IAEA TECDOC SERIES

IAEA-TECDOC-1963

IAEA-TECDOC-1963

Development, Use and Maintenance of Nuclear Power Plant Simulators for the Training and Authorization of Personnel

IAEA

International Atomic Energy Agency

DEVELOPMENT, USE AND MAINTENANCE OF NUCLEAR POWER PLANT SIMULATORS FOR THE TRAINING AND AUTHORIZATION OF PERSONNEL

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The Agency's Statute was approved on 23 October 1956 by the Conference on the Statute of the IAEA held at United Nations Headquarters, New York; it entered into force on 29 July 1957. The Headquarters of the Agency are situated in Vienna. Its principal objective is "to accelerate and enlarge the contribution of atomic energy to peace, health and prosperity throughout the world".

IAEA-TECDOC-1963

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FOREWORD

The use of simulators for the training and qualification of nuclear power plant control room operating personnel has become a standard practice throughout the world. Such simulators are used to develop and reinforce knowledge of plant systems and their relationships; to increase the ability to apply plant procedures; to advance practical skills in operating the plant in normal, abnormal and emergency conditions; and to build supervisory skills and teamwork. They are also used to conduct the authorization or licensing examinations of control room operating personnel, and there is an increasing trend in the use of simulators for non-training purposes.

This publication provides useful information and a wide range of practical examples that will be helpful for both nuclear power plant operating organizations and regulatory bodies in developing and improving the processes of authorization of control room personnel — a standard practice in all IAEA Member States operating nuclear power plants. The publication includes information from three previous publications: Use of Control Room Simulators for Training of Nuclear Power Plant Personnel (IAEA-TECDOC-1411), Guidelines for Upgrade and Modernization of Nuclear Power Plant Training Simulators (IAEA-TECDOC-1500), and, Authorization of Nuclear Power Plant Control Room Personnel: Methods and Practices with Emphasis on the Use of Simulators (IAEA-TECDOC-1502).

The preparation of this publication was based on contributions from both IAEA staff and external experts. The IAEA wishes to acknowledge the assistance provided by the contributors listed at the end of the report. The IAEA officer responsible for this publication was L. Halt of the Division of Nuclear Power.

CONTENTS

1. INTRODUCTION

1.1. BACKGROUND

The authorization of personnel in NPPs is based on whether personnel have a direct impact on safety, in accordance with the IAEA Safety Standards Series No. NS-G-2.8, *Recruitment, Qualification and Training of Personnel for NPPs* [1]. The methods and practices for authorizations are not identical amongst Member States, and the organizations granting the authorization may differ in practice. The various authorization processes are usually based on written and/or oral examinations and in many cases also include the testing of practical skills. Differences in the authorization processes also exist in the examination methodology and in the scope of the practical examinations (e.g. plant walk through, use of simulators). The increase in the availability of full scope simulators, in particular, full scope plant-referenced control room simulators, provides an additional and efficient tool for testing the practical skills of the candidates for authorization.

The simulator should be adequately maintained and upgraded to ensure that it continues to be a viable training tool that accurately replicates the operational characteristics of the reference NPP. The upgrade or modernization of the simulator should be conducted based upon the proven project management principles and methods discussed in this report.

Safety analysis and operational experience consistently indicate that human error is the greatest contributor to the risk of a severe accident at an NPP. After the Three Mile Island accident major changes were made internationally to reduce the potential for human error through improved procedures, information provided and training of operators. The use of full scope simulators in the training of operators is an essential element of these efforts to reduce human error. In cases where a 'replica' plant-referenced full scope simulator is not available, it may be necessary for operators to receive their training using a computer simulation or travel to another plant that is like their own that can provide a simulator for operator training and authorizations.

Simulator training is required for:

— Control room personnel;
— System engineers;
— Fault studies engineers;
— New instructors.

Changing training needs affect not only the simulation facilities used for the training and qualification of control room operating personnel, but also for the way authorizations are carried out at the NPP by control room personnel. Changes affecting both the training methods and practices employed result from improvements in technology for simulator capability/fidelity improvements and the need to improve operator training quality and standards.

This publication incorporates revisions from three previous publications: *IAEA TECDOC 1411 Use of Control Room Simulators for Training of Nuclear Power Plant Personnel* [2], *IAEA TECDOC 1502 Authorization of Nuclear Power Plant Control Room Personnel: Methods and Practices with Emphasis on the Use of Simulators* [3] and *IAEA TECDOC 1500 Guidelines for Upgrade and Modernization of Nuclear Power Plant Training Simulators* [4].

1.2. OBJECTIVES

The objective of this publication is to provide Member States with comprehensive guidance, information and methodology to support simulation and digital learning for NPPs and to provide guidelines for the authorization of NPP control room personnel.

1.3. SCOPE

This publication provides guidance on NPP operator training and describes the use of simulators in training and qualification programmes for NPP personnel. Current trends in the use of simulators in training programmes, as well as approaches to maintaining and upgrading simulators, are also presented.

1.4. USERS

This publication is intended for all nuclear personnel involved in training and qualification programmes, and specifically in the use of simulators. It will be of primary interest to operating organizations in Member States with NPPs, including those planning to seek plant lifetime extensions. It may also be useful for regulatory bodies and government agencies involved in nuclear power programmes, as well as research organizations, technical support organizations and related agencies.

1.5. STRUCTURE

This publication is divided into nine sections. Section 2 considers the roles and functions of NPP simulators, Section 3 explains the use of Systematic Approach to Training (SAT) when analysing, design and develop training programmes for simulator training. Section 4 describes the implementation of simulator training and Section 5 goes into the evaluation of the simulator training provided. Examinations and the licensing/authorization process are discussed in Section 6 and specialised training in Section 7. Maintaining and upgrading simulators are described in Section 8 and finally Section 9 discusses considerations for new builds.

2. ROLES AND FUNCTIONS OF NPP SIMULATORS

2.1. BRIEF HISTORY OF NPP SIMULATORS

In the 1970's, when the first computer-based full scope simulators were placed into service, the scope and fidelity of plant system process models was severely constrained by limited computer resources (processing power and memory capacity). There were few NPP Operator Training Simulators (OTS) in operation in the world. In general, operators were being trained on simulators

— Not referenced to their plant (simulator to plant differences) possibly requiring the use of different procedures/practices to those employed on the actual plant;

- Simplified models, resulting in degraded fidelity when training, in comparison to modern simulator standards;
- Simulator possibly located at a central training facility or at a vendors' site, often a shared training resource quite distant from the actual plant, resulting in:

  - Limited simulator availability (i.e. operator simulator training time per year restricted);
  - Generic simulator instructors, sometimes unfamiliar with individual plant practices and site-specific operating experience;
  - Simulators are often not available for Emergency exercise training, Infrequently Performed Tests and Evolutions (IPTE) or Just in Time (JIT) training.

On 28 March 1979, the Three Mile Island Unit 2 (TMI-2) reactor (Pennsylvania, USA) partially melted down due to equipment malfunctions, design related problems and human error. Operator training on a vendor's full scope simulator that differed in certain significant ways from the actual plant control room was one of the contributing factors to the TMI-2 nuclear accident.

The accident brought changes in emergency response planning, operator training, human factors engineering, radiation protection and many other areas of NPP operational practices.

Subsequently the Institute of Nuclear Power Operations (INPO) was established in December 1979 with the following mission statement: "To promote the highest levels of safety and reliability – to promote excellence – in the operation of commercial nuclear power plants".

In the 1980's detailed reviews of the lessons learnt from operating experience caused a re-assessment of the adequacy of training for NPP personnel, particularly that of control room personnel. As a result of this review operating organizations and nuclear safety regulators in a number of Member States established more stringent requirements for simulator training of their control room personnel, as well as other aspects of their training programs. Examples of changes implemented included improved emergency scheme operating procedures, improved safety parameter display systems, a greater reliance on practical simulator-based examinations as part of the qualification, authorization and licensing of control room personnel and the use of the Systematic Approach to Training (SAT) as the basis to develop NPP personnel training programs. Plant-referenced simulators (PRS) have been deployed at most Member States sites to increase simulator training fidelity and accessibility for operators to be trained on.

In 1985, the first comprehensive simulator standard for functional requirements was issued, ANSI/ANS-3.5-1985 *Nuclear Power Plant Simulators for Use in Operator Training and Examination* [5].

On 26 April 1986, the world's worst nuclear power accident happened at the Chernobyl Unit 4 reactor in the former USSR (now Ukraine). The severe reactivity excursion resulted in a reactor explosion causing several deaths and contaminated large parts of the Ukraine and Belarus. Insufficient management control and oversight, inappropriate use of procedures, human error and plant design problems, all contributed to this accident. Public confidence in the continued use of nuclear energy was badly shaken throughout the world.

In 1989, faced with the realization the impact of a serious nuclear event can have on the environment and public opinion, the leaders of every commercial nuclear reactor in the world set aside their competitive and regional differences and came together to create the World Association of Nuclear Operators (WANO). WANO's overriding priority is the assurance of nuclear safety and excellence in operational performance.

In the 1990's control room personnel, in virtually all countries with NPPs, received training on control room simulators for both initial and continuing training, with more than 90% of these being trained on plant-referenced simulators. New Full Scope Simulators (FSS) are continuing to be built for existing NPPs; some because the NPPs did not already have a plant-referenced simulator available to them and others because existing simulators were inadequate for training to modern operator standards and expectations. For Nuclear New Builds (NNBs), full scope plant-specific simulators (with similar design) are made available during the commissioning phase or earlier. Operations outside the main control room are also often included in the scope of the simulator (e.g. remote shutdown panels, local/field panels, etc.).

In 1994, the Nuclear Energy Institute (NEI) was founded from the merger of several nuclear energy industry organizations. With member participation, the NEI develops policy on key legislative and regulatory issues affecting the nuclear industry.

Since the millennium, newer full scope simulators have been continually built or upgraded on both existing NPPs and NNBs.

In 2009, a revised version of the simulator standard ANSI/ANS-3.5 (ANSI/ANS-3.5-2009) [6] was issued with increased emphasis on Scenario-Based Testing (SBT) (see FIG. 1). The latest published revision of the standard is from January 2018, addressing needs and requirements for the next generation simulators [7].

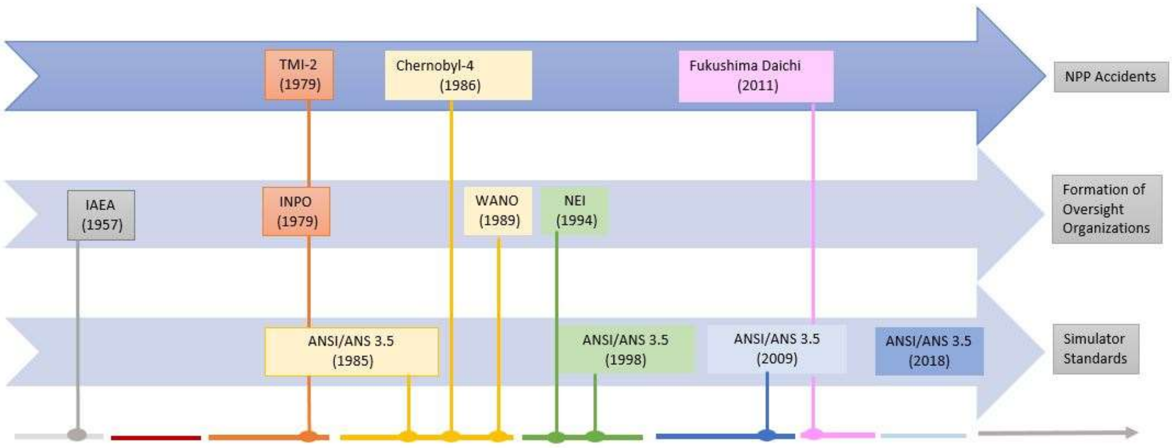

FIG. 1. NPPs and Simulators History Timeline.

2.2. TYPES OF SIMULATORS

As the nuclear industry has matured, experience has shown us the need for the development of simulators to facilitate training of different groups of personnel at various stages of their development, not always requiring the use of an FSS during the early theoretical or fundamental stages of their training.

Examples of the main types of simulators currently available can be found in TECDOC-1887 on *Classification, Selection and Use of Nuclear Power Plant Simulators for Education and Training* [8] which includes:

— *Basic Principles Simulators (BPS):* A desktop simulator that illustrates general concepts (FIG. 2), demonstrating and displaying the fundamental physical processes of an NPP. The main goals for using a basic principle simulator are to help trainees understand fundamental physical processes, basic operation of complex systems and the overall operation of the NPP. BPSs are available for all the main plant design types (e.g. pressurized water reactor (PWR), boiling water reactor (BWR), CANada Deuterium Uranium (CANDU), advanced gas-cooled reactor (AGR) etc.).

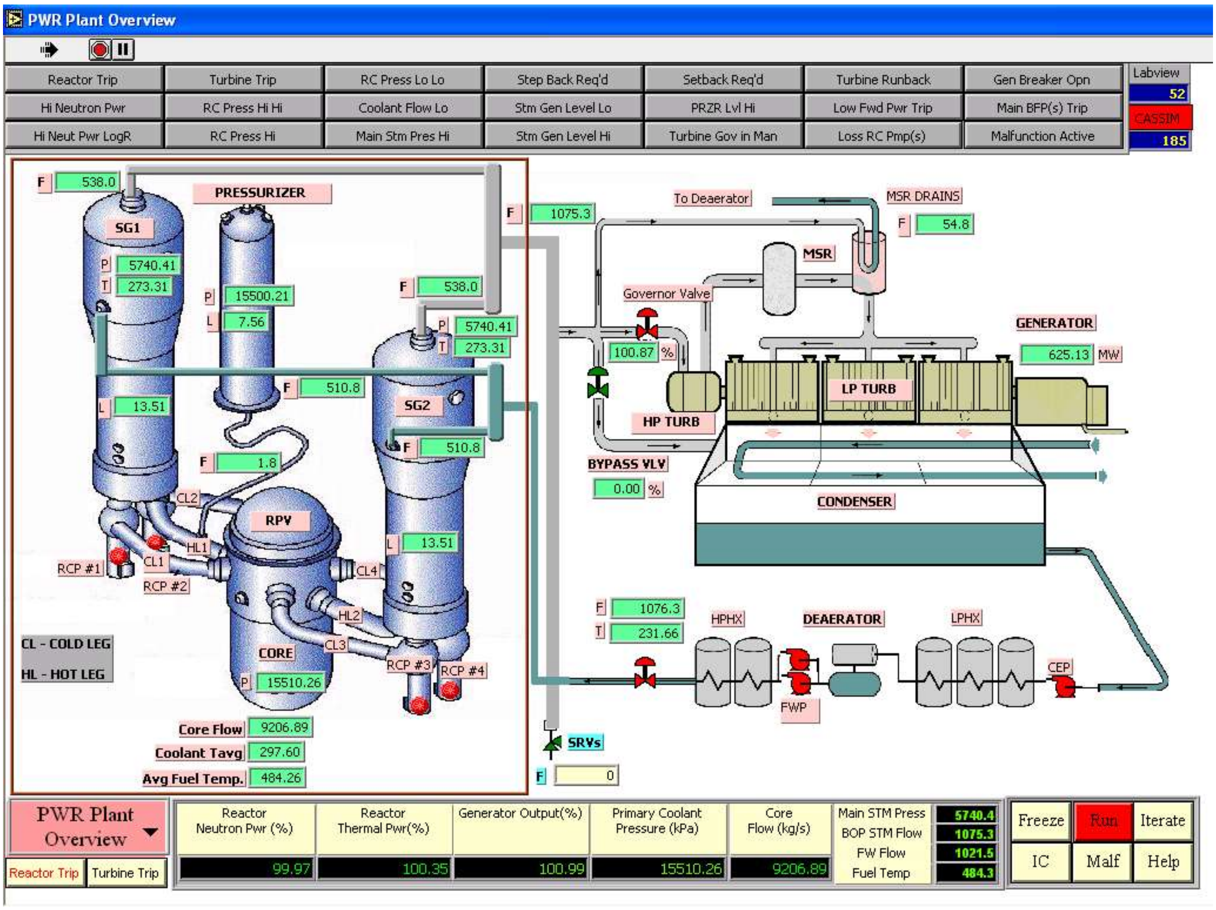

FIG. 2. IAEA PWR Basic Principles Simulator (Austria).

— *Full Scope Simulator (FSS)*, (also known as an Operator Training Simulator (OTS): A plant-referenced simulator incorporating detailed modelling of the main plant systems of the referenced unit. The simulator includes a full main control room replica with operator panels and consoles and may include a replica of the emergency remote shutdown panels, auxiliary and/or local panels, etc. (FIG. 3).

FIG. 3. KSU Oskarshamn 2 BWR Full Scope Simulator (Sweden).

— *Classroom/Portable Simulator:* A desktop simulation with soft (virtual) panels and/or operator Human Machine Interface (HMI) as the main operator interface (no hardware panels). The graphics are displayed on standard monitors, touch monitors or projected screens. The modelling scope of a classroom/portable simulator is like a full scope simulator without the physical panels, consoles and associated instruments (FIG. 4).

FIG. 4. EDF Energy Hinkley Point B AGR Classroom/Portable Simulator (United Kingdom).

— *Part-Task Trainer:* A simulation, with or without physical panels and consoles, modelling in detail, one or more systems. The training with a part-task trainer focuses on tasks related to very specific plant component(s) or system(s) (FIG. 5).

FIG. 5. Florida Power and Light St. Lucie 1 PWR Shutdown Cooling Part-Task Trainer (USA).

— Engineering Simulator: A desktop simulation, equipped with soft (virtual) panels and/or operator HMI as the main operator interface (no hardware panels). The modelling scope of an engineering simulator is like a full scope simulator without the physical panels, consoles and associated instruments. Engineering simulators can be used for other applications not covered by the other simulator types described above (FIG. 6).

FIG. 6. Institut de Radioprotection et de Sureté Nucléaire PWR Engineering Simulator (France).

2.3. SIMULATORS AS A TRAINING TOOL

Simulators are an integral part of NPP training programs and their effectiveness in training plant operators and other plant personnel is undeniable. The quality and care invested in these important training tools has a direct impact on nuclear safety by contributing to the reduction of human errors and ensuring plant procedures are accurate & effective in preventing and mitigating the consequences of plant events/accidents through simulator trials before being employed on the plant.

2.3.1. Regulators' perspective

Although national regulatory bodies have different requirements for simulators and their associated training, there are common trends defined by regulatory bodies establishing more specific requirements for simulator design and usage in the context of operator training, licensing/authorization and examinations. Considering the consequences of human error resulting from an operator being trained on a non-plant-referenced simulator (potential negative training) regulatory agencies generally require at least one plant-referenced full scope simulator per existing NPP and likewise for NNB. Today almost all plant sites have at least one plant-referenced full scope simulator. Furthermore, some plant sites have multiple simulators to address their training needs.

2.3.2. Operating experience

Simulators, as well as other training settings, should be utilized to the extent that it is possible to disseminate industry and plant-specific operating experience accurately.

2.3.3. Crew resource management including teamwork, human factors & human performance tool use and practice

The simulator training environment need to be conducive to the development of crew resource management (CRM)/teamwork dynamics, within all training scenarios, where human performance practices such as the error-prevention techniques described by the human performance tools are an expectation (e.g. three-way communications, conservative decision-making, peer checking, procedure use and adherence, etc.). By constant use and application during simulator training scenarios it will form a natural part of operator day to day business in the Main Control Room (MCR). Different Member States will use MCR and Central Control Room (CCR) as the same control facility for the reactors.

2.3.4. Plant Operational and Safety Performance

In recent years there has been a significant overall improvement in the operational and safety performance of NPPs worldwide. While it is difficult to determine the extent to which improved simulator training has contributed to these improvements, it is clear from operational feedback processes that improved simulator training has contributed to fewer unplanned shutdowns and more effective operator responses to abnormal and emergency plant conditions when they have arisen.

2.3.5. Training responsibility

Management of NPP operating organizations are ultimately responsible for resourcing the training and qualification of their personnel. The training organization will facilitate such processes, with the support of the line organization. Simulator continued, refresher, IPTE & JIT training, particularly for control room personnel, has been found to be essential in maintaining high standards of operation. Involvement of senior facility management & Operational line management in simulator training is of primary importance to ensure its successful outcome, regarding setting and enforcing the required standards and expectation of the operations department. Experience has shown that simulator instructors alone are generally not effective in establishing and maintaining performance standards for control room operators, particularly for established teams during refresher and/or continuing training. It is only when the operating crews know that the standards established in the simulator during training are indeed the standards expected by senior management on the plant, that these levels of performance will be consistently achieved and maintained throughout both plant and the simulator activities. The way that many NPPs have achieved this objective is through line management regularly observing simulator exercise scenarios, particularly those where established shift team performance is being assessed. Those line managers trained or briefed to participate in the post exercise critique can then contribute to the outcome by identifying and enforcing the required standards and expectations to both teams and individuals. Acknowledgement, encouragement and highlighting exemplary performance will ensure these behaviours are repeated when crews return to the plant. Likewise, substandard performance and areas for improvement (AFI) must be identified and a plan for correction agreed with the team or individual. Other effective ways of management involvement in simulator training include:

- Establishing and participating in training review committees, including reviews of training requirements as well as simulator aspects (e.g. simulator fidelity, change and discrepancy correction testing, down time, etc.) with representatives of all involved parties including line and training management, training instructors and the operators undergoing training;
- Ensuring the allocation of the appropriate resources for simulator training;

— Facilitating a rotation mechanism of plant personnel in assigning operators as instructors to support the development, implementation and evaluation of simulator training;
— Operations managers contributing to the identification of simulator training, need to support the production of the appropriate training.

Once the training has been agreed and produced operations management must visibly demonstrate the importance of the training through positive reinforcement of the simulator instructors and the training being provided.

2.4. THE USE OF SIMULATORS OUTSIDE OPERATOR TRAINING

Traditionally, simulators have been utilized almost exclusively for operator training purposes. Current simulator modelling and physical fidelity and realism are well suited for a multitude of other applications such as:

— Plant design validation and verification (V&V) on NNBs and existing plant modifications;
— Plant procedures (operating, maintenance, commissioning, etc.) development, V&V and dry-run;
— System process (system design and equipment characteristics functionality testing);
— Instrumentation & control (closed loop and all kinds of automation on at least functional level);
— MCR ergonomics applications;
— Main MCR human factors engineering research and subsequent training;
— Digital Control System (DCS) & PCS HMI (Operator Displays) man machine interface (instrumentation ergonomics) suitability analysis, etc.;
— Alarm management and handling; Safety Assessment Studies (LOCA, SGTR, Inadvertent Dilution, PSA, etc.);
— Training and familiarisation of other plant personnel, e.g. operator technicians, systems engineers, management, regulator (licensing support), dignitaries & visitors (community relations);
— Emergency drills;
— Severe accident & severe accident mitigation guidelines (SAMGs) analysis.

