise expedient besides the reduction of the simulation scope to the essentials. Such an interface makes it possible to represent the systems in more details and more clearly than the mimic diagrams in conventional control rooms can do.

- Different simulation devices can be based on the same hardware and software.

  With the evolution of the computing capacities, complex developments and models can be shared for different types of simulators. The use of graphic interfaces, can allow the use of the same set of models and the same hardware configuration for different type of training interfaces. Multifunctional simulators have been designed to use the same hardware configuration and be used as basic principle simulators, part task simulators, full scope simulators, or graphics based simulators according to the training needs and the target population.

- Utilities have found it useful to build their training infrastructure gradually by the use of cost effective simulation alternatives that allow later expansion.

  Simulators with reduced simulation scope which are equipped with graphic interfaces, represent cost effective alternatives to achieve many training objectives. Utilities have taken advantage of this opportunity to gradually build a training infrastructure. These simulators can be later extended to full scope, plant reference simulators.

The data sheets below present examples of different types of simulators developed and used in various countries.

INFORMATION SHEET ON SIMULATOR APPLICATION

(Training) utility: Magnox Electric plc. (UK)

Reference plant: Magnox General

NPP type: MAGNOX

Main supplier(s): Several UK consortia

Simulator type: Portable Basic Principles Simulator

First commissioning date: 11/1994

Supplier: Magnox Electric plc.

Latest upgrading date: 7 /1996

Supplier (if different):

Number of such (similar) simulators in use at the utility: 2 (+2 occasionally available from Nuclear Electric Ltd., who share training facilities with us)

			Answer	Comment if any ...
Target user groups				
1		Main control room staff initial training	√	
2		Main control room staff refresher training	√	For special purposes only.
3		Op.s' management initial training	√	
4		Op.s' management refresher training		
5		Technical support training	√	
6		Safety regulatory authorities		
7		University students	√	Used for occasional student visits to the Training Centre
8		Public		
Training objectives				
9		Knowledge	√	
10		Skill based practice(know-how)	√	
11		Rule based practice (team behaviour)		
Mode of use				
12		Self-training	√	
13		Instructor led training	√	
14		Crisis management		
15		Engineering		
Operating range				
16		Refuelling		

17		Cold startlup to full power	√	
18		Limited operating range	√	Model becomes increasingly inaccurate beyond normal range.
	Transients			
19		Normal load operations	√	
20		Design basis accidents (DBA)	√	Not all faults can be modelled.
21		Beyond design basis accidents	√	Only for giving rough behaviour.
22		Beyond core melting		
23		Open vessel accidents		
	Malfunctions			
24		Number	15	
	Time modes			
25		Real-time	√	
26		Fast time range		Certain areas of simulation can be accelerated
27		Slow time range		
28		Time resolution (ms.)	150	
	Human-machine interface			
29		Hard panel	√	
30		Mimic (soft) diagram	√	Schematics of the primary circuit
31		Photo (soft) panel		
32		Pedagogical Interface	√	
33		Process computer		
	Models			
34	Nuclear Steam Supply S	Thermohydraulics: 1 or 2 phase flow	Not applicable	Gas cooled reactor technology.
35		non-condensible gases	2	Iodine, Xenon
36		number of equations		
37		number of nodes		
38		Neutronics: number of dimensions	Point	
39		number of nodes		
40		number of groups		
41	Containment	Number of nodes		
42		Number of radioactive products		

43	Balance of plant	Thermohydraulics		Water reserves are regarded as infinite.
44		Radioactive product transportation		
45		Chemical product transportation		
46		Electrical systems		
47		Instrumentation and control		

INFORMATION SHEET ON SIMULATOR APPLICATION

(Training) utility: Paks Simulator Centre
Reference plant: Paks NPP
NPP type: WWER-440/213
Main supplier(s): Atomenergoexport (SU)

Simulator type: Paks Compact Simulator
First commissioning date: June /1989
Supplier: KFKI - Atomic Energy Res. Inst.
Latest upgrading date: June /1995
Supplier (if different):

Number of such (similar) simulators in use at the utility: 1

			Answer	Comment if any ...
	Target user groups			
1		*Main control room staff initial training*	√	
2		Main control room staff refresher training		
3		Op.s' management initial training		
4		Op.s' management refresher training		
5		Technical support training		
6		Safety regulatory authorities		
7		University students	√	
8		Public		
	Training objectives			
9		Knowledge	√	
10		Skill based practice(know-how)		
11		Rule based practice (team behaviour)		
	Mode of use			
12		Self training	√	
13		Instructor led training	√	
14		Crisis management		
15		Engineering		
	Operating range			
16		Refuelling		

17		Cold startup to full power	√	
18		Limited operating range		
	Transients			
19		Normal load operations	√	Simplified plant operating procedures can be used
20		Design basis accidents (DBA)		
21		Beyond design basis accidents		
22		Beyond core melting		
23		Open vessel accidents		
	Malfunctions			
24		Number	6 generic and 18 specific	See additional comment. Each malfunction can be addressed to several objects, thus the total number is more than 3000.
	Time modes			
25		Real-time	√	
26		Fast time range	10, 60, 120	Valid only for the Xenon-Iodine model
27		Slow time range	5	
28		Time resolution (ms.)	1000/100	Time resolution in the input/output system: 100 ms., main simulation cycle time 1 sec.
	Human-machine interface			
29		Hard panel	√	Control Desk. See additional comment.
30		Mimic (soft) diagram		
31		Photo (soft) panel	√	Neutron Flux Monitor and Control System
32		Pedagogical Interface		
33		Process computer	√	The mimic diagrams are different than those in the real plant
	Models			
34	Nuclear Steam Supply S	Thermohydraulics: 1 or 2 phase flow	One-phase flow	
35		non-condensable gases	1	Nitrogen
36		number of equations	3	
37		number of nodes	31	See additional comment.
38		Neutronics: number of dimensions	Point model	
39		number of nodes	NA	
40		number of groups	6 delayed groups	One energy group.
41	Containment	Number of nodes		

42		Number of radioactive products		
43	Balance of plant	Thermohydraulics	√	Auxiliary systems are simulated.
44		Radioactive product transportation		
45		Chemical product transportation		
46		Electrical systems		Only the main generators are simulated
47		Instrumentation and control	√	All main control circles, interlocks and protections are simulated.

Ad. 24.: **Generic malfunctions**: valve stuck, valve move to a given position, safety valve leak, pump trip, plant logic failure, analogue measurement drift

Specific malfunctions: failure in the unit power controller, drop of control rod, pressurizer heater failure, pressurizer pressure controller failure,

Pressurizer level controller failure, turbine bypass valve failure, turbine control valve failure, failure in the steam generator level controller, Air Leakage into condenser, generator breaker opens, loss of load, loss of turbine lube oil, change of grid frequency, break in the primary circuit, Break in the feedwater system, pipe break in a steam generator, trip of a main circulating pump, erroneous boron acid supply.

Ad. 29.: The control desk has a controller station with input devices, an engraved mimic diagram displaying the actual state of the plant (pump states, valve positions, etc.) and alarm windows.

Ad. 37.: Reactor vessel contains 4 nodes. upper plenum, lower plenum, core and bypass.

The six cooling loops are modelled by 3 models. One cooling loop model represents a single cooling loop, one model stands for the average of two cooling loops and one model describes the average of three cooling loops. Each loop model is divided into 8 nodes, thus the primary cooling loop model contains 3*8=24 nodes.

Pressurizer contains 3 nodes: saturated steam, saturated water and non-saturated water regions The boundaries among these regions are moving.

INFORMATION SHEET ON SIMULATOR APPLICATION

(Training) utility: KSU (Sveden)

Reference plant: FORSMARK3

NPP type: BWR

Main supplier(s): ABB-Atom

Simulator type: Graphical Simulator

First commissioning date: /19 96
Supplier: KSU

Latest upgrading date:
Supplier (if different):

Number of such (similar) simulators in use at the utility: 1 (+2 in 1997)

			Answer	Comment if any ...
Target user groups				
1		Main control room staff initial training	√	
2		Main control room staff refresher training	√	
3		Op.s' management initial training	√	
4		Op.s' management refresher training	√	
5		Technical support training	√	
6		Safety regulatory authorities		Can be used in the future.
7		University students		
8		Public		
Training objectives				
9		Knowledge	√	
10		Skill based practice(know-how)	√	
11		Rule based practice (team behaviour)		
Mode of use				
12		Self training	√	
13		Instructor led training	√	
14		Crisis management		Can be used in the future
15		Engineering		Can be used in the future
Operating range				
16		Refuelling	√	