The use of simulators for other applications offers both quantitative and non-quantitative benefits.

2.4.1. Quantitative benefits

Here are some of the many quantitative benefits for using simulators to support plant activities:

— Protect the public, personnel, environment and plant against any accident or event that may cause death or injury;
— Prevent equipment failure and/or damage due to incorrect operational practices or lack of understanding basic physics of the NPP processes (e.g. turbine overspeed, main feedwater pump cavitation etc.); depending on the equipment under stress, this could result in high repair costs plus loss of generation;

- Prevent unplanned plant shutdowns, as a result of Human Error and an increased number of un-planned trips with possible extended plant outages resulting from possible malpractices during operations;
- Early identification and correction of deficiencies for NNBs or new equipment/systems to be installed in existing NPPs. Significantly less costly than during commissioning or in operation.

2.4.2. Qualitative benefits

Here are some of the many qualitative benefits for using simulators to support plant activities:

- Increase credibility with regulators, outside organizations and peers (IAEA, WANO, INPO, other utilities, etc.);
- Considered industry best practices;
- Increased confidence in the facility from the public by preventing plant events;
- Enhanced quality/user friendliness of plant engineering products;
- Higher acceptance of plant modifications by plant operators;
- Enhanced coordination/understanding among crew members;
- Increase the operator confidence to face unexpected transients;
- Testing and validation of simulation beyond standard testing.

The indirect benefits of using simulators for other applications is an opportunity to also identify and correct simulator deficiencies that may not have been discovered during normal operator training in the full scope simulator. Ultimately, this results in a better-quality simulator and improved training.

For utilities, the procurement of a full scope simulator is a relatively large investment. Leveraging this investment for other purposes makes sense considering the potential safety and financial benefits and is considered industry best practice.

2.5. CURRENT TRENDS

The following section includes brief descriptions of what are considered current trends in simulation-based training.

2.5.1. Simulation portability

Simulation is now more portable than ever before due to computer technology advancement in the last two decades. Making simulation available outside the full scope simulator to improve classroom training quality and reduce demand on the full scope simulator is a reality. It is also recognized as industry best practice to use simulation for other applications, as well as operator training. Classroom/portable simulators equipped with soft (virtual) panels displayed on touch screens are a trend that is expected to continue. Utilization of virtual machines or remotely connecting to simulator resources facilitates the deployment of simulation to desktops, laptops, and tablet personal computers (PCs) to enable more interactive training. Most simulator environments are now very portable but have significant limitations as a result of using external emulated or stimulated systems such as plant process computers or DCS systems. These can provide extremely accurate representation of the reference unit but may not have similar flexibility in terms of hardware compatibility or licensing.

2.5.2. High-fidelity object-oriented graphical models

Although high-fidelity object-oriented graphical models have been in use since the early 1990's, Member States continue to upgrade their legacy non-graphical models to graphical models. These new models are very user-friendly, facilitating model creation, maintenance, testing and troubleshooting. Although care has to be taken when upgrading models with more capabilities as they will represent new physical phenomena and challenges both to the users and developers of the new models. For example, replacing an old single-phase flow model with a proper multi-equation two phase model gives a much more realistic response but also requires the user to realize that water now boils, gas can accumulate into the flow network, etc. – complex phenomena which did not appear previously. Also new models require much more accurate documentation, input data implementation and testing to control all these aspects. Advanced models may also be more unstable or less predictable than old very simplified ones.

2.5.3. Instructor tools

Several advancements have been made in recent years regarding the instructor supporting tools. Instructors have access to user-friendly graphical tools to efficiently control and monitor all aspects of the simulation and debrief of the operators after a training session. Here are a few examples of features available to instructors today:

- Monitor/operate control panel instruments using soft (virtual) panels;
- Powerful data collection (e.g. simulator testing, scenario-based testing records, etc.) data comparison tools (e.g. operator performance data against benchmarked data, to improve objectivity in assessments, plant best-estimate and simulator response comparison);
- Monitor plant parameters from system diagrams and directly from modelling schematics;
- Create purpose-built customized soft panels by combining instruments from different areas of the control room;
- Create/execute scenarios graphically;
- Audio/visual systems synchronized with the simulation for operator debriefing purposes;
- Support of touch-enabled monitors and devices;
- Instructor station software running on mobile devices for floor real time instructor usage;
- Realtime 3D visualization of processes like core neutronics or primary system thermohydraulic.

2.5.4. Part-task trainers

Several utilities of Member States have added the use of part-task trainers to their training programs. These part-task trainers should be designed to address specific training needs for operators or other plant personnel. As an example, a plant with identified human performance issues on Emergency Diesel Generator (EDG) start up, could procure/develop a part-task trainer with soft (virtual) local panels for the operators to obtain familiarization training on the controls and operating parameters during start-up (FIG. 7).

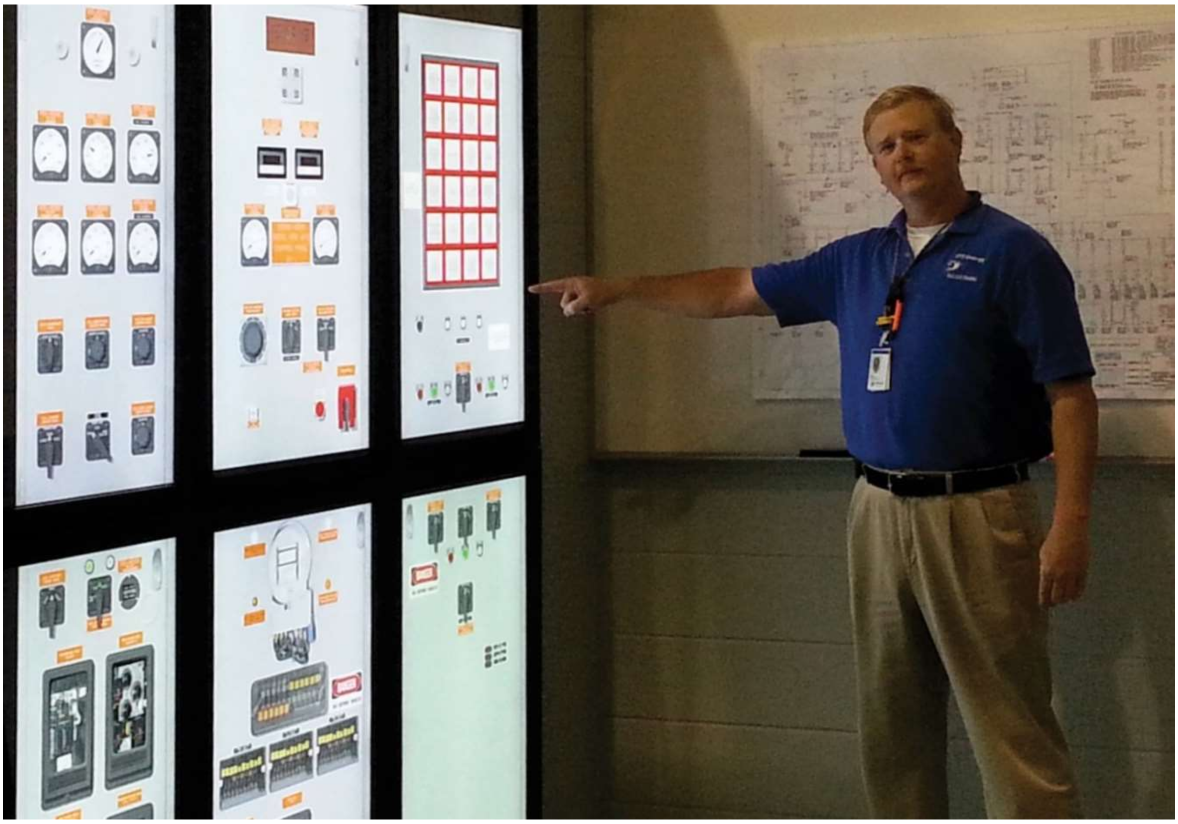

FIG. 7. DTE Energy Fermi (BWR) Emergency Diesel Generator Part-Task Trainer (USA).

2.5.5. Severe accident simulation

The Fukushima-Daiichi nuclear accident (2011) prompted many utilities of Member States to examine the role of severe accidents in their training programs, included updating training on their full scope simulators, so that plant personnel are well trained on how to cope with a severe accident. Several utilities around the world have integrated an engineering-grade severe accident simulation model (e.g. MAAP[1], MELCOR[2], etc.) into their simulation (FIG. 8). These severe accident simulation codes include the modelling of the NSSS (including the reactor vessel), containment and spent fuel pool, integrated with the simulator boundary models. Severe accident simulation can be equipped with 2-D and 3-D visualization for plant personnel to practice SAMGs and better understand severe accident phenomena. Severe accident simulation can be integrated with the full scope simulator such that operators can take appropriate actions, or as a stand-alone training tool, allowing operator actions using the soft (virtual) panels. The simulator is also used to develop strategies and guides to attend accidents beyond the design basis.

[1] Name of a Severe Accident Code
[2] Name of a Severe Accident Code

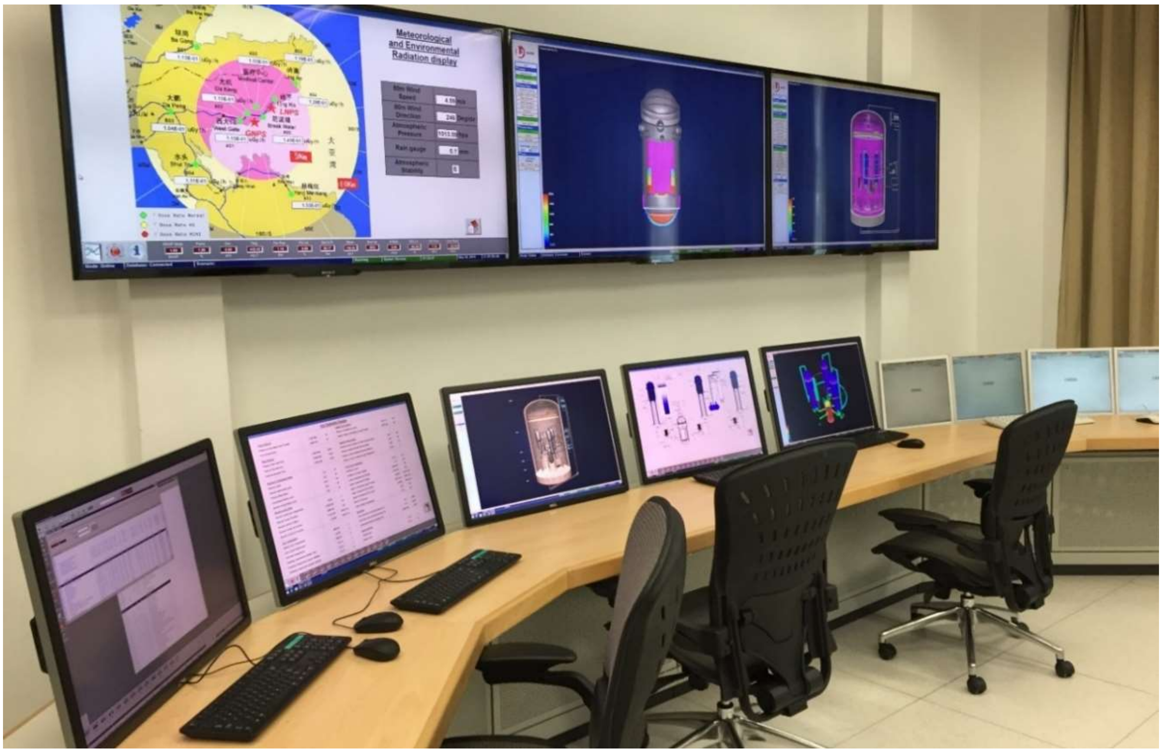

FIG. 8. CGN Ling Ao Phase II PWR Severe Accident Simulator (China).

2.5.6. Digitalization in Training

Application of digital technologies enables new forms of innovation and creativity, rather than merely reinforcing and supporting existing methods. Technology and pedagogical skills really must work together to provide effective training.

One challenge for the nuclear industry is to utilize the potential of digitalization to create the best possible training for the new generation of trainees. To succeed in this endeavour, it takes an innovative culture, high digital skills and specialized capabilities that enable high level training skills amongst trainers. Digitalization itself brings new possibilities to a student in training. The goal for digitalization in nuclear training is to be able to offer a mix of training tools and learning environments, each one designed to give the best results by allowing effective training to be designed, adjusted and delivered according to the ability and needs of each trainee.

The trend is to now combine multiple digital training tools to create an advanced, experience-based learning environment. Once digitalized, there is a greater potential for further development.

A side effect of digitalization is to support a more personal training program for the individual student as the instructor can transfer the feedback from monitoring the results to the tool. This enables more trainees per instructor and in the long term provides a lot of input to support training evaluation. Several digital features will be helpful when producing new or updating existing digital training materials, for example, facial recognition, content finger printing, speech recognition, object recognition, content duplication, etc. This means that a large amount of training material can be scanned in a short period of time and exams can also be graded automatically.

2.5.7. Apps

Applications for mobile phones or tablets (Apps) can be used for creating digitalized and individualized training (e.g. training for nuclear generic fundamentals can easily be supplemented with apps). The main advantages for using mobile applications instead of regular web-enabled solutions are:

- The start-up time and navigation response time of an App is typically faster than web pages;
- An App can make use of the phone's built-in features such as a camera, GPS, address book, etc.;
- Mobility.

An App supports innovation and digitalization in training by:

- *Interacting*: Exchange information via different forums; chat, feedback, evaluations and video meetings;
- *Learning*: tutorials utilising; movies, quiz's, tests, e-reading, flashcards, etc.;
- *Sharing*: movies, animations, photos, slideshows and exercises;
- *Create Engagement*: motivation through gamification (satisfaction, pride, motivation, loyalty, joy, curiosity, competitions, etc.);
- *Availability*: easy access and quick to open, no upload time, offline materials, etc.

An App permits instant feedback to and from trainees and teamwork between trainees themselves.

2.5.8. E-Learning

The use of e-learning is not a new concept for nuclear training but with increasing access to digital tools its use has the potential to be further developed. Traditional e-learning often comprises of general employee and fundamentals training for both training and testing purposes of students. Also, e-learning can be used as a tool for operational tasks, executing procedures, problem solving, troubleshooting etc. Giving trainees the opportunity to train where and when it is most convenient for them, using prepared scenarios and different teaching modes, made available to them and aimed at the appropriate knowledge levels of the individual students. Training in this manner, using e-learning, mirrors some aspects of simulator training without the need for instructors, FSS simulators or the possibility/need of repetition for those students that do not require it as students can study at their own pace. Modes of training include:

- Show me: Pure demonstration; no interaction with trainee;
- Teach me: Trainee actions required; showing hints or information when correct/incorrect actions are taken;
- Test me: Evaluation mode where successful results may lead to next step/task or examination of the step or task.

The above is an example of a stand-alone tool (no connection to a simulator is needed), which can then take many shapes or forms and have varying degrees of complexity. The advantage is the mobility and flexibility, but the disadvantage can be a level of training that is low.

2.5.9. Gamification

Gamification is not a training tool by itself but is used in combination with for example, e-learning and VR-scenarios. The idea is to make learning easy and more stimulating by adding an element of competition. Direct feedback, in the form of scores or points advancement to the next level etc. is given. This can also be used as a classroom training technique. Digital training tools provide new opportunities, not only for the trainees but also in the extra data made available for analysis to the tutor.

2.5.10. Enhanced visualization

Visualization in this context means to leave the fidelity of the reference plant and introduce new tools that explain a phenomena or sequence of events. This extended or enhanced visualization (FIG. 9) can be used in the simulator, classroom or any place with a connection to the simulation model (classroom, lecture theatre). The visualization can be in 2-D or 3-D. It includes the possibility, on demand, to show Mollier diagrams, construction specifications, plant drawings, flow charts, parameter trends, etc. and allows the instructor to implement more problem-based learning techniques, making this a powerful complement to traditional full scope simulator training through:

- Problem-based learning;
- Improved visualization of the process;
- Individual adjustment of training (focusing on the desired concepts/components);
- Experiment (make mistakes, make it right);
- Understanding of dependencies, causes and consequences;
- Thinking independently;
- Increased understanding of the process;
- Customized learning.

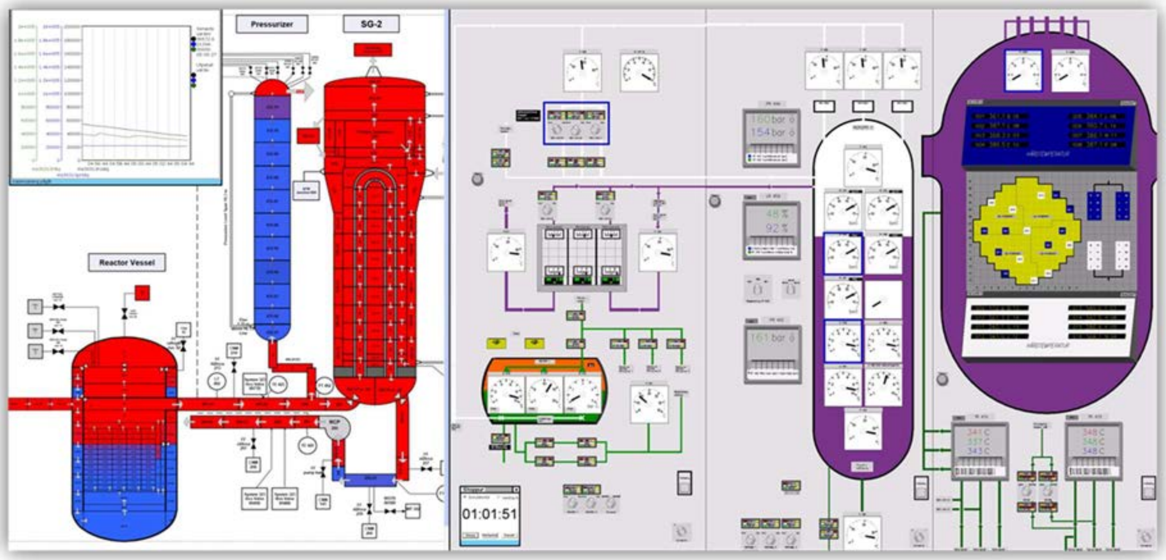

FIG. 9. KSU Example of Enhanced Visualization (Sweden).

2.5.11. Virtual reality

Virtual Reality (VR) is the use of computer technology to simulate real, established or imagined environments to provide a seemingly realistic, physical experience for the user.

The user can perform different actions in the VR environment. Several participants connected to the platform at the same time can act together. The user can manoeuvre valves, climb ladders, and disassemble an item of plant. The user can virtually go where no one has gone before.

VR application examples include:

— Optimization of field operator rounds/tours;
— Pre-job briefing and post-job debriefing;
— Specific just-in-time training;
— Increased plant spatial knowledge and awareness.

Gamification is also easily introduced into the VR environment, giving the trainee instant feedback on performance according to instructor pre-set criteria. VR can be used for training radiation workers, fire fighters etc. without them being subjected to the hazards of the actual environment when training.

2.5.12. VR simulators

If the VR environment is integrated with simulation data, a VR simulator is obtained. Virtual control room environments are often created in connection with NNB or control room upgrade projects with no or very little operator interaction possibilities. This can be done for economical and plant availability reasons and is a technique that is growing in use. VR simulation can be a powerful tool when training operating crews, including field operators, in scenarios where remote local actions are required. A full or partial VR environment of an NPP can be used for many purposes, for example:

— Emergency Preparedness (EP) drills;
— Guided tours in non-accessible plant areas;
— Planning of decommissioning activities;
— Radiation protection;
— Just-in-time preparation;
— Pre-job briefing;
— Post-job debriefing;
— Projects and maintenance planning.

VR simulators and their use are still in the early stages of development and the possible cost benefits are yet to be fully determined. Soon VR models might be deliverable as a standard feature in NNB or plant upgrade projects.

2.5.13. Augmented reality & mixed reality

Based on 3-D models, it is possible to create user-friendly reality experiences using presentation devices such as holographic glasses, tablets or phones.

Augmented reality (AR) provides users with the ability to enhance their natural environment or scenarios. Through the use of AR or Mixed Reality (MR) technologies the enhanced environment of the user becomes more interactive and may be altered for teaching purposes. Information about the environment and its objects is overlaid on the real world. Visualizing data on demand can be useful to many aspects of nuclear plant operation, not only in training.

2.5.14. 360° interactive videos

With 360° videos, it is possible to capture and record large spaces and more of the surroundings. With the use of an application it is possible to create an enhanced interactive video for training purposes that goes beyond the basic play back option with a recording.

360° interactive videos can be used for:

— Training;
— Guided tours in non-accessible plant areas;
— Planning of decommissioning;
— Radiation protection;
— Just-in-time preparation;
— Pre-job briefing;
— Post-job debriefing;
— Projects and maintenance planning.

2.6. MAIN CHALLENGES & SOLUTIONS

2.6.1. Simulator availability & reliability

The full scope simulators of Member States have high usage to ensure each NPP has enough authorized/licensed operators for continued operation. With an aging nuclear industry workforce high availability and reliability of simulators is paramount to meet the required training of replacement authorized MCR personnel and to facilitate the continued training and re-authorisation of existing staff. To accomplish this objective several strategies are recommended:

— Review and upgrade the simulator hardware and software periodically;
— Upgrade the simulation environment with graphical tools to make it easier to maintain and update parameters such as deficiency clearance or incorporate plant modifications;
— Maximize the use of commercial off-the-shelf hardware (e.g. computers, network equipment, power supplies, etc.) and third-party software (e.g. operating systems, compilers, databases, etc.);
— Pro-actively address obsolescence issues (e.g. spare parts management, re-engineering of instruments, etc.);
— Add of UPS and power conditioner and redundant power sources to prevent equipment failures due to power outages and surges;
— Have physical server clones for hot standby or virtualized services which can be quickly switched into action when problems occur;
— Utilize the multi-CPU performance of modern hardware and minimize the number of separate computer systems for critical infrastructure instead of using clusters of computers which fail when a single unit fails;
— Review and rehearse the back-up and recovery procedure periodically, implement automated back-up of all relevant data;

— Delegate development and testing efforts to secondary simulators and minimize the need for the FSS for project works and upgrades.