17		Cold startlup to full power	√	
18		Limited operating range		
	Transients			
19		Normal load operations	√	
20		Design basis accidents (DBA)	√	
21		Beyond design basis accidents		
22		Beyond core melting		
23		Open vessel accidents		
	Malfunctions			
24		Number	130	From them 45 generic.
	Time modes			
25		Real-time	√	
26		Fast time range	2-600	
27		Slow time range	1/5	
28		Time resolution (ms.)	200 - 50	The main loop is calculated 16 times in a second.
	Human-machine interface			
29		Hard panel		
30		Mimic (soft) diagram	√	
31		Photo (soft) panel		
32		Pedagogical Interface		
33		Process computer		
	Models			
34	Nuclear Steam Supply S	Thermohydraulics: 1 or 2 phase flow	2 phase flow	
35		non-condensible gases	3	Oxigen, Hydrogen, Nitrogen
36		number of equations	6	
37		number of nodes	190	142 for SSS and 48 for pressure relive system.
38		Neutronics: number of dimensions	3	
39		number of nodes	2220	12*185
40		number of groups	2	
41	Containment	Number of nodes	55	
42		Number of radioactive products	2	
43	Balance of plant	Thermohydraulics	√	

44		Radioactive product transportation	√	
45		Chemical product transportation	√	
46		Electrical systems	√	
47		Instrumentation and control	√	

INFORMATION SHEET ON SIMULATOR APPLICATION

(Training) utility: 1 Zaporozhe NPP (Ukraine)
2 Kalinin NPP (Russia)
3 VNIIAES (Russia)

Reference plant: Zaporozhe NPP, Unit 5

NPP type: WWER-1000

Main Supplier(s):

Simulator type: WWER- 1000 Multifunctional Simulator

First commissioning date: October 1992

Latest upgrading date: July 1994

Supplier: VNIIAES

Supplier (if different): VNIIAES

Number of such (similar) simulators in use at the utility: 3

			Answer	Comment if any...
Target user groups				
1		Main control room staff initial training	yes	
2		Main control room staff refresher training	yes	
3		Op s' management initial training	no	
4		Op s' management refresher training	no	
5		Technical support training	yes	Multiaimed Objectives
6		Safety regulatory authorities	yes	
7		University students	no	
8		Public	no	
Training objectives				
9		Knowledge	no	
10		Skill based practice (know-how)	yes	
11		Rule based practice (team behaviour)	yes	
Mode of use				
12		Self training	no	
13		Instructor led training	yes	

14		Crisis management	no	
15		Engineering	no	
Operating range				
16		Refuelling	no	
17		Cold startup to full power	yes	
18		Limited operating range	no	
Transients				
19		Normal load operations	yes	
20		Design basis accidents (DBA)	yes	All DBA events are simulated
21		Beyond design basis accidents	no	
22		Beyond core melting	no	
23		Open vessel accidents	no	
Malfunctions				
24		Number	150	
Time modes				
25		Real-time	yes	
26		Fast time range	2,10,100	See comment C 1.
27		Slow time range	10	Up to 10
28		Time resolution (ms.)	250	
Human-machine interface				
29		Hard panel	no	
30		Mimic (soft) diagram	yes	
31		Photo (soft) panel	yes	
32		Pedagogical Interface	yes	
33		Process computer	no	emulated
Models				
34	Nuclear Steam Supply S	Thermohydraulics: 1 or 2 phase flow	2 phase flow	
35		non-condensable gases	1	
36		number of equations	5	
37		number of nodes	10+4×7	
38		Neutronics. number of dimensions	3	
39		number of nodes	144	
40		number of groups	1	

41	Containment	Number of nodes	4	
42		Number of radioactive products	no	See comment C 2
43	Balance of plant	Thermohydraulics	yes	
44		Radioactive product transportation	yes	
45		Chemical product transportation	yes	
46		Electrical systems	yes	
47		Instrumentation and control	yes	

C 1. The slow proceeding processes (reactor cooldown, Xenon dynamics etc.) can be accelerated up to 100 times. The range 2 is for entire simulation acceleration.

C 2. The radioactivity in the primary circuit is divided in two components soluble and gaseous. The transport of radioactivity in containment simulated for one component with representing a mixture of separate nuclides.

INFORMATION SHEET ON SIMULATOR APPLICATION

(Training) utility: Kursk NPP (Russia)

Reference plant: Kursk NPP, Unit 2

NPP type: RBMK-1000

Main Supplier(s):

Simulator type: Turbine part task simulator

First commissioning date: 15 02/1995

Latest upgrading date:

Supplier: ENIKO MIFI

Supplier (if different):

Number of such (similar) simulators in use at the utility: 1

			Answer	Comment if any...
Target user groups				
1		Main control room staff initial training	yes	
2		Main control room staff refresher training	yes	
3		Ops' management initial training	yes	
4		Op.s' management refresher training	yes	
5		Technical support training	yes	
6		Safety regulatory authorities	may be used	
7		University students	no	
8		Public	no	
Training objectives				
9		Knowledge	yes	
10		Skill based practice (know-how)	yes	
11		Rule based practice (team behaviour)	no	
Mode of use				
12		Self training	yes	
13		Instructor led training	yes	
14		Crisis management	no	
15		Engineering	no	