These strategies will result in less equipment failures and overall easier maintenance of the simulator.

2.6.2. Configuration management/control

Whether for an NNB or existing NPP simulator, keeping the simulator up to date with the plant design (configuration management) is a challenge. NPPs need to establish a strong engineering process such that all plant modifications are evaluated for simulator impact. If a specific plant modification is flagged to impact the simulator, the simulator staff needs to scope the hardware and software changes required. The implementation of plant modifications needs to be prioritized based on training needs. Plant changes impacting plant operation significantly may even be implemented in the simulator before implementation on the plant. This approach is considered industry best practice.

Another aspect is configuration control of the software models and source code to ensure integrity of the simulator software configuration and proper documentation supporting simulator changes. Some simulation environments include built-in advanced configuration control (versioning) and configuration management tools to facilitate this. These tools include graphical and non-graphical comparison and data tracking features such that plant data, stored into a repository, can be linked with the model. Some third-party configuration management software can also be utilized but they are typically not ideal for graphical models and do not allow for creating links between the software and the plant design data. Utilize modern web based ‘ticket’ or work management systems for handling the simulator change management workflow and tie this system in with the configuration and version control system. Make both available directly on the simulator computer network so they become a part of daily life for all personnel involved.

2.6.3. Nuclear new builds simulator development

Experience has shown that developing an operator training simulator in time to train and examine plant operators before fuel loading is a major undertaking. NNB plants are highly DCS based and the DCS design changes constantly until very late in the plant construction phase. Therefore, simulator vendors need to find innovative ways to cope with this and ensure the simulator will be ready for operator training. Here are some recommended strategies:

— Engineering simulators can and should be used to assist in plant/DCS engineering (experience has shown that this practice allows for the early identification and resolution of a significant amount of plant design issues) graphical models and real-time graphics allow for prototyping, quick changes and immediate feedback. Modification and fidelity accuracy are paramount as this simulator will eventually become the operator training simulator;
— Seamless organizational integration of simulators with the DCS design and implementation is key;
— Simulation models should match one-to-one plant design documents/drawings to facilitate incorporation of plant changes;
— Using DCS simulation upfront should be considered, such that the simulator is not dependent on the plant DCS design and configuration; emulation or stimulation can be introduced later once the DCS design is more stable. Alternatively, the DCS design could be led on an engineering simulator with implementation to the real unit once the simulator

works as designed, providing that the DCS system chosen supports a flexible stimulation/emulation capability with quick change implementation and initial condition handling;

- Automation of the process to update the simulator DCS controls and HMI (DCS translation process) is key to a quick update of the simulator;
- Strong configuration management and control tools designed for graphical models and graphics is essential.

2.6.4. Existing NPPs external systems incorporation

Another challenge for existing NPPs is the addition of external systems (DCS, digital instruments, Plant Process Computers (PPCs, etc.). Original Equipment Manufacturers (OEM) are typically not forthcoming with technical information on their hardware and software (for Intellectual Property (IP) considerations) making their implementation in simulators challenging. Some of the external systems do not support inherent simulator functions, such as freeze/run, restore/store Initial Condition (IC), etc. The following four strategies are possible for their implementation:

- Stimulation;
- Emulation;
- Simulation;
- Hybrid approach (mix of different strategies for controls and HMI).

Here are some strategy selection factors to consider when implementing external systems:

- Project strategy and schedule;
- Data availability (plant vs. simulator timing);
- Vendor selection (OEM IP considerations);
- Cost of hardware, development and software licenses (including consideration for classroom simulators);
- Licensing restrictions;
- Classroom simulators (portability of hardware/software);
- Configuration control/management (level of effort to implement future plant changes);
- Fidelity requirements;
- Preferences.

2.6.5. Meeting operator expectations

As NPPs become more digitalized, the simulators' response can be evaluated with more detailed scrutiny than ever before. Simulators can be benchmarked against actual plant events to ensure that the simulators properly replicate the NPP response to the specific operation or event. Operators can now easily obtain trends of any plant parameter to analyse (and no longer need to rely solely on instantaneous readings from instruments) to benchmark simulator fidelity. Operators now expect increasingly realistic scenarios from their site-specific simulators when training. Therefore, it is important to improve simulator fidelity and capabilities over time by incorporating new technologies and learning to ensure the operators continue to 'trust and respect' their simulators. Regular polls and questionnaires can be used to record client (operator and instructor) sentiment on the quality and performance of the simulator, as well as find key areas for improvement and topics for which future life cycle development effort should be directed by the technical crew maintaining and developing the simulators.

3. ANALYSIS, DESIGN AND DEVELOPMENT OF TRAINING PROGRAMMES FOR SIMULATOR TRAINING

3.1. SAT OVERVIEW

The use of the SAT methodology to include the analysis, design, development, implementation and evaluation of the training provided to all NPP personnel has now become the accepted nuclear industry standard when developing, delivering and assessing training to NPP personnel of all disciplines (FIG. 10).

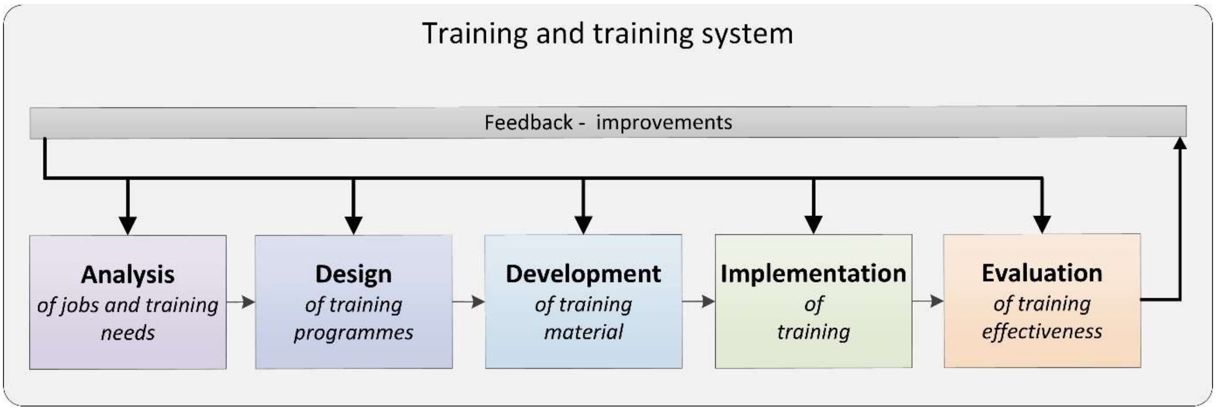

FIG. 10. Overview of the SAT five phases

Procedures for NPP training organizations concerned with the design, development, implementation and evaluation of training programmes needs to be governed by and aimed at achieving the goals dictated by the managerial training policy and its supporting documentation. These training standards and procedures then serve as an agreement between the plant organizations and the training organization when defining the type of training to be provided, with suitable governance and oversight measures put in place to ensure the product is of the desired quality. Inter-organization management is especially important if the technical personnel involved in simulator maintenance and development is from a separate organization than the training and/or operations departments (especially utilities who operate simulators as another technical system and may not have a fully integrated organization for just the simulators and training together).

The strength of a correctly applied SAT based training programme is to ensure a quality management process is built into the programme throughout all stages; this is particularly important for NPPs to be able to demonstrate to nuclear safety regulators, both internally and externally, that thorough, auditable quality processes are in place for training and qualification.

The SAT methodology is fully described in Systematic Approach to Training for Nuclear Facility Personnel [9] and this Section will not look to repeat the contents of that document but rather identify how the simulator training programme demonstrates SAT compliance and makes the simulator training process visible and auditable to any interested parties.

The training requirements of NPP personnel will be governed by several issues and needs, some of them will be mandatory, e.g. operator MCR authorisations. Others will be role related, e.g. initial training of reactor licensed operators, control room supervisors (CRS) and shift managers. The training requirement may be plant driven, e.g. an infrequently performed task or evolution needs to be practiced before being undertaken in the MCR.

Departments other than operations, will also have a need for simulator time, e.g. fault analysis of a perceived problem, or engineering to assess the impact of a new control system. The training resources and priorities will have to be managed with input being provided by all those involved from:

— The line departments (who require the training);
— Training department (who develop and provide the training);
— Management (who resource the training and demonstrate compliance of the training processes to the off-site stake holders, e.g. Governments, regulatory bodies, shareholders, etc.).

The simulator resource will be managed through the appropriate training committees with representation from the above groups to prioritise departmental training requests and needs for simulator resource availability.

3.2. ADMINISTRATIVE PROCEDURES

The design and maintenance of a simulator and the use of the simulator for training are normally governed by separate NPP Administrative Procedures. The maintenance procedure will cover simulator purchase requirements, e.g. design data and specification, commissioning requirements for a new simulator, periodical fidelity testing requirements, fault investigations and maintenance guidance etc. and is covered in Section 8 of this publication.

The Administrative Procedure for simulator training normally governs the Conduct of Simulator Training and Operator Assessments at the NPP and the use of the SAT process for implementing operator training and assessments when conducted on the site simulator.

Typical content of the NPP Administration Procedures Document (Conduct of Training) that impacts on simulator training standards and expectations typically includes:

— Qualification and individual responsibilities of all NPP personnel responsible for the facilitation and qualification of operators on the plant. This could include:

  - Operations Department Manager and Shift Managers (line organization), Training manager, Simulator Instructors, Subject Matter Experts (SME);
  - Their roles and responsibilities that some of these individuals will hold, as part of the relevant training committees they partake in when carrying out governance and oversight on the implementation of training;

— Conduct of simulator training, e.g.:

  - Instructor requirements: qualifications and experience to perform the instructor duties of preparing and facilitating training and assessments;
  - Preparing SEGs for simulator training containing pre-exercise briefings and post-exercise critiques of students, assessors, role playing support, etc.;

— Conduct of operations (Operator Standards and Expectations implementation and re-enforcement during simulator training); Nuclear Professionalism/formality implementation in the MCR of Human Performance and Human Factors practices/ standards;

— Plant procedures: adherence/use and rules of implementation, e.g. Technical Specifications (Operating Rules);
— Performance evaluation guidance for simulator instructors and assessors on:

  - Individuals;
  - Teams;
  - Simulator pass/fail criteria and remediation process;

— Simulator session guidelines for instructors - Simulator Exercise Guides (SEGs):

  - Crew composition requirements (roles and number of attendees);
  - Required candidate control manipulations/evolutions;
  - Instructor use of simulator features and role play participation;
  - Maintaining simulator fidelity through MCR benchmarking and student feedback of simulator performance;
  - Visual and sound recording procedures (use and application);

— Types of simulator training: organisation and administration of MCR Operator training and assessments; Task based evaluations, e.g. Job Performance Measures (JPMs) Shift assessments-CPOs (crew performance observations); Modifications and Procedural changes - implementation training; Demonstrations exercises, e.g. emergency exercises;
— Records Definitions, References, Appendices (references to forms, checklists, stored on NPP controlled document platforms):

  - Pro-forma to record annual/biennial, mandatory/regulatory training requirements (e.g. assessment, examination or relicensing; performance recording pro-formats);
  - Prepared SEGs containing simulator generic training aims, objectives, critical actions, etc.;
  - Individual evaluation standard pro-forma-for use during an observation and assessment;
  - Control room team/crew evaluation standard pro-forma-for use during an observation and assessment;
  - Checklists: references for course administration, simulator set up and run requirements, simulator specific observation pro-forma, etc.

Requirements for each stage of the SAT process to prepare a course for simulator training include (also see FIG.10):

— *Needs Analysis*: request for simulator training received and needs analysis is carried out on the particular operation that is perceived to require simulator training to correct the deficiency.
The tasks/competencies to perform the operation are then identified and from this the knowledge, skills and attitudes/behaviours that require correcting are selected for training. Not all requests have a simulator resolution to the problem; a knowledge issue may be a procedural misinterpretation, competency may be the lack of practical application of knowledge based training, on a particular piece of plant operation, attitudes or behavioural problems may be the result of a lack of implementation/practice of teamwork/CRM skills during pressure situations, due to their lack of use in the MCR during day to day normal operations. A training need analysis will show if simulator training will address the issue in question or if a more appropriate solution will be implemented.

— *Design*: in this phase the training objectives are developed fully, derived from the training requirements identified during the analysis phase. The training committee can now be presented with the analysis results and the resulting objectives from the analysis, to decide if the request for simulator training is to move forward in the SAT process. Once the objectives have been agreed, via the training committee, they are now organized and sequenced. A suitable testing scenario for the objectives is to be identified (typically at this stage existing SEGs may be reviewed and one chosen to revise or develop, to satisfy the learning objectives and testing needs to be applied in this simulator scenario).

— *Development*: SEG - simulator lesson plan developed, and a technical review carried out on completion. The training team, involved with running the scenario and assessment, carry out a pilot of the exercise on the simulator in real time, to ensure the simulator fidelity, assessor role play, Technical Specification/procedural documentation are all correct and the prepared training will meet the needs of the objectives.

— *Implementation*: in this phase, training is delivered, and assessment/examinations carried out as described in Sections 4 and 5 of this publication.

— *Evaluation*: during this phase all aspects of the training effectiveness is evaluated, with feedback provided, leading to training and facility performance improvements as identified (described more fully in Sections 5 and 6 of this publication).

Task analysis to determine the content of simulator training allows utilities to identify tasks to be included in initial training and identified for continued simulator training. The analysis also ensures that performance standards are developed and identifies critical tasks etc. for assessing. Operating experience is also an important source of information for identifying the simulator training needs of NPP personnel. The involvement of subject matter experts in the analysis phase is essential to capture inconsistencies or errors in specialist fields before moving onto the next stage in the SAT process.

Some Member States have specific regulations and/or standards that specify the types of training to be conducted on a simulator.

3.3. DEFINING THE TRAINING PROGRAMME

Training programmes for NPP control room personnel typically consist of a combination of classroom, on the job, simulator, and self-study training. A terminal objective is a statement on the purpose or goal of the training and is usually written in behavioural terms, stating the expected outcome in terms of performance, conditions, and standards. The terminal objective of the training is to provide control room operators with the knowledge, skills, and attitudes/behaviours necessary to operate the plant in a manner that is Safe, Reliable, and Professional. The specific learning objectives and content of the initial and continued training programmes and the selection of the training setting (e.g. classroom, simulator, etc.) are determined through the analysis and design phases of SAT.

The training program for control room operators should cover relevant areas of technology to the levels necessary for the tasks to be performed safely. The training should instil a thorough theoretical and practical knowledge of plant systems (especially safety related systems) functions, system interactions (relationships) layout and operation. In particular the simulator part of the training program should be focused on operator fundamentals and should emphasize the importance of maintaining the plant within the operating limits and conditions, the consequences of violating these limits, the importance of maintaining reactivity control and core cooling at all times, including periods when the plant is not in operation (shut down and outages).

Control room operators are expected to be trained in plant teamwork and CRM skills including diagnostics; control actions/decision making; administrative tasks (workload management); and human factors skills. Shift supervisors and managers require additional training in supervisory and oversight techniques; with all staff requiring strong procedural and communication skills.

The training program must cover and record:

- Preliminary requirements of individual for qualification for respective job/post position;
- A list of the tasks resulting from the task and job or competency analysis of the functions related to the specifics of the particular job/post position;
- A list of the courses trained on (simulator scenarios), a brief description of the content of scenario (SEG aims & Objectives), the duration of course or scenario, documented records of results obtained (training forms supporting training results and computerized records and ways of verifying obtained knowledge including records of instructors and assessors marking and crediting the training and assessment;
- A list of the technical means used; details of training location, techniques employed, type of assessment, etc.;
- Criteria for successful examinations at the completion of the specialized training under the program. (pass fail criteria and remediation process);
- A list of documents and administrative procedures related to the management of specialized training activities.

3.4. INSTRUCTOR REQUIREMENTS QUALIFICATION AND EXPERIENCE

3.4.1. Instructor Selection

The appointment of simulator instructors will be based upon a clear policy, defined in the operations training administrative procedure for ‘Conduct of Simulator Training and Assessments’. The qualifications and experience required, and the means of attaining these pre-requisites will be defined by the facility/NPP in their standards documentation.

As well as attaining the operational competencies (plant experience, system knowledge) stated in the post profile for the position, to carry out the simulator role, the instructor will require Human Performance and CRM skills, as well as the technical competences needed for simulator instructors, e.g. oral and written communication skills, interpersonal skills, leadership potential, observation skills and debrief training for individuals and crews.

In some Member States it will be a pre-requisite for the simulator instructor to hold or have held an MCR operator’s license or have obtained MCR operator experience to an equivalent level, as defined/requested by the NPP or regulator.

After the selection process has been satisfied and appointment confirmed, appropriate training and familiarization with MCR and simulator operation and the completion of the appropriate mentor guide for the position will enable the individual to meet the qualifying standard to perform the duties of a simulator instructor.

Consideration should be given to the importance of the simulator instructors ability to maintain their MCR (in line) competencies and stay up to date and current with present MCR practices to maintain their authorization/licence.

At some Member State NPPs, rotational assignments (secondments) of MCR operators to training centre simulator instructors roles is implemented; typically, of 1-3 years duration.

MCR operators will obtain additional simulator training and certification as simulator instructors; typically require training in critiquing and debriefing skills and mentoring in the operational practices for running the simulator scenarios. This secondment will be on a temporary basis at the FSS facility, supporting the training team and this ensures that current plant knowledge and experience is constantly being refreshed within the simulator delivery team.

The advantages and motivation for the seconded MCR operators to obtain instructor qualification and experience is that they gain experience from observing and training a number of shifts and positions, including CRS and SM positions. This allows them to revisit/refresh and build upon many aspects of operational practice. Many of the people management skills learnt and practiced on the simulator will be of benefit when the individual returns to the line. This secondment period will increase their career development prospects, improve their profile with senior line managers and could potentially increase their promotion prospects.

To keep simulator instructor operational SQEP capabilities up to date with present NPP practices, some Member States return the seconded instructors to the line for a period defined in the facility standard, typically 10-14 days per year. A simulator instructor that has been seconded for a considerable amount of time from the line, e.g. 3 years may also have to sit a re-Authorisation panel before returning to MCR duties. This could be avoided if the instructor is attending 2-3 yearly assessments during his training period, on the condition that he is not tested on a scenario he has previously prepared for or facilitated running.

3.4.2. Instructor training and mentoring programmes

Initial simulator instructor training and mentoring programs should be designed and developed to ensure that instructors possess the necessary competences to conduct simulator training to their peers. Technical aspects related to possible operational scenarios and instructional skills should be the basis of the initial training programmes of simulator instructors. The content of such a training programme will change depending on the qualification and previous experience of individual candidates. Besides technical and instructional skills, skills related to other complementary aspects, such as CRM, teamwork, human factors and human performance, along with the facility policies, philosophies and principles captured in NPP operational standards documentation relating to reactor/core safety etc. The simulator instructor is required to understand the principles of all these topics and build them into the simulator exercises they are to deliver and debrief operators on. Annex I provides an example of a training programme for initial specialized training of full scope instructors.

Depending on the Member States route to the individual becoming a certificated simulator instructor, the following can be considered:

— Train instructors from graduate intakes with no previous power station operating experience;
— Recruit individuals from the line with MCR operator licenced experience; of reactor/unit operator, CRS or SM line experience;

- MCR Operator secondment from the line for an agreed period, typically 2-3 years (not always necessary to train these seconded individuals to all SAT mentor guide qualifications);
- Recruited from another facility; nuclear or conventional with generating plant experience;
- Recruited from another industry/organization, e.g. military sub-mariner with reactor operator authorization (often requires more mentoring in the cultural/behavioural aspects of NPP operation before leading training of MCR personnel).

The instructor training and mentoring programme can be individually designed/tailored to allow an individual from any of these backgrounds to become a simulator instructor. They will all have to attain the same SQEP level to facilitate training to the required standard specified at the facility and captured in the training programme and authorisation for the post. However, the time scales to reach this SQEP level will differ considerably for individuals. Some of these attributes may well have already been attained from the individuals' previous post, and with evidence to support this they can be exempted from repeating all these aspects of the instructor training programme.

Topics typically included in a simulator instructor initial training programme, will require them to have obtained or obtain the required levels in fundamental processes, theory knowledge and plant technical knowledge (task to training matrix for this obtainable from the existing analysis of the MCR operator training programme for that particular NPP). This knowledge will be supplemented by the Human Factors and Human Performance skills and knowledge (also mirroring the existing operations program requirements). Alongside this the instructor will be required to install all the Procedural and Regulatory operator understanding and implementation required to train MCR personnel in the safe operation of the plant to satisfy all regulatory/legislative conditions/provisions.

In addition, the simulator instructor will require mentoring and training in the NPP training department standards and protocols; operation of the simulator facility; production of simulator documentation, including SEGs and training to facilitate individual and team debriefs of their peers.

Considering the different reactor/plant designs and configurations and the variety of existing simulator capabilities, some NPP simulators receiving upgrading for continued operation, some being replaced with new models and NNB in some Member States providing them the opportunity to take a fresh look and start, as to the way they are going to operate/manage their simulator facilities in the future. Despite all these differences there is a lot of common ground in the skills and attributes required from simulator instructors on all these plant types when operating their simulators, such as being able to train, coach and mentor the Operator Fundamentals, CRM, as well as technical reactor and conventional plant control principles.

Some of the topics to be considered for the simulator instructor programme, along with a continued training programme are listed below. Like all other NPP training programmes, the construction of the instructor training programme will follow the SAT process. As previously stated, the reactor/plant control and operations will mirror the operations task to training analysis to the level required for the instructor to confidently deliver the standard of training required to instruct and debrief the MCR students of all positions. The instructor training programme would be a combination of classroom and simulator training with a considerable amount of mentored tuition and coaching to support this (FIG. 11).