Operating range				
16		Refuelling	no	
17		Cold startup to full power	yes	
18		Limited operating range		operations concerned with preliminary circuit filling are not simulated
Transients				
19		Normal load operations	yes	
20		Design basis accidents (DBA)	yes	
21		Beyond design basis accidents		
22		Beyond core melting		
23		Open vessel accidents		
Malfunctions				
24		Number	4457	* general - 4236 ** specific - 221
Time modes				
25		Real-time	yes	
26		Fast time range	yes	
27		Slow time range	yes	
28		Time resolution (ms)	100	
Human-machine interface				
29		Hard panel	no	
30		Mimic (soft) diagram	yes	
31		Photo (soft) panel	yes	
32		Pedagogical Interface	yes	
33		Process computer	no	
Models				
34	Nuclear Steam Supply S	Thermohydraulics 1 or 2 phase flow	2 phase	
35		non-condensable gases	yes	
36		number of equations	3	with additional correlation
37		number of nodes	94	
38		Neutronics number of dimensions	no	
39		number of nodes	no	
40		number of groups	no	

41	Containment	Number of nodes	no	
42		Number of radioactive products	no	
43	Balance of plant	Thermohydraulics	yes	
44		Radioactive product transportation	no	
45		Chemical product transportation	yes	
46		Electrical systems	yes	
47		Instrumentation and control	yes	

* The number of general malfunctions was calculated as product of number of simulated valves by number of simulated malfunctions for each valve plus product of number of simulated transmitters by number of simulated malfunctions for each transmitter

** The number of specific malfunctions was calculated as the sum of following values:

- product of number of regulating valves by number of simulated malfunctions;
- product of number of control rods by number of malfunctions, simulated for them;
- product of number of leakages, simulated for the various nodes of scheme;
- product of number of specific malfunctions such as worsening of heat exchangers.

INFORMATION SHEET ON SIMULATOR APPLICATION

(Training) utility: SIEMENS, KWG
Reference plant: Grohnde
NPP type: PWR
Main supplier(s): SIEMENS

Simulator type: Plant analyser ASN
First commissioning date: 8 /1993
Supplier: SIEMENS
Latest upgrading date: 4/1996
Supplier (if different):

Number of such (similar) simulators in use: 2

			Answer	Comment if any ...
Target user groups				
1		Main control room staff initial training	√	
2		Main control room staff refresher training	√	
3		Op.s' management initial training	√	
4		Op.s' management refresher training	√	
5		Technical support training	√	
6		Safety regulatory authorities	√	
7		University students		
8		Public	√	
Training objectives				
9		Knowledge	√	
10		Skill based practice(know-how)	√	
11		Rule based practice (team behaviour)		
Mode of use				
12		Self training	√	
13		Instructor led training	√	
14		Crisis management	√	
15		Engineering	√	
Operating range				
16		Refuelling		

17		Cold startlup to full power	√	Besides the start of operational auxiliary systems
18		Limited operating range	√	No mid loop operation
	Transients			
19		Normal load operations	√	
20		Design basis accidents (DBA)	√	Without great LOCA accidents
21		Beyond design basis accidents	√	
22		Beyond core melting		
23		Open vessel accidents		
	Malfunctions			
24		Number	approx. 150	Comtinuously new malfunctions are created
	Time modes			
25		Real-time	√	
26		Fast time range	10	Partwise faster for special variaables, e.g.: Xenon
27		Slow time range	10	
28		Time resolution (ms.)	250/125	
	Human-machine interface			
29		Hard panel		
30		Mimic (soft) diagram	√	
31		Photo (soft) panel		
32		Pedagogical Interface	√	
33		Process computer	√	
	Models			
34	Nuclear Steam Supply S	Thermohydraulics: 1 or 2 phase flow	2 phase flow	Phase separation is calculated only in the reactor vessel
35		non-condensible gases		
36		number of equations		See additional comment.
37		number of nodes	80	4*12 nodes in the loops and 32 nodes in the reactor vessel.
38		Neutronics: number of dimensions	3	
39		number of nodes	72	
40		number of groups	6	
41	Containment	Number of nodes	2	
42		Number of radioactive products	5	
43	Balance of plant	Thermohydraulics	√	Water balance is calculated