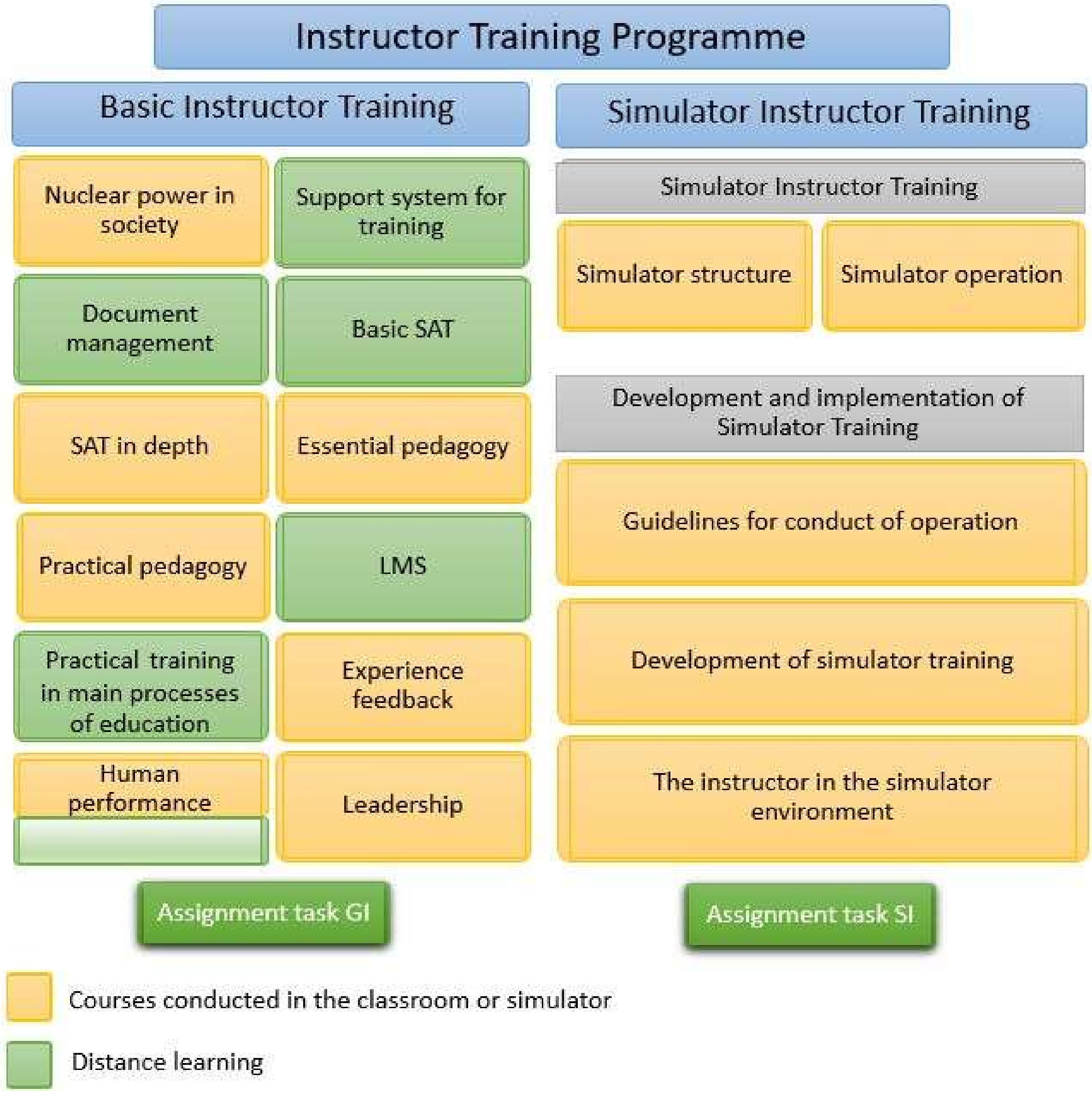

FIG. 11. A Typical example of an Instructor training programme showing courses conducted in the classroom, simulator or as distance learning.

Some examples of Instructor Initial Training Topic Headings are proposed below:

— Role and application of the FSS in NPP personnel training;
— Regulatory and NPP (facility) standards documentation on simulator management, training and assessments.

Operation/familiarization training and mentoring of the location FSS include:

— General hardware and software configuration set-up;
— Simulation scope and limits;
— Deviations from reference plant and contingency arrangements and remediation plans;
— Use and Troubleshooting Procedures on encountering simulator malfunctions;
— FSS Instructor Station;

— Instructor computer interface, console and control functions.

Simulator instructor competencies include:

— Role and responsibilities of the Simulator Instructor;
— Use of simulator training features to facilitate simulator training scenarios. Use of SEGs during:
  - Demonstration scenarios;
  - Training scenarios;
  - Performance evaluation scenarios, etc.;
— Efficient communication skills - student feedback and coaching techniques;
— Student/crew conflict management techniques and styles;
— Teamwork/CRM training including diagnostics and decision-making theory;
— Simulator exercise guide: development, validation, application and the review processes to control modifications and amendments to SEGs (lesson plans);
— Assessment techniques, e.g. observation, evaluation and debriefing to agreed standards (pre-exercise briefings and post-exercise critiques);
— Adult learning theory/pedagogy- to enhance and evaluate trainee performance when trainees are involved/receiving simulator training;
— Feedback to line management, e.g. on student performance, raise a condition reports on simulator observations that identified a potential plant event;
— Facilitate Operator examinations and assessments on the simulator, providing feedback and training to assessors on current standards and practices.

Additionally, on the job training should be provided for instructors who have no previous experience of plant operation at the location. This will normally require a period of secondment with duty shift teams.

3.4.3. Instructor Continued Training

For operational training team to remain SQEP (current and up to date) on the present MCR practices, standards and expectations being employed at the NPP, whilst continually reviewing worldwide standards and practices to improve local training and qualification standards.

The purpose of Simulator instructor continued training is to improve upon current levels of instructor performance. Simulator instructors must be kept up to date with current MCR practices, standards and plant modifications and any impact that these may have on reactor control, safety margins, operator performance etc. They must update their knowledge on industry, worldwide and local improvements in operating practices, standards, legislation, OPEX etc. and pass this information and its relevance on to the MCR operators in the training, instruction and advice they develop and provide. Importantly instructors must be allowed to develop and improve themselves, if they are to be able to facilitate the improvement of others and maintain their own interest and motivation for continuous improvement.

Topics for consideration for instructor continued training (improvement) include:

— Participation in shift operations through the rotation procedure (secondments) to ensure up to date current practices are continually being refreshed within the training team;
— Re-familiarization training of regulatory/site licence documentation updates;

- Industrial events/operating experience notification and significance to the NPP for consideration in future training or briefings;
- Simulator training teams to be involved with shift training being delivered by other departments and outside agencies to the line, to ensure they remain current;
- Instructional skills:

  - New instructional methods, techniques, technologies (software tools);
  - Correction of performance deficiencies identified though feedback, observations and evaluations taken by the line;
  - Review of selected topics from the initial instructor training programme;
  - New instructors will require observation skills training to provide feedback, and training simulator instructors as assessors ensure that they are familiar with assessment standards and practices and are always therefore in a position to reinforce these standards and expectations to students and line assessors.

Simulator team needs to liaise and communicate with the simulator engineers and management in order to:

- Facilitate and encourage feedback with simulator engineers to help maintain simulator fidelity during FSS modifications and upgrading;
- Be aware of current status of FSS deviations from the reference plant and required compensation measures employed for simulator training;
- Reference plant equipment and system modifications;
- Reference plant operating procedures modifications.

The expectation is that simulator instructors can address the performance issues of the students/participants to reinforce standards and expectations and contribute to increasing their performance capabilities.

Feedback from simulator instructors is one of the main sources of information for the content of the continuing training programmes. Personnel who provide simulator training are expected to maintain routine communication with feedback to plant personnel and line management; and to participate regularly in shift operations to maintain operational expertise and familiarization with plant procedures and current practices. This can be done by periodical secondments to the line and by carrying out observations and benchmarking in the MCR and on the plant.

At some sites, instructors are involved in the formal authorization process as well as capable of facilitating an assessment scenario and debrief. Therefore, the instructors require training in the assessment process and be trained/mentored as assessors. Parts of this training process are required to support them in the feedback and coaching (critiquing) of teams and individuals.

3.4.4. Simulator instructor assessment

At the end of the initial instructor training programme, the instructor will be authorized to carry out duties within the defined limits allowed by the authorisation. For example, this may mean that the instructor will be initially confined to training and debriefing reactor desk training and supporting the facilitation of team training and authorization being led by the lead simulator tutor.

A re-authorization process may be carried out periodically, following the defined criteria of the facility and/or Regulatory requirements. This could take the form of:

— A formal instructor license, maintained by completing the periodical shift assessment;
— Observations of training and/or assessments. This is often carried out by a senior manager from training and/ or supported by the line manager.

Effectiveness of simulator instructor performance should be periodically assessed by line management based upon agreed criteria. Feedback from trainees concerning simulator instructor performance, course relevance and its effective online performance should also be solicited and reviewed.

3.5. OPERATOR TRAINING PROGRAMMES

3.5.1. Initial training programmes

Initial training programmes are established for NPP control room personnel to develop their knowledge and skills to operate the plant safely and reliably. These programmes are structured according to everyone's specific control room operating or supervisory position. The initial training usually begins with classroom training on fundamentals and theoretical training followed by training on systems, components, and plant equipment. During this training the simulator is first used to familiarize the trainee with plant instrumentation and control locations in the control room, followed by demonstrations of the operation of systems and components. Simulator training exercises then usually begin with instructor demonstrated and coaching exercises that involve normal reactor start up and shutdown, and the introduction of progressively more complex malfunctions to develop the skills and confidence of the trainees. These initial training exercises emphasize the importance of the use of plant procedures and provide practice in the diagnosis of plant events. As operators gain experience, exercises are introduced involving integrated plant operations and incorporate multiple malfunctions with emphasis being placed on teamwork and communications to diagnose problems and how to work with the team to safely operate the plant, to mitigate abnormal and emergency occurrences within NPP operating limits and maintaining safety margins whilst adhering to plant procedures and processes.

Training programme plans or procedures are typically written for each NPP control room job position and may include separate plans or procedures for initial training programmes and continuing (sometimes referred to as re-qualification) training programmes.

These plans address the total training programme for the position and address all training settings. Annex II contains a typical outline (list) for an initial training programme plan for a reactor operator. Further information/guidance can be found in Ref. [10].

3.5.2. Continuing training programmes

Continuing training programmes are established to maintain and enhance the knowledge and skills of NPP control room personnel. These programmes are structured commensurate with the specific control room assignment and are typically conducted over a 2-3 year rolling training plan. Continuing training programmes for control room personnel typically consist of pre-planned classroom training, on the job training, and simulator training on a regular and continuing basis throughout the period. Continuing training programmes include simulator training on topics such as:

— Significant plant system relationships, routine plant operations;
— Procedure changes;
— Plant and industry operating experience;
— Normal, abnormal and emergency operating procedures with emphasis on the use of the team to demonstrate control of the reactor and plant systems, to mitigate event effects;
— How to pit emphasis on refreshing selected fundamentals (e.g. seldom used knowledge and skills that are necessary to assure margins to safety are maintained during an event);
— Identifying training, required to correct plant performance issues;
— An emphasis on prioritized/mandatory training of event scenarios based on the results of deterministic and probabilistic risk assessments (PRAs).

3.5.3. Simulator exercise guides

Simulator exercise guides are the 'lesson plans' for the instructor to facilitate MCR operator training and assessments on an FSS simulator.

SEGs are the standard documents that direct, dictate/govern the implementation of the scenarios, containing the training objectives, an outline of the sequence of events, operator critical actions, etc.

Annex III contains a typical Member State blank outline of a SEG for a training or assessment scenario.

The NPP Operator standards and expectations, covering Operator Fundamentals, Human Performance, and Human Factors; including Teamwork and CRM are the generally accepted criteria defined in most NPP operator standards documentation. These expected behaviours sometimes captured in NPP conduct of Operations documentation (described more fully in next section) will be the accepted operating minimum standard captured in the SEG training objectives. Examples of performance objectives described/captured in the SEGs to be considered include:

— The Shift Supervisor to be informed of any activities that influence power distribution (change of power control modes, manoeuvring of control rods, change of main circulation flow);
— All alarms appearing on the control panels must be acknowledged and the person who acknowledges any alarm is responsible for initiating the required procedural response action and communicating this to the rest of the MCR team;
— Events are recorded/logged extensively and in detail in logbooks and in the shift change/handover log to ensure communication of important information is captured at shift change/handover;
— The necessity of HU activities (pre-job briefing, post-job debriefing, peer checking, independent checking etc.) is considered at the start of all work tasks. HU activities are assessed for appropriateness and implemented according to the requirements specified in pre-job briefs, procedures and operating instructions;
— 3-way communication is used in the control room and messages verified between receiver and sender to ensure complete understanding of the message;
— The control of the reactor core, e.g. power level changes are carried out in accordance with operating instructions by the authorized reactor engineer and under the supervision of the CRS, e.g. control rod movements are implemented in a pre-defined sequence; as per the operating procedures. Many Member States implement a reactivity brief to all those involved, before any activity that has the potential to effect core reactivity are undertaken;

— Reactivity is always monitored and controlled, to ensure that reactor power and the main circulation flow remain within defined operating limits and margins to safety are maintained.

SEGs are used as the lesson plans by the instructor for all simulator training. On conclusion of the training scenario the SEGs are used to support debriefing and evaluation/assessment of individuals as well as team performance. SEGs can be designed and developed for:

— All levels of simulator training scenario;
— Assessment scenarios (also referred to as performance or evaluation scenarios) will differ from a training scenario as the omission of critical actions in an assessment scenario will almost always denote a failure and remediation training to a defined level (judgement to be made by the assessors as to remediation training required);
— Others (e.g. training on modifications, etc.).

Annex IV lists some examples of typical plant normal, abnormal and emergency operating evolution scenarios on which to be trained during the operator training programme on a simulator for a pressurized or boiling water reactor.

INPO *Guidelines for Continuing Training* INPO 86-025 can provide additional support [11].

SEGs for training each of these topics will need to be created, often containing one or more of these topics during normal, abnormal and emergency situations. SEG design will need to take into consideration such things as:

— Key instructional and pedagogical characteristics of the different types of scenarios;
— Description of the types of scenarios and their purpose in training and evaluation;
— Instructor roles and interventions during the scenario process;
— Pre- and post-simulator control of the scenario, trainee awareness/understanding of the scenario topics, and trainee activities.

The selection of a specific type of scenario is a function of the training aims and objectives to trainees (new or previously qualified) that differ in levels of understanding and receptiveness to differing styles of learning. The differences in the scenarios and students under tuition will dictate the need for different instructional strategies and instructor activities which require pre-thought and planning before implementation.

Training scenarios are used to implement simulator training designed to instruct individuals and team operation and control of unit systems and equipment during normal, abnormal and emergency conditions. Training scenarios have the following instructional characteristics:

— Trainees assume the MCR role they are training for and manipulate FSS controls in accordance with station operating procedures;
— The levels of interaction between instructor and trainees will differ, depending on student ability. This may range from high instructor input on initial training, moderately high during continuation or refresher training (the instructor may be asking questions even as scenario unfolds or may freeze the simulator to take time to reinforce a specific point), almost no interactions (instructor observing trainee performance only) and measuring understanding via self-critique techniques, post scenario, through to no interactions

during an assessment scenario, either formal or informal. All of this is dependent upon the point reached in training, the experience of trainees, prior performance, etc.;

— Trainees may have some degree of control of the training session in that they may be able to ask questions of the instructor or request to freeze or terminate the scenario if they require further explanation or understanding as to what has happened, where they believe they currently are and where they believe the scenario is taking them etc.;
— Simulator features such as freeze, replay, fast and slow times may be used but not as frequently as in a demonstration scenario (depends on factors such as the point in the training process and trainee performance);
— Trainee can be made aware of the content and purpose of the training scenario;
— There is generally a post-simulator session used to analyse system/equipment performance and to critique trainee performance and review training goals;
— It is current practice that the responses of field operators are provided by a simulator instructor (for example, role play on the phone to the MCR of an operator or maintenance technician).

Assessment Scenarios are used as part of the final assessment process of the trainee when the line organization and training department have agreed that the student is competent, in their opinion, to be put forward for qualification to perform the MCR duties they have been trained for. Readiness to perform specified tasks and fulfil position/job functions defined in the NPP MCR post profile and to operate the reactor unit and associated plant systems and equipment safely during normal, abnormal and emergency conditions is also tested.

Typical assessment scenarios have the following instructional characteristics:

— Trainee assumes the role of MCR operator being authorized for and manipulates FSS controls to the required standards and expectations, defined in NPP documentation and captured in the assessment SEG objectives, critical actions, significant actions and performance actions;
— There is no interaction between candidate or instructor/assessors once the exercise has commenced and during the assessment scenario. Except when the instructor or role players provide technical information, as defined in the SEG or any role player prepared briefs. Instructors should not anticipate requests from, or decisions made of the MCR floor individuals or shift teams;
— There is no pre-simulator training session;
— Trainee is not aware of the content and purpose of the scenario;
— Simulator features such as freeze, backtrack, replay, slow times are not used. Fast time may be used to accelerate time-consuming waiting if candidate is made aware that this is being employed and the consequences. May be dependent on simulator capability;
— Debrief is used for further assessment of the candidate to define understanding and situational awareness throughout the assessment scenario. A candidate self-critique technique is employed, and open questions employed to gain further explanation of observed facts.

3.5.4. Job performance measurement

Job performance measurement (JPM)is an assessment/practical performance test used to assess the level of performance of an individual when carrying out a specific task or set of related tasks, benchmarked against a predetermined performance standard for that task.

3.6. CREW PERFORMANCE OBSERVATIONS

Crew performance observations (CPO) in the simulator environment is the application of the full scope simulator facility to review and evaluate main control room teamwork performance. This observation is particularly important for new builds, with newly qualified crews who will not have had the opportunity to work together as a team in an actual MCR working environment. CPO is also particularly applicable to existing MCR teams, who are required to demonstrate the dynamics of good team performance in a high pressure/event-based scenario. In some Member States the periodical MCR assessment of an individual's performance will take place simultaneously with the team assessment.

It is important to note that teams evolve/change continuously (e.g. holiday, promotion and illness) and may require cover from another shift team member, so it is important to recognise that team dynamics can change and training team standards and processes have to allow for this in their methodology, design, development and implementation of SEGs for Teamwork and CRM application by MCR operators.

In some Member States' use of CPO is not as a formal examination tool, whilst at other utilities the teamwork assessment processes have been extensively reviewed, developed and applied, post Daya Bay event, and these scenarios are often of interest during targeted NPP technical assist exercises, internal audits and Peer Reviews from a number of organisations.

A pre-requisite to achieve beneficial results from any CPO is the availability of a set of credible, realistic and challenging teamwork scenarios. The requirement for developing, testing and validation of scenarios for CPO observations are like those applied in assessment scenarios through the use of SAT principles (e.g. adopt and develop a suitable teamwork standard and develop simulator scenario objectives from this for all MCR positions).

The purpose of a CPO observation is to observe and/or evaluate team performance and dynamics. Typical observations include:

- The ability of operating crews to respond, as a team to simulated plant and equipment malfunctions during normal, abnormal and emergency situations;
- The ability of the simulator location, hardware and software to accurately model plant conditions and performance dynamics for the teamwork scenario;
- The simulator instructor's ability to create a realistic environment in the FSS and support MCR personnel, through simulator instructors having a full understanding of Teamwork/CRM process application and developing these habits and behaviours in the MCR teams/crews, through the effectiveness of the simulator instructors' scenario design, debrief and feedback techniques to and from the shift MCR crews.

4. IMPLEMENTATION OF SIMULATOR TRAINING

4.1. PRE-EXERCISE

Briefing of the control room team is typically conducted prior to any simulator demonstration, training exercise or assessment scenario being carried out. Such a briefing may be conducted in the classroom or on the simulator floor. In most cases, a prepared brief for a combination of training scenarios, or the simulator exercise guide (for one off exercises) is used as the lesson plan by the instructor. These briefings usually cover team member assignments (roles), plant initial or as found conditions and immediately prior to the commencement of the exercise, a shift handover and control board (panel) walk down by the trainees. For demonstration or training scenarios the training will also include all relevant information about the specific scenario and any refresher training regarding fundamentals theory, plant systems or components re-familiarisation training, needed to support the exercise:

- Prepared material, such as MCR logs, work orders or tag-outs, etc., should be provided prior to starting the exercise to maximise realism during training scenarios;
- Any simulator related issues to be included as part of the briefing, if relevant to the exercise being run, e.g. any simulator fidelity issues that may have an adverse effect on the training exercise.

4.2. IMPLEMENTATION

It is normal practice to agree a multiple-year training curriculum with the line; typically, 3-5 years, for the continuing training needs of MCR operators. A training plan is developed, captured, recorded and agreed by operations management, via the relevant training oversight committee. This ensures all mandatory training requirements, arising training needs, important topics, e.g. operational learning, are reviewed for their training need and repeated systematically as required to maintain the knowledge, understanding and practice of all Operator Fundamentals to the expected standard.

The curriculum (task to training matrix) typically ensures that the identified training aims, and objectives are captured in the training scenarios – SEGS, and are trained during initial training, as well as ensuring that they are repeated continuously in a systematic manner, as per the identified need stated by the responsible training committee.

In addition to the identified plant specific topics, the fundamentals, taught during initial training, should be refreshed periodically (e.g. reactor physics, thermo-hydraulics (dynamics), system knowledge, etc.).

The purpose of the curriculum is to ensure that the essential topics are identified and training of these topics repeated systematically over a specified time span to ensure that the knowledge and practical skills of the operators remain at the expected standard(as defined in NPP standards and expectations documentation). This overview of the training needs identified, when the training was completed and the level of proficiency attained by the individual trainees, will help prevent the gradual degradation of operator standards over time, after completion of initial training and authorisation.

Topics covered should include fundamentals – both technical fundamentals, as taught during initial training, as well as the Operator Fundamentals defined by both INPO and WANO as:

- Monitoring plant indications and conditions closely;
- Controlling plant evolutions precisely;
- Operating the plant with a conservative bias;
- Working effectively as a team;
- Having a solid understanding of plant design, engineering principles and sciences.

In addition to the above fundamentals "two overarching characteristics are necessary to achieve excellence in operator fundamentals – operational proficiency and operator engagement" (INPO 15-004). Therefore, the operator training being provided has to be designed with this in mind [12].

Regulatory requirements may differ from country to country but the basic knowledge, operating skills, e.g. continued use of Human Performance tools in the MCR and on the plant, Safety Culture (operator behavioural attitudes, e.g. a conservative approach to operational aspects of an NPP) should be constantly re-enforced and assessed during the training provided on station simulators.

The analysis stage of the SAT process is essential to identifying:

— Who is going to be trained using the simulator? (e.g. MCR operators, systems engineers, fault studies & research engineers, maintenance department, operator technicians, etc.);
— What they are required to be trained in? (MCR operators requiring full fidelity of control room operations, fault studies engineers looking at cause and effect scenarios, operator technicians training on an individual plant item or system);
— What level of training must be attained by the trainee? (formal assessment for MCR staff and at the other extreme running a demonstration exercise for management, dignitaries or the regulator).

Resourcing the analysis stage of the SAT process adequately, prior to contacting a simulator manufacturer, will help ensure that a clear picture of the simulator training requirements is communicated to the vendor accurately when specifying and finally placing a contract to purchase or update a site simulator. Getting a clear understanding of the simulator training requirements can prevent the buyer from over specifying or under specifying their new simulator performance requirements. It will provide for an accurate plan of training needs to ensure that future simulator availability can be met, with provisions being considered towards future simulator requirements/modifications and possibly prevent a large, avoidable budget overspend including crossing time schedules.

All departments that require simulator training will require time for the training to be allocated on the simulator plan and a full analysis for each group needs will have to be carried out individually with the line organization by the training department.

The subsequent information provided in this section is to demonstrate some of the considerations required of an operations department plan and should not be considered as comprehensive fully.

The basic principles to enable a practical approach to this process are contained outlined below, with no NPP design in mind. Guidance in forming a detailed training plan can be resourced from a number of organisations including IAEA, WANO and INPO (e.g. see INPO Guidelines for the training of licensed personnel or Non – Licensed personnel) this information can form the basis of the design of an individual NPP training curriculum but will need to incorporate any gaps identified by the NPP themselves when carrying out their own analysis on their particular training needs.

Operator training programs are generally designed to initially build upon the trainee’s technical and fundamental principles knowledge. This initial stage traditionally would start off being largely classroom-based training, leading onto the inclusion of basic simulator training to demonstrate fundamental system processes, often symptom-based cause and effect training at this early stage of the programme.

With the capabilities of the modern simulators described in Section 2, it is now realistic to incorporate digitally supported training practices from the outset, of any operations training programme in the technical and knowledge-based training of such topics as:

— Nuclear physics principles;

— Water-steam cycles;
— Thermal core design;
— Design basics;
— Safety margins;
— Safety barriers;
— Safety systems (including plant configuration, e.g. isolation valves);
— Operational systems (particularly those having an impact on safety related plant availability, possible precursors to an event if mis-managed);
— Control systems and reactor protection systems;
— Design basis accidents;
— Beyond design basis accidents;
— Electrical concepts/Emergency Power supply arrangements;
— Control rod drives/Shutdown systems.

For systems training, during the early stages of initial operator training, the simulator training can focus on procedural use during routine operations, such as plant start-ups and shut downs, plant line up during particular modes of operation, taking plant items (e.g. motors or pumps) in and out of service in a controlled manner, etc.

At this point in the trainees programme a combination of simulator types can be employed. It may be desirable to train the student on one system in detail with the instructor managing all other variables. For example, it may be desirable to train the student on the detailed aspects of a reactor start up one week with the student concentrating on the various modes of reactor operation during the start-up and the instructor looking after other variables such as turbine run up and synchronization. Then on the turbine detailed training the student would concentrate on the turbine detail of the run up with the instructors managing all the reactor variables.

This approach allows the training team to focus on one particular aspect or system of the training program, easily facilitated on a classroom simulator and freeing up the full scope simulator for other duties, such as shift revision or continued training, MCR team or individual periodical assessments, simulator maintenance or periodical simulator fidelity checks.

Once the trainees have gained the base knowledge and experience of the individual systems, they can then be moved on to the FSS to start bringing all these aspects of the fundamental and systems training together. Human Performance and Human Factors aspects have become an essential part of operator MCR training. Lessons learnt from events as TMI, Chernobyl, Salem (marsh grass event) and in more recent times Daya Bay (WANO SER 2009-3) has been taken into consideration in training scenarios. Other aspects, as the teamwork/CRM issues highlighted at Daya Bay and Fukushima Daiichi NPPs and to the adequacy of NPP emergency scheme arrangements and training, are important parts implemented into operator training.

The modern site simulator fidelity must not only be accurate for plant performance and response to any manoeuvre or plant perturbation but also the simulator MCR layout must mirror the actual MCR workplace setting precisely. This allows the team dynamics skills required on the plant to be developed and practiced by the crews as part of their everyday simulator training, so that it has become very familiar by the time they return to the MCR to carry out their normal duties. Teamwork/CRM skills and coping strategies now form an important part of MCR crew and individual final assessment and authorisation.

Sometimes termed soft skills, the following are important parts of the training:

— Teamwork/CRM including leadership, roles and responsibilities, communications, procedural use and adherence, decision making including CDM (conservative decision making) ODM (operational decision making), and diagnostics;
— CRM human factors aspects of MCR operations including; workload management and prioritization, human information processing, shift working and the effects of fatigue/stress on performance, situational awareness & mental models;
— Human Performance practices (HP tools) communications, peer checking, etc.

Objectives focusing on these skills are required to be built into the operators training SEGs and have equal importance as the NPP technical aspects of the operators training.

Simulator exercises commonly combine many aspects of Human Performance along with the technical issues to be trained by creating scenarios that include a settling in period for the MCR crew to carry out their brief and plant status checks, along with some distractors built into the scenario to keep the crew occupied, e.g. operator technician phone calls and queries. The exercise will then move on to include a routine operation, which facilitates practice of all the fundamentals and often then leads into an event to be managed by the crew.

As the operators under training become more experienced and confident, the initial training program will move on to cover scenarios of ever-increasing complexity, containing routine operations and fault schedule events, incorporating the operator actions required to mitigate the effects of such events on reactor safety.

This fault scenario and station emergency exercise training is designed to stretch the operators to the limits of their performance abilities, with the simulator instructors occasionally creating scenarios that necessitate the need to introduce individuals from outside of the immediate shift team, or make the shift crew employ certain facets of their CRM training to seek additional support, prioritise their workload, or take remedial actions dependant on the severity/importance of the scenario being trained.

This event-based training will typically include such topics and scenarios as:

— LOCAs (inside and outside of the containment area);
— Reactivity events;
— Abnormal operations (turbine trip, steam leaks, house-load, fire,etc.);
— Loss of the (main) heat sink;
— Steam generator tube rupture;
— Station black-out and subsequent station priorities;
— Earthquake;
— Flooding;
— Tsunami.

The training should cover a combination of event-based and symptom-based, normal and emergency operating procedures, with severe accident mitigation guidelines training being built into the program.

From the analysis and resulting task-to-training matrix comes the identified objectives, allowing the training program to be designed to form the multiple year curriculum described earlier. As well as covering the theoretical lessons and practical scenarios, instructors should add local, company/facility, national and international operating experience, along with eventual plant and procedural changes brought to the attention of the program owners since the last review to be considered for future training.

It is common practice to have some form of assessment throughout the training cycle, with regular feedback to line management on the progress of the students throughout.

These assessments will be a combination of theoretical exam conditions and practical assessments on the simulator, benchmarked against the same criteria as used for the final assessment and authorization.

Table 1 is an outline of a possible MCR operator training programme. This will be a living programme, constantly under review and needs to be adjusted, within the boundaries defined by the programme owners. Carrying out periodical self-assessments and benchmarking of the training programme between NPP departments or on other Member States' plants may highlight gaps or weaknesses which will require adjustments to the programme periodically, e.g. adjust the frequency of certain aspects of training, incorporate recent operational feedback from an international or local event, etc.

Table 1. A GENERAL CONCEPT OF MCR OPERATOR TRAINING PROGRAMME

Year	Course 1	Course 2
1	Plant start-up Reactivity events Nuclear physics Thermal core design Water steam-cycle Main cooling water system Component cooling system	Hot stand-by LOCAs (steam leaks) Safety systems Feed-water system Monitoring / Control Ventilation system
2	LOCAs (feedwater) Earthquakes Turbine trip Turbine-related systems Operational decision making Safety margins (LCOs)	Plant shut down House-load operation Reactor protection system Teamwork Electrical concept / Emergency power
3	Beyond design-basis accidents Station black-out Symptom-based emergency procedures Severe accident management guidelines Design basis accidents / Safety barriers	Flooding Fire Loss of the main heat sink steam generator tube rupture Event-based emergency procedures Control rod drives / Shutdown system

Table 1 is not intended to be detailed. It is designed to illustrate some of the components and the general concept of a MCR operator training programme. The NPP will need to define each of the topics required for training and through the implementation of the SAT process develop a detailed list of what is required for initial training and authorization within each of the defined topics:

— Who requires training in initial training?
— What can go on to continued training, shift team/CRM revision training, etc.?

Once past the initial training and MCR authorization stage, continued training and re-authorisation is normally conducted using the shift team/crew concept on a routine basis. Trainees should be assigned to the same control room team positions as those to which they are normally assigned to on the plant. The plant administrative procedure describing NPP operational activities should be used to define areas of responsibility of individual team members. This method of training develops the trainees' proficiency to fulfil their normal MCR position and associated duties, provides an understanding of the roles of others in the team and helps to develop the ability of the team to work cohesively together when diagnosing and correcting operational problems. Depending on the NPP organizational structure, other personnel (such as the shift technical advisor, reactor physicists, etc.) should be included periodically in shift continuing training.

The attitude and professional behaviour of trainees and instructors should reflect the professionalism expected in the main control room. Plant operating philosophy should be re-enforced in the areas of:

— Control room formality/professionalism;
— Conservative thought processes and decision making;
— Procedural use and adherence;
— Reactivity management and control;
— Crew (team) roles and responsibilities;
— Communications (3-part communications, phonetics, MCR protocol…);
— Self-checking, peer checking, independent verification;
— Emergency plan classification and implementation;
— Technical specification implementation and adherence.

Periodic observations and participation in operator simulator training sessions by Operations Department managers will reinforce the importance placed on these practices. Consideration should be given to involve operations management as classroom lecturers for the topics related to operational standards and expectations. This will ensure that operators receive first-hand information and re-enforcement regarding the formal arrangements and requirements of them regarding standards and expectations. Annex V demonstrates an example of course observation checklist.

During simulator training, every attempt should be made to make the simulator control room feel and act like the NPP main control room. Simulator problems and possible fidelity issues should be treated as actual plant problems. If these are not identified beforehand to the crew during the course opening brief, as a possible simulator issue, the operators should carry out the appropriate actions, fill out the correct paperwork, make the necessary calls for assistance and notification, and troubleshoot problems, where appropriate, using the correct procedures.

Operators should be taught to perform normal control room duties, especially the recording of information in the appropriate official records and MCR logs.

Controlled copies of plant documentation (flow diagrams, operating and administrative procedures, technical specifications, etc.) should also be used when conducting simulator training to assure consistency between the simulator training and control room work practices. The updating of the simulator documents should be a part of the NPP document review process for the actual MCR and should be a formal part of the NPP modification process and completion sign off.

Prior to conducting simulator training or an assessment, the scenarios should first be run on the simulator by the instructors to verify and validate the desired performance and fidelity of both the exercise and simulator response. This is necessary to ensure that the instructors are familiar with the expected plant responses and the correct/expected simulator responses do occur, so that negative training experiences do not occur.

The required number of instructors needed to conduct simulator scenarios and assessments needs to be considered. Typically, one instructor is assigned to the simulator instruction station to run a scenario and one or more instructors are either on the simulator control room floor, or in the specially provided tutor gallery to observe the students. For initial training there will be more 'one to one' instructor-student training on the simulator floor requiring one or two instructors only, with them gradually retreating into the background as the students get more experienced and requiring less input from the tutors.

Assessment scenarios will require more instructors/assessors. Typically, an instructor will be required to run the scenario with another one required to facilitate the assessment process, supporting the responsible line management leading the assessment debrief/critique. The instructor makes the final pass/failure judgement, based on the assessors noted observations and discussions. The number of instructors/assessors required is also dependant on the number of students being assessed at one time, typically requiring one observer/assessor per assessed student plus one instructor to run the assessment scenario.

4.3. POST-EXERCISE

Simulator training exercises and debriefs serve to provide instruction and facilitate a forum for the students to obtain and enhance their operational skills and experience. Self-identification of the desired operator good performance practices, which need to be repeated and shortfalls/AFI to be corrected, must be highlighted during the debrief process. Post-exercise critiques and debriefings on trainee performance are an important form of instructor-trainee interaction, to improve the students understanding and learning on completion of the floor exercise. Such critiques may involve different instructor styles, techniques, and activities, including self-critiques carried out by the team or the individual. The instructor facilitates the self-critique through discussion and open questioning techniques, based on a combination of the instructor observations, noted during the exercise, and the team's self-identified findings. This may require the instructor or trainees to re-run portions of the exercise on the simulator, use the monitored parameters, simulator functions and data from the simulator instrumentation to diagnose what actually occurred, along with an examination of any video recordings taken of the crew during the exercise, to identify any actions the crew did or did not take.

The review of the exercise should accomplish the following:

- Reinforce good behaviours, practices, skills and knowledge observed and gained during the training;
- Recognize and highlight improvement/progress and good performance;
- Reinforce a conservative approach to reactor safety and control;
- Identify trainee and team performance weaknesses and provide guidance on training to correct these weaknesses;
- Correct observed trainee misconceptions;
- Review the accomplishment of position specific learning objectives;
- Facilitate self-evaluation practices of performance by the trainees;
- Review & summary of the objectives and any other learning points that may have come out as a result of the exercise;
- Review and discussion of questions asked during the exercise, including during the debrief and the provision of the correct answers;
- Identification of any procedure improvements identified and owner of update;
- Identification of any plant policy clarification needed and responsible person to pursue and provide update;
- Identification of any simulator improvements noted during training and reporting process to ensure follow up by identified individual post training.

To facilitate an effective review, simulator instructors should use good observational techniques along with accurately taken notes, recording what occurred, when it occurred, why and to whom it occurred. Observations should contain demonstrated performance strengths and AFI/weaknesses (e.g. effective use of 3-way communications, actions required in procedures that have not been observed or inappropriate actions initiated by the operators that are not in the appropriate procedure). During complex or rapidly developing scenarios, consideration should be given to using more than one simulator instructor/assessor to provide adequate observation of trainees' and their actions.

Instructors are typically involved in training on the same subject/scenarios to different groups/shifts and their subsequent observations and feedback may be additionally 'shaped' by practices/performance observed in previous crews. These observations of good practices and lessons learnt from different teams can be carried foreword by the simulator instructor to contribute to the group learning that can then go on to contribute towards building a more harmonized, common approach to the desired operational good practices captured in company and departmental procedures.

Another effective approach to debriefing is to encourage a team self-critique in which the shift manager serves as the facilitator of his team's critique and the trainees identify good/strong performance and AFI themselves. This self-identification of potential corrective actions to enhance the improvement of their team performance results in a higher value and ownership by the team on their agreed corrective actions than if they were told by an instructor or manager to do it.

A formal assessment is an indispensable part of the simulator training and authorisation process when demonstrating an individual or team's competencies regarding the safe operation and control of an NPP, either internally to the company's satisfaction or externally to the public or a licencing body. This authorization, supported by the training program and developed using the SAT process allows the whole training process to become visible and accountable through its development, implementation and through to signing off an individual's final authorization.

Individual and team performance should be evaluated regularly to identify performance deficiencies and to verify that previous training was and remains effective. Assessment of the operating crew's proficiency in operating the plant in a manner consistent with the philosophy and standards established by plant management is an essential element of their initial and continuing training programmes. Trainees should be made aware of the evaluation process and the standards and expectations required, as their participation and continued questioning contributes to the objectivity and effectiveness of training and assessments.

During a simulator exercise, the evaluator identifies differences between expected performance standard and the actual performance observed from the trainee. These differences/gaps in performance should then be analysed to identify key performance problems that should be critiqued during debriefing. The evaluator should supplement any observations through open questioning techniques to determine the understanding, knowledge level and thought process behind the trainee's actions. During simulator exercises used to evaluate trainee performance, it is not appropriate to coach or support the operator being assessed. This minimizes interference with trainee actions, thus avoiding compromising the evaluation process. On completion of the assessment any shortcomings can be highlighted as AFI for the student to take away and address post assessment, if these AFI are not of a significant nature to affect the outcome of the final assessment result.

It is important that formal assessments are based on predetermined standards and that evaluators are thoroughly familiar with the appropriate standard being employed for the assessment.

Evaluators should receive appropriate guidance and training on the current evaluation process and procedures in use, including debriefing techniques and should acquire the necessary observation skills supporting appropriate simulator training. Observation skills are best developed through observation, participation and practice in observations supporting skilled evaluators.

Well prepared assessment scenarios, containing information on expected individual and crew performance are essential to conduct objective evaluations. It is important that all identified weaknesses and suggested corrective actions be documented and analysed to determine individual or generic performance trends and thus determine areas that need emphasising or changed in future training events.

During initial operator training, a formal assessment on the simulator should be a part of the final qualification process. Periodic 'progress' evaluations should be conducted by operations management and qualified evaluators throughout the initial operator training programme to identify individual and potential programme weaknesses. Any such identified weaknesses would then be remediated during a subsequent training period.

The performance of control room personnel should be evaluated regularly. It is important that the abilities of each operator and crew to cope with normal, abnormal, and emergency operations be formally evaluated during each continuing training segment. NPP line management should be involved in this evaluation by observing crew performance during selected assessment scenarios.

Consideration should also be given to performing evaluations of crews and individuals at the beginning of a training course ('as found' evaluation). This will be followed up with an assessment at the end of the training period. This allows the instructor to identify any proficiency gaps and allows them to be addressed immediately and serves as a method of measuring effectiveness of the training provided.

Assessment results should be treated as confidential and only made available to the appropriate training personnel and line management involved in the authorization process or for the development of any remediation training action requirement.

5. EVALUATION OF THE SIMULATOR TRAINING PROVIDED

5.1. SOURCES OF INPUT DATA

5.1.1. Trainee feedback

Trainee feedback is often identified as level 1 feedback. If not managed properly, level 1 feedback will fail to obtain useful information to facilitate the improvement of the simulator training programme. This level 1 feedback of the trainee is normally completed immediately after all aspects of a training session have been completed, whilst the experiences remain fresh in the student's mind and easier for them to recollect and record.

The feedback could be recorded by each student on the completion of each training scenario during the day, including subsequent debriefs, or at the end of the day's training on a specially prepared feedback form. A combination of the two being another alternative, advantages of this being that the feedback for each exercise is more likely to contain detail from the students immediate recollection and experience of what occurred, followed up with an overall summary at the end of the day, giving the students time to reflect and discuss the day's training before providing feedback individually and/or as a team.

Feedback requested at the end of a course, that may have been running for a couple of days or a week of instruction, often does not contain detail useful to the instructors for the development/improvement of the program. This feedback can often be too general or rushed by the students, as the detail from previous days of training is no longer fresh in the trainees memory, or they may not feel as passionately about some aspect of the training as they did on completion of the scenario, so may be less likely to provide that initial feedback which may have some significance.

If feedback is requested towards the end of the course, typically post exam and course summary, the students may feel that the summary discussion was their feedback and are less likely to provide details. Satisfactory results are more likely to come from feedback given before completion of the course summary and exam. The end of course summary discussion could be facilitated by the instructor or shift manager as a flip chart exercise, so that it can be captured by the training team for the final course review to be completed by the department shift and training managers.

The instructors will usually obtain more considered thought going into the feedback, if they encourage it throughout the course in short directed questions and comments rather than as the final 'can you just fill in your feedback form before you leave' request to the students. If the instructor does not demonstrate value and purpose to the feedback process, then the students certainly will not become sufficiently engaged.

The trainee's level 1 feedback is typically collected using pre-prepared feedback/training response questionnaires. It is desirable that each individual complete one to ensure their individual thoughts on the course are captured before any team feedback/response is requested from the crew, as this group feedback may be overly influenced or controlled by a particularly strong individual or group.

It has been considered good practice to ask for the following aspects on the feedback forms using a scoring system:

- Feedback on the pre-course preparation of the participants (joining instructions, pre-course work);
- Timelines/effectiveness of the training provided;
- Suitability of training to trainee's position/normal duties;
- Level/degree of difficulty of scenario;
- Simulator fidelity/performance;
- Scenario realism;
- Instructor performance;
- Areas of strength or improvement required.

The scoring facilitates post course trending, but it is good practice to ensure students provide supporting comments to the score they have provided before including it in any trending. Asking open questions for written comments that can be used to further analyse the participants' feedback is considered a far better practice than scoring alone.

The process will gain credibility and future support from the MCR teams if a summary of applicable actions, as a result of their feedback, can be discussed and decided upon by the responsible managers, through the relevant training committee and subsequently fed back to all the shifts for comment on the final completion and review of the whole suite of courses provided to the shifts. This facilitates:

— higher levels of training effectiveness feedback and it is deemed good practice to solicit feedback a short time after training, and prior to further continued/shift revision/assessments training being carried out on the simulator to the MCR crews. For example, issuing a follow up questionnaire 3-6 months after the training to the shift, summarising the training provided and asking for feedback on any aspects of the training that related/supported their role upon return to the line, or any topic that should be considered for the next round of revision/continuing training, etc.;
— Encourage the MCR crews to raise reports/CR (condition reports) on good and bad occurrences that may have occurred to them when working back on the plant that may have been influenced by the training they received.

5.1.2. Instructor reports

Instructor reports on individual and crew performance, training issues and simulator fidelity are summarised on completion of a suite of any training courses provided, e.g.:

— Shift revision training being provided to all the shifts over several weeks;
— Individual and MCR team 2-3 yearly re-authorization assessments;
— Continued, IPTE or JIT training for a modification or infrequent operation training to the shift crews.

Feedback from the tutors on the effectiveness the training has on student performance must go back to line management periodically throughout a long training programme (e.g. initial training over an extended period 1-2 years). This is to engage the line manager, at an early stage of an individual's training programme, to assist and rectify any identified weakness reported back to them by the tutors. A plan for remedial action, with line support will be required to ensure any weaknesses are worked on and remedied long before the completion of the training programme and before the student sits through an authorisation panel.