44		Radioactive product transportation	√	
45		Chemical product transportation	√	Only boric acid.
46		Electrical systems	√	Simplified
47		Instrumentation and control	√	Reactor and turbine I&C are very detailed.

ad. 36. Detailed description can be found in the publication "Adaptation of the FTN Simulation Models to the Results of Thermal Hydraulic Tests"

Directions to Complete Simulator Application Information Sheet

Nos 1-8: Please indicate the appropriate user group(s).
No. 9: This training goal indicates that the simulator gives general understanding of the plant design/behaviour (e.g. basic principles simulator).
No. 10: This training goal indicates that the use of the simulator is to provide a practice of the plant control.
No. 11: This training goal indicates that the simulator is used to practice team work in the control room.
No. 14: The simulator is used for developing, testing and running crisis scenarios, involving crisis organisation actors.
No. 15: The simulator serves engineering purposes, e.g. to test new control/safety devices in hardware-in-the-loop mode.
No. 16: The whole plant operating range is covered, including refueling procedures.
No. 17: The whole plant operation range is simulated from cold shut-down state to full power with both startlup and shut-down procedures.
No. 18: The simulator can only be used in a limited operation range, e.g. in nominal power range. In the comment field please specify the limitation.
No. 19: Normal operations mean each operation procedures which can occur in the indicated operation range.
No. 20: Please indicate here if DBA events can be simulated. In the comment field, please indicate the limitations.
No. 21: Please indicate here if severe accidents can be simulated. In the comment field, please indicate the limitations.
No. 22: Please indicate here if severe accidents can be simulated beyond core melting. Indicate the simulation limits in the comment field
No. 23: Please indicate here if accidents can be simulated with open reactor vessel, e.g during mid-loop operation.

Please provide data where adequate. If the comment field is not enough for the clarification, add additional comments after the table.

No. 24: Please define the number of different generic (e.g. valve stuck) and specific (e.g. pressurizer heater failure, or pipe break) malfunction types.
No. 25: Indicate if the simulator can be used in real-time.
No. 26: Please define the time acceleration factor(s) of the simulator.
No. 27: Please define the time slow-down factor(s) of the simulator.
No. 28: Please define here the minimal time interval between two events which can be separated from each other in the simulated process.
No. 29: Please indicate here if the simulator has any hardware panel, controlling device, control desk.
No. 30: Please indicate here if the simulated process can be controlled by selecting the control device in mimic diagrams
No. 31: Please indicate here if the simulated process can be controlled by using animated keys, push buttons, etc., on displayed photographs of the MCR.
No. 32: Pedagogical interface means a device which displays parameters not directly observable in the plant (e.g. power excursion during rod ejection).
No. 33: Please indicate whether the actual plant process computer functions are simulated or emulated.
No. 34: Please indicate whether the nuclear steam supply system is described by a 1- or a 2-phase flow model.
No. 35. Please define how many different non-condensable gases are simulated (if any).

No. 36: Please define the number of equations of the flow calculation (e.g. 5 or 6 in two-phase flow calculation).

No. 37: Please define separately the nodes of the flow model in the reactor vessel and in the cooling loops

No. 38: Please indicate here if the neutronics is described by a point model, by a linear model or by a 3-D model.

No. 39: Please define the number of nodes in the neutronics model.

No. 40: Please define the number of the simulated neutron groups.

No. 41: If the containment is modelled, please define the number of nodes in the thermohydraulic containment model.

No. 42: Please define the number of the radioactive nuclide groups modelled in the containment (and in the primary circuit).

Nos 43-46: In these points, please indicate how the auxiliary systems are modelled, partially or totally Are automatic code generators used ?

No. 43: Please indicate if the water reserves of the plant are calculated or they are regarded as infinite.

No. 44: Please indicate if the transportation of the simulated radioactive materials is simulated.

No. 45: Please indicate if the transportation of the different chemicals (e.g. hydrogen) is simulated.

No. 46: Please indicate if the emergency power supplies (e.g. accumulators) are calculated or their charge is regarded as infinite.

No. 47: Please indicate if the electric power supply and the location of the tranducers (e.g in the containment rooms) are simulated in the I&C models.

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[1] INTERNATIONAL ATOMIC ENERGY AGENCY, Guidebook on Nuclear Power Plant Personnel Training and its Evaluation, Technical Reports Series No. 380, IAEA, Vienna (1996).

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[4] INTERNATIONAL ATOMIC ENERGY AGENCY, Manual on Quality assurance for Computer Software Related to the Safety of Nuclear Power Plants, Technical Reports Series No. 282, IAEA, Vienna (1988).

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