After conducting a shift-team course or initial training the performance of the individuals involved needs to be fed back to the line manager for analysis. The shift manager (if not in attendance during the training) and department manager will need to discuss between themselves any remediation of an individual and decide at the appropriate overview committee if there are any outcomes, trends, gaps identified that require addressing as a department and how they intend doing this.

This is an important stage in closing out the loop of the SAT process to enable assessment of the value of the training provided and identify any gaps in process or personnel to facilitate the continuous improvement of the training. For example, gaps identified in:

— Operator knowledge, experience and practical application of operator fundamentals;
— Plant performance limitations that might reduce plant availability or may not be the optimum design or implementation method for human machine interfaces in the main control room;
— Processes or administration documentation that set the operator up to fail, e.g. missing, incorrect or difficult to understand procedures or processes;
— Simulator performance issues that may have a detrimental effect on the training provided.

Following the SAT process ensures that information gathered during the training is captured and considered in a systematic manner to ensure any lessons learnt during the training are considered for future training improvement.

The decisions and supporting actions to support any changes in the training process are decided upon at the appropriate committee with membership and input provided from all with a vested interest, contributing to the required output of the training. Based on the analysis of the reports, the implementation of any changes should go through the SAT process to identify that the training need is, in fact, still valid.

5.1.3. Managers feedback

The collective performance of NPP personnel should be continually evaluated to identify any gaps, omissions or AFI to their training programmes. Simulator training provides a unique opportunity for NPP managers to observe performance and re-enforce the desired managerial standards of control room personnel in such areas as reactor/plant configuration and control, responding to infrequent, abnormal operations, or any emergency situations which they may encounter and have to react to during an event. This is important to demonstrate high standards regarding reactor and process safety, to all those within the business, to the stakeholders and investors, to the wider nuclear community and to the regulatory bodies and the general public. Thus, NPP managers, particularly those responsible for control room operations, should establish schedules to periodically observe simulator training activities for all shift teams/crews. These observations should be collectively evaluated to identify overall strengths and opportunities for improvement in control room standards and personnel performance. Similarly, this performance should be benchmarked against the operator shift performance observed in the plant MCR to ensure that management standards and expectations are being maintained in a consistent manner in the simulator and control room alike. Simulator instructors should also facilitate and participate in such observations and evaluations.

5.1.4. Performance indicators

Identifying trends in performance to prevent the drift of standards away from the desired performance levels over time, in any part of the NPP business, is typically supported by identifying and monitoring number of KPIs (key performance indicators). The operations world will have number of KPIs identified through different facets of its business, which are constantly under review. The operator performance levels can be based on on these KPIs and hence this can be used to monitor/measure operator training intervention effectiveness, if used correctly. Well-conceived, monitored, measured and acted upon KPIs are a powerful tool to support the prioritizing and directing of resources to aspects of the business that obtain the biggest effect/gain in safety and production regarding time and money spent. Review of performance improvement or degradation using KPIs as one tool, can indicate or predict degraded training programme trends and/or effectiveness before they result in an unwanted event on the actual plant.

The principal challenge is to identify appropriate KPIs, monitor and trend the information provided by them accurately and review the information obtained as to its significance. These indicators should be based upon, and have a visible link to, the organization’s current policies, philosophies and principles, leading to setting the departmental aims, goals and objectives. The relevant departmental manager is then made responsible for resourcing to enable their team/department to act upon these KPIs accordingly.

Detailed operational KPIs could result from safety and/or performance issues highlighted by the NPP looking at occurrences and the underlying causes, such as:

- Technical Specification non-conformances (operations rule breaches at varying levels of significance);
- Number of Planned/controlled reactor shutdowns;

— Number of unplanned reactor shutdowns or trips;
— Safety rules non-conformances;
— Plant configuration and control misalignments, etc.

Some of the short comings and causal factors of the above may lead to training being highlighted as one of the tools to rectifying the problem. This in turn might lead to more specific KPIs to be monitored to see that any adopted training cure is trained upon, measured and has the desired effect on performance.

Examples of interventions leading to operator training specific KPIs, in relation to simulator training, which could influence the above KPIs might include:

— Operator training hours over a set period (operator time on simulator scenarios);
— Review of failures in the operator fundamentals being analysed, measured and assessed in their component parts to see if there are common themes or weaknesses in:

  - Knowledge (operator knowledge related to unit trips);
  - Monitoring;
  - Controlling;
  - Teamwork (human factor related events included);
  - Decision making;

— Periodical Assessment performance/exam results;
— Failures to apply performance tools to the required standard;
— Simulator availability or down time;
— Cancelled training activities.

Continually reviewing and trending these KPI values, amongst any others identified, is seen as good operational practice and is one of the ways NPP can demonstrate their ability to meet compliance conditions to their regulator. The KPIs should include a log of what training observations and coaching activities have been carried out, and by whom, as well as recording and trending plant performance. The idea is to relate plant performance issues, whether it be man or machine, to any lack of or incorrect training issues.

5.2. METHODS

5.2.1. KPI trends

Performance indicators should be trended to identify both positive effects and any negative effects the corrective actions taken have had on performance. Over an extended period of time this trending will highlight and allow the NPP to recognise any degradation in standards of performance in people or plant (FIG. 12). This will allow the NPP to undertake a proactive course of action, when implementing their corrective actions on noticing the early signs of a lowering of performance standards as indicated in the diagram below in the 'threshold for corrective actions window'.

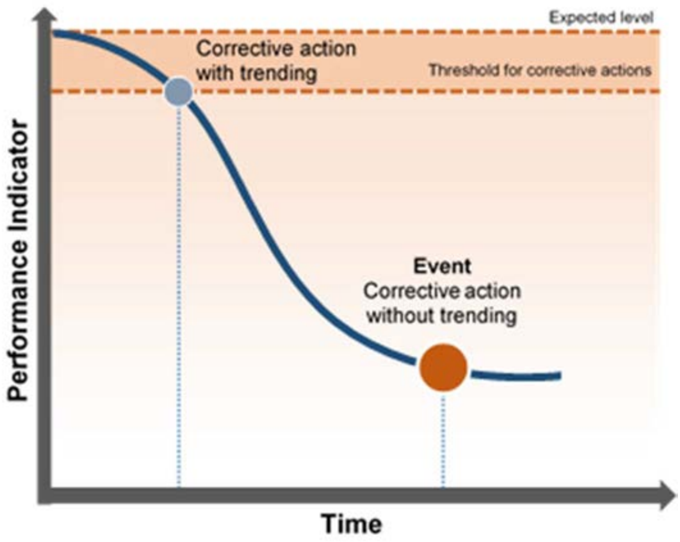

FIG. 12. Example of Performance Indicator used for corrective action with trending.

5.2.2. Regular (periodical) post-training analysis

The purpose of NPP staff training is to improve performance in both Safety and Production throughout the process of generation of electricity. Facilitating training is an expensive outlay for any NPP and every effort is required to ensure that the time and money being invested has and continues to be done so wisely. The various approaches to training evaluation and feedback (levels 1 – 4) are described more in depth within the SAT methodology guidelines [8] (FIG. 13),

Level 1 approaches to training evaluation refer to how satisfying, engaging, and relevant the trainees find the experience. Data obtained show how the students feel about the training but do not tell whether or not the NPP is improving and achieving business and performance objectives.

Level 2 allows for the data to show whether or not the trainees have learned anything. This evaluation is an integral part of most training procedures (e.g. quizzes, final exams).

To see if the trainees reproduce the desired outcome when back from training, to their normal working environment, it requires the NPP to obtain level 3 (behaviour) and level 4 (result) feedback.

A good example of this is the adoption, implementation, and verification of the desired changes in the use of the human performance tools by the staff on NPPs throughout the world in recent times (level 3).

Level 4 evaluation requires the establishing of the links between the training provided and evidence that there has been a measurable improvement in station performance due to these changes. This measurement of improvement is often first highlighted and recorded via the KPIs. The degree that the training contributed towards this improvement might not always be easy to establish as often several contributing factors and groups will have a share of the credit for this improvement.

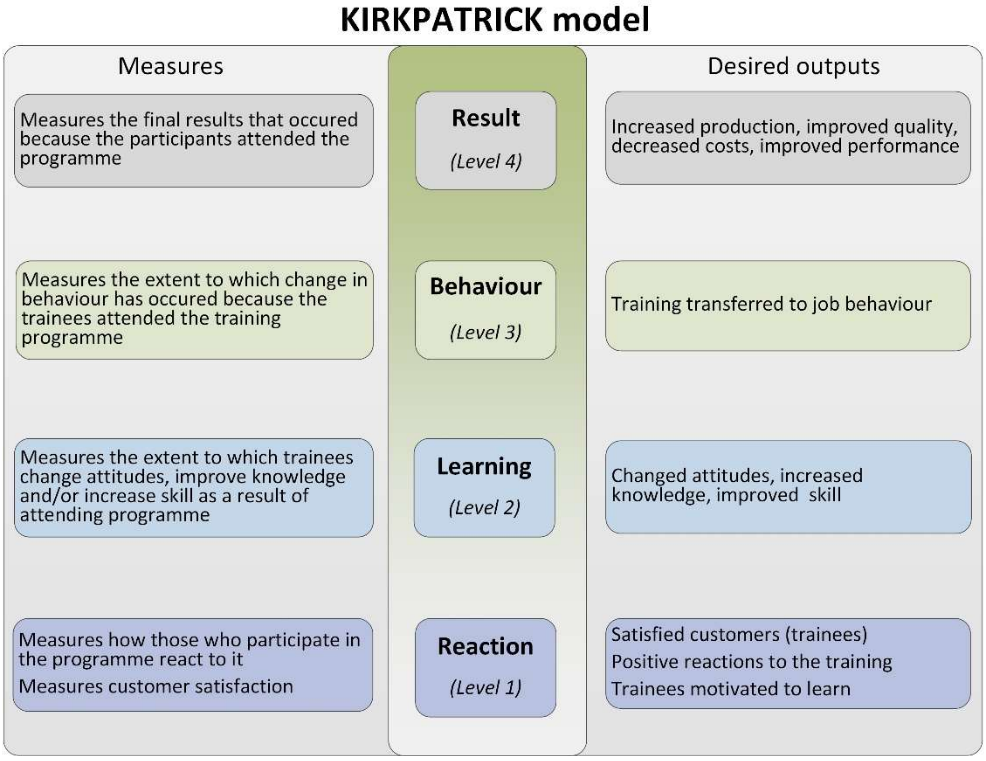

FIG. 13. The different approaches of training evaluation (level 1-4) within the SAT Methodology are well described in Ref. [3].

5.2.3. Benchmarking (results vs expectations)

The purpose of carrying out benchmarking activities is to determine the differences in processes/activities that effect safety and performance between departments, NPP within the same company, NPPs of different organisations and Organisations from outside the nuclear family, e.g. oil and aircraft industries.

The objective is to observe the practices in place, outside and independent of the plant's normal mode of business and then take this information back to the home location and compare it against current practices.

Eventually identified gaps observed during the benchmarking could go forward to the analysis phase to help identify further what improvements needs to be done to achieve the same high-performance level as found during the benchmarking (based on measurements taken against high performance locations operating in line with recognized international standards of performance). These measurements of performance are typically measurements taken at peer locations considered to be amongst the best in the industry.

It is appropriate to apply benchmarking activities as a method for evaluation of training effectiveness on an annual basis internally. External organisations can also be invited to carry out benchmarking visits and peer reviews providing the host station with input and guidance. Information and support are available from organizations dedicated to improving performance and safety, e.g. IAEA, WANO and INPO, etc.

5.2.4. Self-assessment

A self-assessment is usually a more detailed look at a programme and the processes employed in designing, running and administering the training programme. The self-assessment will be carried out within defined limits under a responsible manager and his team regarding the adherence to the defined standards and expectations set by the business.

The self-assessment is set out to ensure that there has not been a drift away from the required standard with the additional aim of identifying any gaps or weaknesses before they can have a detrimental effect. Reactive self-assessments of a training program will occur as a result of training weaknesses being identified in a programme after an event or near miss has been investigated.

5.3. DETERMINATION AND IMPLEMENTATION OF CORRECTIVE ACTIONS

Corrective actions should result as part of the corrective action process, quite often as a result of an investigation after an event or near miss. Recommendations from the actions agreed then need to go through the SAT process to ensure that the action is in fact a training issue. The resulting actions need to be SMART, which is well known acronym used worldwide when giving criteria in setting objectives. SMART stands for;

— **S**pecific – target a specific area for improvement;
— **M**easurable – quantify or at least suggest an indicator of progress;
— **A**ssignable – specify who will do it;
— **R**ealistic – state what results can realistically be achieved, given the available resources;
— **T**ime-specific – specify when the results (goals) can be achieved.

Also, as part of the process defined, criteria are required to facilitate measurement of the results of the intervention to check that the corrective action was successful or not.

6. EXAMINATIONS AND THE LICENSING/AUTHORIZATION PROCESS

Overview of the process and methodology to develop and conduct MCR simulator examinations is outlined in this section.

The requirement to monitor and measure trainee performance and improvement, as the student progresses through the training programme designed for the role, they are to undertake in the MCR, is essential for both the NPP/facility and the Regulating bodies providing governance and oversight.

The training programme must be able to demonstrate that it can consistently deliver individuals to a standard capable of carrying out their MCR duties, to world recognized standards in safety and performance. It is also important for the individuals themselves to be able to recognize their strengths and AFI. This will enable them to target their efforts to correct any areas of weakness identified and prevent these from becoming a stumbling block in their continued progress towards authorization, or later impacting upon their performance in a negative manner whilst carrying out their in-line duties in the MCR once authorised.

The requirement and degree of oversight of the regulatory body, regarding training and authorization, will differ in application from one Member State to another. However, all regulatory bodies will require the NPP to demonstrate and make transparent the processes they have in place to ensure consistency in the training provided, authorization process requirements, and the on-going continuation training plan and re-authorisation practices, implemented to ensure operating standards are being maintained and reviewed for continuous improvement.

The SAT process describes fully how to develop, deliver and measure a training program to ensure the training provided is fit for purpose. By adhering to the process, the NPP makes visible/auditable, to those not involved in the on-site delivery of the training program, the scope of the training being delivered, and the performance levels achieved by those under instruction.

This section is designed to offer guidance when applying the SAT process to the use of simulator training, assessments and final authorization of a candidate, making the whole process transparent and auditable to all those engaged in the governance and oversight of the NPP operation.

By maintaining good performance, including active participation in continuing training, an individual is not subject to formal authorization examinations as often. This can be a positive motivation and reduce stress. The involvement of the operating organization's staff and management in the preparation of examinations helps to improve the quality of the tests and to build confidence in the process. The objectivity of the personnel assessment process is very important to help ensure the added values of the authorization process.

It is important that before assessing personnel in a simulator, they are properly introduced to the testing techniques and examination process to be used and have an opportunity to participate in practice sessions. This will provide an opportunity for self-evaluation and will reduce the stress of subsequent examinations. Sometimes the regulatory bodies get feedback from the NPPs relating to the authorization process for the training programme in order to continually improve the process and specifically the examinations. Feedback mechanisms such as 'operator feedback programmes', 'frequently asked questions', compilations and periodic meetings are some of the methods used to provide feedback.

Improvements to the authorization process includes more and better use of multiple-choice questions in written examinations, improved examination planning and test specifications, improved grading methods (in particular, the improvement of assessment criteria and standards for simulator examinations to reduce their subjectivity), increased emphasis on team skills during simulator re-authorization examinations, development, conducting and grading of the examinations by the NPPs to better assure plant specificity, with granting of an individual's authorization by the regulatory body or, as designated, by the operating organization and improvements to oral examination board questions and grading.

6.1. NPP/FACILITY

It is both costly and time consuming to train and authorize individuals to become MCR operators. The training time required, and expense undertaken make it necessary for the NPP to employ a selection process at the onset of recruitment to try to ensure the correct candidate is chosen. This may include:

- A technical interview;
- A personnel interview involving HR aspects;
- A practical element on the simulator to see how the candidate manages simple tasks, such as communications, alarm management and procedure application, questioning attitude, workload management and prioritization of tasks, etc.;

— Psychological profiling.

The Regulatory body demonstrates, by agreement with the NPP, processes designed, developed, and implemented by a facility as to its own requirements. Some regulatory bodies may also provide guidance documents to help support the development and administration of these processes.

Regulatory oversight can be provided by:

— Auditing administration documentation, training records, course material;
— Observations of training being delivered;
— Regulatory staff attending NPP facility training courses, as part of their own training needs, attending as a participant, this then places them in a position to feed back on the training course effectiveness;
— Observations and questioning of staff when back in line, carrying out their normal duties, to monitor that the training delivered has been effectively transferred back to the workplace.

6.1.1. Administration security and supervision of simulator operator assessments

The regulatory body and the NPP must consider examination confidentiality and the security measures required for its safeguard. The NPP must establish, implement, and maintain procedures to control examination security and integrity for the examinations that they prepare, review and administer.

The regulatory body (via their agreement with the processes defined by the facility), typically requires NPP personnel involved in the preparation, administration and authorization of examinations to be fully aware of their own NPP processes (described in company training standards documentation) and understand their roles and responsibilities for administration and security when enacting out these duties.

Individuals who are directly involved in the simulator training programme are generally not involved with the final assessment decision of the trainee. The simulator instructor may be in attendance to facilitate the running of the scenario but will have discussed and agreed with the student’s line manager that the trainee is now suitable to go forward for an authorization panel. This agreement between the senior instructor and line manager denotes that they are both satisfied with the trainee’s ability to fulfil future MCR roles and responsibilities and prevents them from offering an impartial opinion on any subsequent authorization panel.

The assessment panel now needs to be set up to take an independent, unbiased opinion of the performance they observe for the assessment, and on this performance they will make their decision on the individual’s suitability for authorization and future control room duties.

Examination/assessment security guidelines will be defined in the NPP local SAT process documentation. The security of operator examination papers and simulator assessment scenarios (assessment SEGs) and the content of any final examination/authorisation panel must always be continuously controlled by the training department. Any result/decision from an examination or authorisation panel must also be protected as sensitive information, along with the assessment material.

Any associated training centre, working on behalf of the NPP, must implement security measures for simulator examinations and assessments to ensure security of material is maintained in accordance with the facility training standards and expectations documentation.

Confidentiality and security of simulator assessments can be reviewed under 3 categories:

- Simulator security;
- Personnel security;
- Examiner/assessor independence.

Simulator security includes the physical facility as well as the computer software and hardware used in facilitating an examination or assessment scenario.

Physical security of office locations, where exam material is developed, the simulator area, including instructor stations, operating floor and observer galleries, these all require access to be restricted and monitored closely by the training team. Locked doors with authorized pass access and egress prevents unauthorized personnel from entering un-announced, un-escorted and possibly observing sensitive material or interrupting on-going assessments.

Security measures to consider can include:

- Secured instructor stations; programmer tools in place and any external computer interfaces available to access examination material;
- Controlled access to examination question banks and computer networks used for written examinations;
- Restricting access prevents the ability to over-hear training team conversations during the development of scenarios or discussions on individual's assessment results. Also, the ability to observe control panel set up for an assessment or scenario dry run is prevented;
- Controlled access to prevent deliberate or accidental interruption causing disruption during an exercise, examination administration, execution or development work of a scenario.

Software security must be in place so that only authorized staff has access to examination scenarios and that examination confidentiality is maintained throughout. This can be achieved by such means as software security within the computers or by transferring the scenario files to separate secure locations when not in use.

When simulators are linked, or assessment material is held at a remote site, the same protocols defined in the home facility standard must be applied and maintained at these off-site locations. NPP governance and oversight measures must be taken to ensure that there is no interference with the scenarios from these off-site facilities when administering NPP exams and assessment scenarios.

Personnel security is essential so that only the examination team is aware of the scenario content to be used for an assessment. Each member of the team should be briefed on the need for security and reminded of their roles and responsibilities, as defined in the location training standards documentation. To avoid inadvertent breaches, there should be no discussion of examination content or results outside of the secure areas of the simulator examination office or classroom areas.

The candidates must also be briefed on the need for examination security, especially when there are several candidates, e.g. shift teams who will be tested over a period of days or weeks, as is common when different shift teams are re-authorised on the simulator.

Similarly, information on an individual's performance and examination results should be treated confidentially, in accordance with each Member States' policies on the handling of sensitive information.

Examiners are usually led by a senior manager who is SQEP for the role. This individual will be independent from the day to day MCR operations of the NPP and independent of the

NPP training organization. This will support an impartial overview of any examination, assessment, or panel interview.

6.1.2. Administration of assessment process

This phase of the simulator assessment/examination process includes planning the examination activities, the need to schedule the examination team members, and simulator time required to setup and tests the scenarios prior to running the assessments.

The 2-3 yearly assessments of the shift-teams will be scheduled into the operator training programme as part of the NPP 3-5 year rolling operations training plan. Individual assessments will be programmed in provisionally at the estimated end of the individual's training programme but are constantly under review as the date draws nearer depending on the student's performance.

To ensure effective use of the simulator, initial scenario development and subsequent documentation preparation can be carried out at a secure office location and does not need the use of the simulator facility initially.

The topics for consideration for the operations department assessments will be discussed and agreed at the appropriate training committee with a nominated member of the training team being made responsible, by the committee, to produce the scenarios and present them for approval to the training committee. Other aspects for the training instructor responsible for facilitating the assessment include:

- The final preparation of all documentation; simulator exercise support material as well as the training administration documentation for the course;
- Preparation/photocopying of documents for any examination and its safe storage; photocopying activities of assessment/exam paperwork as well as electronic copies should be carried out in a secure manner to ensure sensitive information does not become revealed to any unauthorized personnel (may require dedicated printer for exam material or a special lockable printer room);
- Briefing all participants as to their role during the exercise. For example, examiners, additional simulator staff supporting the running of the scenario's and individual's role playing in the exercise should be briefed prior to commencing an assessment scenario and candidates briefed on how the process works, as well as initial reactor and plant conditions for the start of the assessment scenario itself;
- The preparation, recording and filing of examination results, as defined by the NPP assessment standards documentation;
- Provision of a secure means of collecting and disposal of assessment material on completion, e.g. exams, SEGs including any drafts and extra document copies made that are no longer required.

6.1.3. Simulator course supervision

The lead tutor for the examination process will need to plan and coordinate availability of the candidate, simulator, assessor, and instructor. The costs attached to the availability and use of these resources requires the instructor to get them all resourced well in advance and ensure that they have completed all the assessment preparations to meet this agreed date.

The lead tutor will be the first point of contact to deal with any conflicts leading up to the assessments or any enquiries after the event, e.g.:

- Scheduling of simulator or staff time;

— Maintenance support of simulator or role-playing members;
— Security breaches of material, etc.;
— Enquiries from senior NPP management, the regulator, etc.

The lead assessor for the simulator assessment should be SQEP and in a position to provide an independent oversight of the whole assessment process, including any panel interview of the trainee as well as the simulator scenario exercise. The lead assessor requirements regarding experience and qualifications will be fully defined in the facility assessment standard but ideally will include:

— Being conversant with the current operator assessment standards being applied at the NPP location;
— Knowing the operational experience in a MCR role and conversant with current operational standards and expectations applied on the simulator to Operations department personnel;
— Experience in observation and debriefing skills;
— A suitable managerial seniority to resolve issues, as they arise, during the scenario, debrief and assessment decision making process; facilitated and supported by the lead simulator instructor.

6.1.4. Assessment scenario development

The development of the SEG assessment/examination scenario is undertaken by the designated exercise lead tutor once the operations training committee has identified and agreed the assessment criteria identified for testing.

A typical operations training committee will have in attendance the senior operations/department manager, an operations shift manager, training manager, lead simulator instructor and an operations MCR operator on the training committee to ensure the main groups responsible for operator performance, standards and expectations are represented and in a position to provide and influence the final input and outcome of line training and performance objectives.

Input to the final decision of the assessment criteria, as well as the training programme can come from several sources including:

— A request from the regulator to the NPP director;
— Request from senior NPP managers, via the Operations Department manager;
— Request from the line management, e.g. Operations department shift managers may have identified something from their line operations or previous revision training or assessments that they require assessing;
— An event, either externally or internally, highlighting a possible AFI action;
— A change in operating practice due to modification of plant and/or procedures or process;
— Standards and expectation competencies improvement, e.g. implementation and review of Conduct of Operations and Operator Fundamentals practices requiring the bar/level to be raised in Human Performance/Human Factors practices, etc.

Once the assessment format, content and criteria has been decided then the responsible tutor will draft the initial outline of the assessments and present to the training committee members to ensure that it will meet their expectations. The responsible tutor will then construct a draft of the SEG for a pilot run.

6.1.5. Format and content of the scenarios, assessment criteria identified and agreed

With a lead tutor identified for producing the assessment SEG, co-ordinating the preparation arrangements and finally facilitating the running of the simulator assessment scenario and debrief process, the next stage is for him to produce a draft scenario SEG document for verification and approval. It is essential that the scenarios be documented as fully as possible. This will provide consistency in the running of the scenario and assessment of the candidates. Once the draft is agreed by the management and the training committee then there are number of tasks to be completed including:

- Scenario to be verified in real time on the simulator;
- Checking the simulator instructor input and actions;
- Checking the simulator fidelity and responses are accurate and as predicted;
- Check role player actions, e.g.:
    - Actions are realistic;
    - Occur at the appropriate times;
    - Provide the required information to the candidate;
    - Have the required results where field operations actions are simulated.

The scenario pilot run with simulator instructors, ensures the expected candidate actions and response options meet the intended aims and objectives for the assessment. This pilot run allows the instructors to familiarize themselves with the running of the exercise, so that they can concentrate fully on performance and facilitate the assessors when the assessment is being run. A pilot run also limits the amount and degree of unexpected occurrences likely to surprise the instructors when running the scenarios. This minimises the complication of having to deal with actions not planned for or practiced which could easily jeopardize the flow of the scenario and final outcome/validity of the assessment process:

- Assessment of candidate performance is managed fairly by ensuring a consistent approach is taken, by defining and implementing the assessment criteria from the appropriate assessment standard;
- Plant management standards and expectations are required to be clearly defined, documented, trained on and assessed when implemented by the assessment team in a consistent manner. To support this an assessment check sheet, designed from the expectations identified in the standards documents, can be developed to support the assessors during their observation and assessment;
- Candidate debriefs should be carried out by trained assessors. Assessors should be briefed by the lead tutor on the contents of the SEG and current standard requirements and expectations, prior to the commencement of the assessment programme;
- On completion of the assessment there should be an exercise debrief and decision with appropriate feedback given to the candidate as soon as possible, capturing the overall decision, strengths observed and any AFI to be addressed. In the case of candidate’s failure, immediate discussion of how this is to be resolved with candidate and line SM. Appropriate security and confidentiality should be maintained throughout.

6.1.6. Simulator exercise guide

A simulator exercise guide is used as the lesson plan for the instructors to run a simulator scenario. An Assessment SEG scenario will, in addition to the training SEG, include information to support the Assessors with their observations and debriefs. Role player actions and responses are also recorded here to ensure accuracy and consistency throughout.

As per any lesson plan, the development of the assessment SEG will need to follow the SAT process throughout its life cycle.

The training department can produce several assessments SEGs over time building a selection of scenarios to be drawn upon, as and when required, and used as the basis for creating any new assessment scenarios.

The SEG will contain a summary statement detailing the major events in the scenario and outlining all the expected major/critical actions to be taken by the candidate.

Other information to be provided in the SEG can include as the following:

- Detail of scenario content; the type of scenario;
- Initial conditions on simulator set up;
- The positions in which the candidate/candidates will be tested;
- Important 'secondary malfunctions' that are scripted to occur, which the candidate must address. This need to be initiated by the instructors at the appropriate time in the exercise.

The SEG will also contain all the information to allow the simulator instructors to run the scenario on the simulator in order to:

- Activate the correct scenarios and establish a secure simulator operating mode;
- Set up the control room panels with the appropriate initial conditions;
- Input the planned malfunctions and equipment conditions, if not already built into the simulator IC (Initiating Condition) as planned during the scenario development or incorporate changes due to previous runs requiring slight adjustments to be made to the scenario and then change, as per Lead examiner/assessors' cues;
- Arrange the end of the scenario outlining the cues for when the assessment team believe all critical actions and objectives have been covered or decide the scenario has reached its logical conclusion.

The assessment documentation must have enough information to allow the assessors to easily record the candidate's performance whilst still being able to observe the trainee's actions including:

- The ability to intervene as needed, through the role players, to provide additional information or direction if the scenario dictates, e.g. due to a minor deviation from the expected path by the operators;
- Define process in place if the scenario prematurely ends, due to an external event, simulator malfunction or a major deviation occurs that invalidates the scenario. Finally, if candidate performance, for whatever reasons, necessitates the cessation of the assessment.

Simulator instructor knowledge of the simulator's specific capabilities, as well as its software and hardware limitations in modelling plant performance, is needed to be able to develop training and examination scenarios that meet the required assessment standards and stretch the student performance levels and assess candidate performance.

In some Member States assessors and not simulator instructors develop simulator assessments and partake in their shift teams assessment debriefs. Line managers senior Operators (CRS/SM upgraders) of shift personnel can fulfil these roles. In this case they may not be trained instructors but are sufficiently experienced from receiving and partaking in debriefs and have received subsequent training and mentoring in observation and feedback skills to carry out these rolls. In all such cases the company defined processes are to be followed under the guidance of the training department with Governance and oversight being provided by the training manager.

Line manager/assessor developed scenarios will be verified by a SQEP and a pilot course is run as per the normal process. Line MCR Operators are typically seconded to the training department to carry out this role for 1-2 years to support their development for future MCR promotion or to support the training department need for current operator experience being involved in Operator training development.

6.1.7. Initial conditions

The SEG will contain a description of the plant initial conditions for the start of the scenario. This information can be passed to the candidate in several ways, e.g. by the instructor carrying out a start of shift handover to the candidate for the position that the candidate is going to be assessed on by the simulator instructor, using a pre-prepared shift log can carry out a brief of current reactor conditions and answer any questions that the candidate may ask on the current plant state, as per a normal MCR handover. Identifying any pre-existing conditions that the SEG requires highlighting to the candidate.

The initial brief might include such information as:

- Reactor power and generator load;
- On-going operations, such as raising power after a long outage;
- Heat sink conditions if the reactor is shut down;
- Control rod or other reactivity management control activities (device status, time and day of occurrence, simulated for the scenario);
- PSCC (Plant Status Configuration Control) equipment out of service or aligned in an unusual manner;
- Maintenance or testing in progress or imminent on the plant;
- Equipment tagged out as a precautionary measure but available for service if required;
- Shift crew and support staff available to assist MCR during the scenario.

Initial plant conditions should be varied between scenarios, and not all plant equipment out of service should have an impact on the scenario. Telephone calls and alarm distractors can be utilized to make the exercises subtlety different on each running, without impacting on the main objectives of the assessment. This will minimize the possibility of inadvertently revealing to the candidate the format of the scenario or the systems they will be tested on during the scenario.

The Candidate Action Checklist (CAC) during the SEG scenario development helps provide a structure for the candidate's expected actions to be documented at the points of the exercise at which they are expected to occur. They can be in an easily referenced, pre-determined format in the SEG, such as a table or checklist. These critical actions can form a part of any assessment pro-forma if one is to be produced and utilized by the assessors to support their observations. Assessment criteria includes such candidate actions and behaviours as described in the 5 Operator fundamentals including:

- Operators monitor plant operations and conditions closely;
- Operators control pant evolutions precisely;
- Operators establish a bias for a conservative approach to plant operations;

— Operators work effectively as a team;
— Operators have a solid understanding (knowledge)of plant design and system inter-relationships.

Under these 5 Operator Fundamentals headings all operator MCR actions and behaviours, such as those listed below, can be assembled to be assessed on an assessment pro-forma.

6.1.7.1. Monitor to include

— Increased frequency of monitoring of key parameters during transients;
— Identify adverse parameter and equipment trends;
— Validate expected system response, accuracy and proper function of indications.

6.1.7.2. Control to include

— Establishing limits to control key parameters within specified bands and rate changes;
— Anticipate automatic trips and equipment protective features, pre-emptively taking manual actions or ensuring an expected automatic trip occurs where appropriate;
— Verify that indications and initial plant conditions are appropriate for the procedure to be used before implementing;
— Operators know the objective of the procedure and the basis for procedure steps before implementing;
— Verify and report automatic system actuations or responses, including operator actions if the plant has not responded as expected.

6.1.7.3. Conservatism to include

— Ensuring equipment required to support effective plant operation is available and operating properly;
— Manage scheduled activities and emergent work to avoid simultaneous evolutions overloading control room staff and hampering plant monitoring;
— Question conditions and situations that are out of the ordinary, un-expected or could erode safety margins;
— Set Conservative bands for critical parameters to ensure safe margins to undesirable states are maintained;
— Establish contingency plans, commensurate with the associated risk, to mitigate/ manage potential adverse consequences during plant evolutions.

6.1.7.4. Teamwork (including leadership and workload management) to include

— Ask questions to gain information and a clear understanding; Question inappropriate actions of other team members;
— Clearly communicate important information on plant conditions, actions taken and present position;
— Resolve conflicts to achieve the best solution and improve team effectiveness;
— Roles and responsibilities identified, accepted and followed through. Supporting other team members when the need arises;
— Be critical of own and team performance to identify performance improvements;
— Team apply diagnostic process to plant abnormality/transient, implement abnormal and emergency plant procedures when required and apply systematic decision-making

processes if normal and/or emergency operating procedures no longer apply or deal fully with the situation;
- Independent oversight maintained on the plant and crew to ensure safety functions and margins are maintained and mitigation strategies implemented by the team are done so effectively (have the desired effect).

6.1.7.5. Knowledge: Solid Understanding to include

- Before operating a component, operators confirm an understanding of its function and its interactions with other components and systems;
- Operators understand the risk associated with plant configuration, including the collective risk of having multiple and/or diverse components out of service;
- Operators have a strong understanding of basic core fundamentals in reactor theory, electrical theory and thermodynamics, etc.;
- Operators apply this knowledge to anticipate expected responses as they operate the plant;
- Operators discuss expected system and parameter changes and their basis during pre-job briefing.

6.1.7.6. Debrief: open questioning techniques

At the end of the assessment scenario the assessors will discuss their observations and benchmark this against the required standard. Actions undertaken by the candidate can be observed during the scenario, the rationale behind decisions made, the student's situational awareness and mental model, will not always be evident from the observation. This can be further explored by using open questioning techniques to allow the candidate to fully explain his thoughts and reasoning behind any course of action taken. With this extra information the assessors can then go away and make a more informed decision on the candidate's performance. Considered open questioning techniques can be used to further explore the candidates understanding on such things as:

- The rationale for taking the expected or an un-expected action during the scenario;
- Check the students understanding of the plant conditions initially and as they evolved throughout the scenario;
- Procedures followed and any further steps/procedures considered to place the plant in a known safe state;
- Explain their understanding of the event or transient where the expected actions were not taken by them;
- Whether the procedures available were adequate in dealing with the situation and what else could they have considered mitigating the effects.

To aid debrief process it can be advantageous to have pre-planned questions prepared in the SEG, associated to each of the defined assessment objectives. The candidates will have been briefed fully as to how the assessment process is applied, during the lead up to their assessment. This process should be adhered to on each occasion by the assessors, with the candidate expecting the formal debrief and questioning, to check their understanding, followed by some time for the assessors to consider/discuss their judgement in private, and the candidate then being called back for the decision.

Following this routine for debrief, the candidates will respond normally and not become defensive because they suspect they may have made an error.

In some cases, questioning may reveal that the simulator assessors may have missed something during their observations, exercise itself may not have acted as expected, indications did not occur as planned or that role players did not provide the required information when requested. This input will be useful to assess the candidates' performance fairly and make amendments to the exercise if required before running it again. In some cases, questioning has revealed that a seemingly strong performance observed from the floor team was in fact not as it seemed. On questioning of the team, it becomes evident that the event had led the team and they were purely responding to what they could see and using the Surveillances/SOIs (station operating instructions) to cope with the situation but their reasoning, situational awareness and decision making were not in fact ahead of the event. They were instead reacting to/led by the transient.

6.1.8. Role player instructions

A detailed role play pro-forma can be prepared and referenced in the SEG to ensure that exercise support staff role players know:

— When to respond to a request from the MCR, e.g. to respond on the phone or enter/leave the control room as required by the scenario?
— The limitations of verbal information to be given to the candidate when requested.
— What simulated field actions are carried out when requested and feedback of plant response to these actions in communications the MCR candidate?

The instructions and information should be identified during scenario development. If the candidate makes unexpected requests, role players should respond as they normally would on the plant, without providing information that the candidate would be expected to determine for themselves. When role players are unsure of their response, they should consult with the Lead Examiner/simulator instructor as appropriate. Role players should be briefed on the objectives of the scenario to support their decision-making process, if they should receive a request for information not considered in the SEG.

6.1.9. Assessment team rehearsals

The complete team, including any additional simulator operators and role players should be brought together for a final rehearsal of the assessment scenarios. This will ensure that each scenario proceeds as planned and that all involved are familiar with their roles. The support staff will need to be briefed on the content of the scenarios and then practice their roles. At the same time the visual and sound recording equipment, as well as the simulator data gathering systems, are tested to ensure they perform as expected:

— Clerical support staff who prepare, copy or handle examination material; simulator technical and maintenance staff, who may be required to resolve simulator hardware or software problems if they should arise, need to be in a position that they can be made available to respond immediately if required;
— Observers who have a defined need to observe the conduct of the examination, other than the examination process team, need to be briefed as to their role and conduct during the process. Arrangements made for their access and egress to ensure they do not interfere with the assessments need to be made;
— Arrangements to exclude all other personnel from the assessment location need to be put in place when assessments are in progress.

In rehearsals the simulator setup and performance are verified, and baseline information can be gathered such as:

- Printouts of alarms received;
- Trends of plant system parameters relevant to the examination scenarios outcome.

This baseline information can be used in the assessment phase to ensure that the plant system parameters responded as expected and may be required as part of debrief process.

6.1.10. Availability of the assessment team

The availability of the examination team members must be confirmed at an early stage of the planning, with a firm commitment to participate understood by all those involved. The schedule for running the scenarios is then planned and agreed with the examination team, support team and candidates notified of their examination schedule and them confirming their ability and agreement to participate, in writing to the assessment lead instructor.

The preparation and conducting of a suite of assessments can be a complex process, involving several key personnel. Delays can be costly and the unexpected absence of an assessor at late notice may jeopardize the schedule or cause an assessment to be cancelled if no back up arrangements have been put in place.

If several assessments are planned, over a defined time frame, e.g. a shift cycle over several weeks, then the assessment team support roles can be covered by number of SQEP personnel, briefed and trained for their role.

By doing this, cover should be available and be more easily arranged, given reasonable notice, to facilitate re-scheduling of the assessor team programme should an assessment team member not be able to attend due to an emergency. Any replacement will require briefing and be fully qualified to carry out the required role, as defined in the assessment standard, and ideally have been involved in earlier rehearsals.

6.1.11. Conducting simulator examinations and grading performance

When conducting assessment scenarios, they should proceed as rehearsed and documented in the SEG the assessment day agenda should proceed by:

- Gathering the examination team together for the pre-job brief to ensure their understanding of their assessment roles, the days agenda, issue copies of SEGs, pro-forma observation documentation, e.g. observation sheet and relevant procedures for the scenario. Whilst the lead tutor is carrying out any briefings the support tutor can be setting up and checking the simulator operation for the first exercise;
- The MCR team brief of the candidate or candidates to be assessed will identify their MCR roles and the plant initial conditions, specific to the assessment scenario; identifying any simulator fidelity issues if pre-existing, or special conditions identified in the exercise guide. MCR team members supporting the exercise will require briefing on the limits of support they are permitted to offer to the assessed candidates during the role play in the exercise;
- Issuing and confirming that candidate sound recording equipment is functioning correctly and visual recording equipment is running and functioning as required. On completion of the MCR team brief and agreement from the students that they are ready to start the assessment. The simulator instructor will then agree with the assessment team that they

are also ready to commence, and the simulator is then set running and the MCR floor team informed that the scenario has now started;

- The assessors will follow the SEG and observe the candidate's actions, noting only the facts observed, recording what was observed (actions), when was it observed and by whom if more than 1 person is being assessed. This is done in short bullet points so as not to interfere with the assessor's observation process capabilities. The observation can be simplified/supported by the assessor employing pro-forma forms incorporating headings of the benchmarking criteria, critical actions, procedure document number use, etc., as a form of check list.

On completion of the assessment scenario the examiners should call a halt to proceedings and freeze the simulator. Assessor discussions should be done away from the candidates, the candidates could be stood down at this point and called back for debrief and result after the assessors have:

- Individually benchmarked their own observations of the candidate's performance, compared against the desired criteria contained in the standards and expectations documentation provided. From this information make their own decision on pass or fail criteria;
- Next the assessors compare their personnel recorded observations and decision with each other assessment and determine if there are any areas of disagreement that clarification is required before making their joint decision. Clarification will be obtained through open questioning of the candidate.

Before calling the candidate back the assessors need to decide:

- Their own roles during debrief process, e.g. who will open and close debrief (usually lead assessor) lead assessor usually having the final say on any minor disagreement between assessors and the non-participating simulator instructor facilitating clarification concerning any scenario exercise issues/detail;
- What the assessor's final decision is, dependant on any clarification questions they may require answering satisfactorily from the candidate;
- Strengths and AFI to be identified and highlighted to the candidate during the feedback of the result or more normally afterwards;
- Clarification questions need to be agreed between the assessors and who is going to lead with what question and any follow up questions required;
- On satisfactory completion of debrief the candidate will be told the result. Reinforcing strengths and clarifying any minor examination team concerns, not significant enough to fail the student. These may have been raised by the assessment team as AFI to be worked on after discussion with the candidate and line/shift manager.

In the case of an un-satisfactory result the assessment team need to identify the areas of concern and discuss any required remedial training with the line manager and simulator instructors and on satisfactory completion of this the candidate will be required to re-take the assessment using a different scenario but ensuring the AFI noted on the first assessment are re-tested on the follow up assessment.

On completion of the assessment scenario the simulator instructors, operators and role players can proceed to set up the simulator for the next scenario. All material, that has been marked up by the student has to be gathered up and cleaned or replaced for the next exercise. Including:

— Assessor notes, simulator computer printouts, charts, trends, visual and sound recordings, to be wiped post debrief if used; in the case of simulators using chart recorders, the chart should be marked with the candidate's name and scenario, then advanced to fresh paper for the next candidate; ensure the material is clearly marked with the candidate's name and stored securely if required to be retained.

During the assessment, simulator performance is partly monitored as a result of how well the scenario ran. A quick discussion between the team, to capture any simulator abnormalities at the end of the assessment, will highlight if any essential changes are required to the scenario. This should only be done if necessary, to ensure that all candidates are treated equally, by using the same scenario, any changes made in an ad-hoc manner are no longer undertaken as part of the assessed scenario development process, perhaps introducing their own unique problems, e.g.:

— Unexpected response of the simulator to the change;
— The change not having the desired effect on the scenario (not piloted/tested);
— Unexpected but proper candidate response, away from the intended assessment criteria.

A process to deal with the premature termination of an assessment scenario must be included in the NPP assessment standard.

Premature termination of an assessment scenario may be necessary due to several circumstances, e.g.:

— A simulator malfunction occurs, which is observable by the candidate and/or the simulator assessment team, which causes the scenario to deviate from the expected/ normal plant response, such that the planned scenario is no longer reliable to assess and record the performance of the candidate against;
— The simulator freezes;
— A member of the support team must leave the simulator, and this member's absence jeopardizes the conduct of the scenario (as defined in the assessment standard document) or questions the reliability of the assessment of the candidate;
— The candidate must leave the simulator for any reason;
— Site musters due to an emergency or incident.

If such an event should occur, the simulator should be frozen; if the simulator is not at fault, and the candidate escorted from the simulator and kept in seclusion until the situation is resolved. The examiners will determine if the scenario can be fairly restarted or if it must be ended at that point and a new assessment arranged. If the scenario is to be resumed, it must commence in a reasonable time frame and the candidate must agree that that they are happy to continue and be given time to settle in and collect their thoughts before re-commencing.

6.1.12. Grading – individuals

Member States can approach grading and assessment in number of ways, but it is a good practice to provide students with feedback immediately, if not very soon after completion of a simulator assessment and debrief, on their performance and result. Feedback is most effective if provided as soon as possible, whilst it remains fresh in the student's mind and this allows both student and instructor to easily recall what happened during debrief discussions.

6.1.13. Initial training examinations and assessments

The student training programme will include number of assessment techniques, as the student progresses through a lengthy training programme, being tested periodically along the way with:

- Classroom theory and written examinations on each stage of fundamental theory, plant, legislation training, etc.;
- Simulator training on fundamental simulation exercises followed by normal, routine and emergency scenario operations training on the site-specific full scope simulator, with assessment/debrief panels or classroom assessments to examine scenario understanding afterwards;
- End of training final classroom examination on all topics studied, followed by an independent Authorization panel and Authorisation scenario assessment exercise;
- Re-authorizations of in-line operators (nominally every 1-3 years).

If the Member State includes a theory examination, followed by a simulator assessment and authorization panel as part of re-authorisation, it may be worth considering the examination and authorization panels being held prior to the simulator assessment. Allowing outcome of re-authorisation to be fed back immediately after simulator debrief (theory & panel pass as a condition/requirement before being put forward for the simulator assessment).

The common method for NPP re-authorisations is to run specially prepared Assessment scenarios containing an element of normal operations, followed by a routine operation, leading on to an event scenario. This runs as near as possible to normal/real time and can typically run for 1.5–2.5 hours to examine all the Operator Fundamentals, as defined previously. This is followed by a comprehensive self-critiquing and questioning debrief by the assessors of the individual or team as this type of assessment can be used to examine individual and team performance simultaneously if facilitated correctly.

Candidate grading will proceed once all the examination and assessment scenarios have been completed.

Member states manage this in number of ways according to custom, facility and Regulator requirements.

Leading up to the review of this document, a survey was undertaken of the IAEA Member States titled (see Appendix).

6.2. ASSESSMENT OF CANDIDATE PERFORMANCE

To assess operator competencies during a simulator scenario, the assessors/examiners need to observe and note the facts, actions performed, verbal statements made between the candidates/MCR team and role players. Noting instruments observed, procedures being followed information requested from each other and role players. ANNEX VI demonstrates an example of personal evaluation for FSS.

The detailed candidate performance requirements should be described by the licensee or the regulatory agencies in such documents as:

- Job and Task Analyses (link from analysis to SEG objective and training implementation and examination, visible through adhering to and recording/documenting the SAT process during course design and development);

— Training aims and objectives defined in course material;
— Licensee documentation that specifies staff operating roles and responsibilities during normal day to day operation as well as during plant transients and emergencies.

6.2.1. MCR operator performance assessments

The NPP assessment criteria for the training and qualification of their operators will be defined and captured in the Facility Standards and Expectations documentation. The outline for this will be agreed by the facility (some Member States, this may require defining or approving by their regulator) and implemented by the NPP in their training and assessments, within these defined boundaries.

Evaluation of candidates during simulator assessments will be carried out to these defined assessment criteria. Documenting the criteria will help to ensure that standards of performance are applied to the competencies identified in a consistent manner throughout the Utilities NPPs.

The assessment criteria are designed to reflect the performance, behaviours and skills, supported by the knowledge required to perform the Operators day to day MCR position duties. This includes the fundamentals of:

— Operators monitor plant operations and conditions closely;
— Operators control plant evolutions precisely;
— Operators establish a bias for a conservative approach to plant operations;
— Operators work effectively as a team;
— Operators have a solid understanding (knowledge) of plant design and system inter-relationships.

These Operator Fundamentals are relevant to all the MCR roles being evaluated. Common skills, such as procedure compliance, panel monitoring, effective communication, diagnostic and decision-making skills, teamwork, etc.

The CRS and SM (Shift Manager) roles will include some higher levels of performance assessment, testing their experience and skills in supervisory, oversight, diagnostic and decision-making capabilities for their roles, e.g. emergency scheme management outside of daytime working hours.

Pre-defined and documented assessment/examination criteria, as agreed by the licensee and/or Regulatory Body, should be in place. Common practices that support consistent and improving performance levels, through continuous review of present practices and levels attained and comparison/benchmarking with other facilities and world best practices, include:

— Written observations of candidate performance, supported by pro-forma check sheets and/or procedural practices, e.g. SEGs;
— Visual and audio recording of candidate performance and key team support actions (some Member States recording performance is not agreed/permitted);
— Candidate’s log entries, procedural adherence tracking and written notes;
— Simulator recording of plant parameters, trends and alarms received and accepted;
— Simulator/computer records of candidate panel operations (switching and control selections) and simulator operator actions.

With this information, candidates can be assessed on the specific actions and behaviours required by the examination SEG scenarios aims and objectives, e.g.:

- Observed actions carried out correctly, such as selecting, following and adhering to the correct procedures during the scenario;
- Recognition of situations where equipment faults place the plant in a situation of decreasing safety margins or not covered by normal/fault operating procedures;
- Prioritizing actions when multiple faults occur;
- Correct diagnosis of faults and timely execution of required actions;
- Clear and concise communications; requesting procedural deviations where required;
- For supervisory staff; management and oversight of control room and plant resources.

The assessment criteria can be sub-divided to account for different levels of performance, requiring appropriate remedial actions to be in place to address each of these categories.

It is common to grade performance at many NPP as either Satisfactory or Unsatisfactory when benchmarked against the required standards and expectations.

Either side of this pass line there may be levels of performance which are then utilized during debrief to identify Strengths to be re-enforced by the training and assessment teams or AFI that may require addressing under the supervision of the line manager, not causing any impedance to continued line activities for the operator. Or some identified remedial action, which may require some additional training or mentoring and may place limitations online duties.

In addition to this there may be identified critical actions in the assessment scenario. The omission/failure to carry out these actions correctly constitutes a failure and remedial training and assessment prior to commencing MCR duties.

Critical errors are nominally errors that jeopardize plant safety in one form or another. These critical errors are errors that the candidate makes by carrying out an incorrect action or a lack of any remedial action. They can be categorized in number of ways and will need defining in the NPP assessment standard and identified, periodically trained, assessed and recorded on the individual operators training program. A two-level critical assessment system is given below.

6.2.2. Simulator Critical Action

Simulator Critical Action is a significant operator or team action which must be completed correctly during the simulator assessment scenario. Unsatisfactory completion of critical tasks will result in automatic failure during assessments or significant remedial actions during non-assessed scenarios.

An error/improper action, or inaction, that has a serious immediate impact or is a potential threat to plant or public safety, e.g.:

- Non-compliance with Operating Rule/Technical Specification safety limits;
- Not maintaining control of reactor core cooling;
- Failing to take the required actions when it is a procedural requirement, e.g. failure to trip the reactor on a Technical Specification requirement to do so;
- Failure to take timely action on failure of the reactor safety system;
- Taking a deliberate action that results in a violation of the designed plant safety parameters, e.g. violates Technical Specification parameters for reactor power, fuel cooling, etc.;
- Action/inaction as specified in the SEG.

6.2.3. Simulator Safety Significant Action

Simulator Safety Significant Action is a significant operator or team action which must be completed correctly during the simulator training scenario. Un-satisfactory completion of safety significant tasks will require a follow up Shift Manager Action Plan to prevent re-occurrence. An action or inaction may have a potential impact on plant and/or public safety. Depending on the circumstances and the NPP categorization of safety significant actions, two or more of these errors could warrant the automatic failure of a candidate.

Examples of Safety Significant Actions could include:

- Incorrect fault diagnosis leading to poor decision making;
- Incorrect Operation of controls or plant equipment;
- Inappropriate/lack of control room supervision and/or overview;
- In-correct prioritization of actions concerning Public, Personnel, Plant, Environment and Security, e.g. placing staff in a dangerous situation that could seriously affect health or safety;
- Action causing a reduction in effectiveness of a safety system, or not recognizing the reduction in effectiveness of a safety system;
- Not taking timely and proper action to prevent the degradation of plant safety system margins.

6.2.4. Grading – group results and programme deficiencies

An inappropriate action, taken by an operator, may occur with different candidates over several occasions, using the same scenario. On reviewing the assessment scenarios, procedures used, and previous training provided there may be a common mode of operator failure or inconsistency responsible for causing several candidates or shifts to make similar mistakes.

This could be the result of:

- Problems with the training provided on this topic/scenario recently or in the past;
- Problems with the scenario logic itself, leading operators to make the error, may require human factors investigations to resolve;
- Lack of or short comings in the process to deal with the situation being encountered or flaw in the methodology behind the coping strategy in place;
- Inaccuracies in procedures or administration, e.g. logging and PSCC. Once discovered this information should be provided as feedback to the plant operating organization and the procedures corrected via the appropriate process;
- In this case, the reason behind the common mode failure, if in fact that is what it is, will need to be fully explored and once resolved training may be desired to correct the problem.

6.3. REQUIREMENTS FOR DOCUMENTING AND RECORDING THE PROCESS

6.3.1. Examination results

Documenting the results of assessments/examinations is to ensure:

— That the candidate's training and authorizations are auditable and can be reviewed to ensure the candidate is SQEP and up to date/compliant in all aspects of the post profile defined for them to carry out the duties assigned to them;
— That training is undertaken and when completed and the result;
— The reasons for failure of a candidate's remedial training, and those remedial training details will be documented with the results.

6.3.2. Post-examination activities

Using the candidates' results and course/assessment feedback documentation, assessment follow-up activities will include:

— Verbal and written recommendation that the candidate has met the simulator assessment/examination requirements for authorization to the nominated position assessed for;
— If the candidate failed or requires some remediation to complete the assessment process then the candidate and line manager will be informed and verbal agreement will be reached on the appropriate remedial actions required to fulfil the authorization process, according to the location assessment standard defined in location documentation. This can include the need for further simulator training/examination(s) and simulator assessment depending on the candidate's original results. Additional training can be focused on the areas of the deficiencies identified, whilst any final simulator assessment will be required to run in the same manner as the original, testing all areas of the fundamentals including the failure topic from the earlier assessment;
— On a candidate receiving a failure grade during initial training, a decision needs to be made on whether the candidate should return, or not, to the training programme, this decision is dependent on the NPP/Member State practices. Generally, a candidate that continually performs badly on several occasions will be referred for re-assessment as to suitability for the role. All programs will have a remediation process for singular 1 off events;
— Provide feedback to the Operations line/licensee on any lessons learnt, such as procedures or documentation that requires amendment or improvement. Report as per the NPP reporting process and ensure ownership of the problem is assigned with appropriate follow up and correction;
— Identify simulator shortcomings that need to be rectified, as a result of operator feedback, report this as required by the NPP process in place and ensure ownership and follow up;
— Where Member States frequently authorize a lot of staff during a short time, e.g. shift re-authorisations over several weeks, an analysis can be done of pass/fail and remediation rates and the reasons for them. This can monitor for common mode problems across the shifts and NPP locations. It also allows the site to ensure that the testing of the operators they are providing is stretching the operators sufficiently to increase their proficiency in all the Operator fundamentals, continuously raising the bar/standard of training and assessments over time. Remediation in this case does not need to be seen as poor performance, rather as a gap identified that requires correction as part of the improvement process. An NPP that has no remediation needs to ask itself, are we training and testing our operators sufficiently hard enough to equip them to manage an incident or event if faced with one.

Follow-up activities, not focused on the candidate will include:

- Filing the scenario documentation for future reference and/or make the documents available to the licensee and other authorized parties, as per the facility/Member State practices;
- Writing a course report and feeding this back to the relevant Operations training committee along with recommendations.

6.4. TRAINING OF SIMULATOR ASSESSORS

Once an assessor (with no previous assessor experience) has been selected a degree of training and mentoring is required, to ensure that they are competent and SQEP (Suitably Qualified and Experienced) to fulfil the role.

The Assessor is required to be SQEP in the role they are to perform for the assessment panel, when observing and assessing individual candidates or teams when meeting the expected operator competency standards.

To work effectively as a part of the assessment team the new assessor should be familiar with the assessment standard and assessment protocol. To gain insight to this it is suggested that the new assessor observes, without taking part, assessment scenarios, initially carrying out observations and being critiqued on these observation notes by his appointed mentor and guided in the current operation standards and expectations documentation (often termed Conduct of Operations).

Next the new assessor could take part in an assessment, being given the less demanding parts of the assessment to debrief and then build on this as they progress and grow in confidence and experience. It is recommended that new assessors partake in individual initial authorisations before supporting established team debriefs as the techniques are subtlety different and successful management when debriefing established teams comes with experience.

New assessors, who may have previous experience in this role at another NPP or outside of the industry, still need to be familiarized with the NPP assessor standards and assessment protocol along with the Conduct of Operations standards employed at the current location. It is good practice to have them observe assessments without taking part initially. If it is not done from the beginning, the danger may be that they apply their own standards and expectations which may not be suitable for the current location.

It is also a good practice to brief external/independent organisations or individuals, e.g. peer review teams or benchmarking audits, on current practices and standards at the location; before they carry out their observations in the simulator. In this way the observers can offer feedback on any Strengths or AFI they see in the present standards documentation. On observing the crews in the simulator, benchmark them on the current standard the crews/teams have been trained against, highlighting the process weaknesses noted from the documentation review to the NPP management in their final report. These perceived low operator standards, reflected during floor activities, were in fact due to the omissions previously noted from the trained standard, rather than being actual operator deficiencies which now need follow up and improvement in the standard document and during training.

Ideally the assessor will have operational experience, but it is not always necessary to come from an operations background to support an assessment debrief.

Some Member States train individuals in Technical knowledge and Operator Standards up to the standard they are to teach. Other individuals will be called upon to support their area of expertise in such areas when assessing:

— Human performance and/or human factors;
— Reactor physics/kinetics;
— Emergency scheme arrangements CRS or SM assessment in particular;
— Maintenance support capabilities.

It is important that specialist area individuals, as part of their assessor duties, know the limits of their debrief duties and have them de-fined at the initial course/assessment assessor brief, Like wise any visitor joining an assessment to observe, they will be instructed to comment on their area of expertise if/when requested by the lead assessor.

Plant operation experience and technical knowledge will be required by a panel member to lead this aspect of debrief and is often led by a current shift manager and on some Member States the lead simulator tutor can support this if requested, in his role as facilitator. Lead assessors would normally but not always be expected to have operational experience, but it may be from another plant, this may restrict their higher-level technical capabilities on site specific plant issues but debrief questioning skills and suitable line support will correct this limitation.

Training of assessors will typically address the following areas:

— Observation and diagnostic skills training for evaluating;
— Human Factors and Human Performance training for the MCR;
— Identifying the areas of weakness and strengths to support the assessment decision and evaluate, in an objective, un-biased manner;
— Interviewing and open questioning techniques training to encourage candidates to self-critique scenarios;
— Knowledge and understanding of the applicable standards and expectations being employed during the assessment;
— Knowledge and understanding of observation practices and the procedures employed when carrying out assessment observations on candidate performance;
— Relating observations to evaluation criteria, when evaluating student performance scores on the assessment;
— Trained in teamwork dynamics to be able to assess team skills within MCR crew performance;
— Trained in CRM skills to understand and assess their effects on individual and team performance.

At Member States where regulatory organization staff are involved in the assessment of simulator examinations, the competencies and skills described above are required, as well as other applicable competencies, such as knowledge of the legal basis and regulatory processes applicable to control room staff, e.g. the authorization and responsibilities of the nominated MCR roles.

7. SPECIALIZED TRAINING

Outside of the agreed 3-5-year plan for MCR operator training, periodically there becomes a requirement to develop and undertake training to meet an identified, immediate/urgent need, which takes priority over current simulator activities.

This training may be required as a result of several occurrences. Examples of which include:

— A modification to plant and/or limit, which constitute an Operations Rule (Technical Specifications) change and possibly a different running regime required, e.g. plant reconfiguration that the operators may require familiarization training on (simulator and classroom training to be scheduled);
— An unforeseen plant failure that the operators have controlled but before carrying out operations to return to nominal full load require a run-through of identified options, develop a procedure and rehearse their roles, responsibilities and actions on the simulator to ensure the optimum course of action has been; chosen, followed, practiced and validated; prior to any actual control room operations being agreed and undertaken;
— Investigation into a plant event (post event) required by the investigating team to re-enact the event, with the purpose of diagnosing what may have occurred on the plant leading up to, during and post event;
— Make up training as a result of a gap being identified in operator knowledge, skill or behaviours that requires addressing in an urgent manner. May be as a result of recent internal or international OPEX or be an improvement action placed on a facility by their own regulator.

Even though this training is usually of high importance and hence high priority, with perhaps a considerable amount of pressure being applied on the operations department for a quick resolution to the problem, these times above all others it becomes necessary for the Operations Training Department and the Operations Line Organisation to work together, applying CDM principles with the decisions and actions they undertake throughout the process.

Ensuring the SAT process is followed in regard to the analysis, design, development and implementation of the training to be provided, along with adoption of CDM principles, will justify the proposal/recommendations presented to the management for final approval, and will provide a viable course of action, along with an alternative, if required as a backup plan.

It is important that a review is made at a suitable managerial level to have oversight of the proposed solutions being provided. This could be via the appropriate operations training committee and Responsible Manager for the event and agreed by the facility Safety Review Committee. An independent safety review being required if there are Safety/Reactivity management issues to be considered when deciding if the option chosen is fit for purpose (Nuclear Safety) before being implemented in the MCR.

There are a number of decision making processes to follow to control the management of these types of occurrences and the implementation of simulator training may be the result of on-going investigations to an event under an 'Operational Decision Making' process, which in itself may encompass other formal processes, e.g. troubleshooting, risk of trip, or be training required due to:

— IPTE - start up after an extended shutdown, shift that has not encountered a task in the past, a non-routine evolution taking place (circuit or pump in or out of service);
— JIT – training typically provided on request by plant operators on an operation that will happen soon, that they are not familiar with or have not carried out for a considerable time. For example, a shift could request to practice the plant start up process just before starting up after an extended outage. Other applications would be preparations for infrequently performed task evolutions, equipment tests, out of the norm or complicated plant manoeuvres;
— Plant failure that requires investigation as to what occurred and immediate remedial actions;

— Emergency response exercise training has been built into most Member States operations training curriculums for several years. Post Fukushima a worldwide review was carried out regarding emergency response training which resulted in some training being provided prior to the full reviews being completed, to meet immediate operational needs.

As highlighted in earlier sections, it is necessary to build into the training exercises: SEGs the use of Operator Fundamentals, HU tools, CDM/teamwork. During these infrequent, out of the norm operations, these practices need to be heightened during design, delivery and implementation of the action plan, to ensure that when required, those tools of relevance to the plant operation about to be carried out are fresh in the operator's minds.

It is important, post specialized training delivery, to not forget the training that made way for this high priority training requirement. This cancelled scheduled training now needs to be assessed as to its importance and prioritized in the on-going plan, this may require a substantial re-organization of the existing training plan. It could prove to be very embarrassing for the NPP if the cancelled training was itself mandatory and became lost from the plan due to a loss of oversight of the training program and resulted in operators' authorizations lapsing.

8. MAINTAINING AND UPGRADING SIMULATORS

8.1. MAINTAINING EXISTING SIMULATORS

As soon as the simulator is declared as RFT (Ready for Training) the responsibility for maintaining the simulator in good technical condition and compliant with the prototype power unit is transferred from the vendor to customer. Maintenance activities on the simulator can be divided into three main parts:

— Regular (routine) maintenance for hardware and software updates, in accordance with the maintenance manuals provided by the simulator vendor or the manufacturers of the various industrial generic components (e.g. computers, power supply units, measurement devices like meters, recorders, etc.);
— Elimination of defects in hardware and/or software;
— Implementation of small changes in hardware and software, following relevant changes at the power unit prototype and deficiencies or discrepancies found during use of the simulator.

These activities, especially, the second and third, should be supported by an effective Configuration Management System/process to co-ordinate and control any changes, otherwise the simulator technical support group will lose control over simulator updates. Repairs, fidelity, etc., and further implementation of changes could negatively affect the simulator model fidelity and reliability as well as simulator hardware availability. An efficient and transparent work management system allows the instructors to have an up to date understanding of the current state of the simulator in regard to recently implemented changes and currently known deficiencies in the simulator as well as recording issues immediately when they are found.

8.1.1. Configuration management system

Simulator configuration commonly refers to simulator hardware and software configuration. In some facilities training scenarios, this is also considered part of the Simulator

Configuration Management System/process. This section does not include training materials configuration management as training material SEGs, etc., are considered in the administration section.

8.1.1.1. Hardware configuration management

Hardware configuration refers to the installed hardware of the simulator. Management of the hardware configuration mainly includes maintaining up to date the following:

- Hardware specification;
- Hardware layout and connection documentation (wire list);
- I/O database;
- Operation and maintenance manuals;
- Hardware defects log;
- Hardware testing reports;
- Spare part inventory and external support/service contract information;
- Hardware third party documentation;
- Life cycle assessment with a roadmap planning ahead the future of the platform (longevity and development options).

8.1.2. Plant data configuration management

One of the requirements for a full scope simulator is to have the maximum fidelity of the prototype power unit. The fidelity should be realized when designing and building a simulator and maintained throughout the full lifecycle of the simulator in two aspects:

- Visual, audible and haptic fidelity of equipment and appearance/layout of the MCR Trainer (control panels, desks, lights, communication means, etc.);
- Scope and realistic response of simulated technological systems and equipment.

The basis for the development of the new simulator, and subsequent maintenance of its fidelity to the NPP power unit-prototype, is the corresponding sets of plant design and operational documentation. Given the complexity and scale of nuclear power plants, working with the plant documentation relevant for the simulator design and manufacture is a difficult task:

- A lot of documents;
- Documents of different types; different manufacturers, source countries, etc.:
- Documents presented in various forms and formats (paper, electronic, etc.);
- Current versions of documents are not always available (especially design documents in paper form);
- Documents have often been updated, an analysis of the contents of these changes and their applicability for the simulator is also then necessary;
- Maintaining links and references between what is implemented on the simulator and the reference document and revision for the implementation throughout the lifetime of the simulator.

All items mentioned above, justify the need to implement an integrated configuration management system for all simulator documents (FIG. 14). It is recommended that such a system be introduced at the design stage and maintained throughout the lifecycle of the simulator. The simulator document management system should either be fully integrated with the station document management system or be able to integrate controlled station document versions and import new/updated versions of station documents to ensure there is no discrepancy between the station and simulator databases. This will ensure simulator personnel do not to miss any changes in the configuration of the power unit-prototype during construction and modify the simulator design and build at an appropriate time. Automated alerts for document updates can help detecting changes and connecting them to plant or simulator change orders and versioning the simulator configurations implemented.

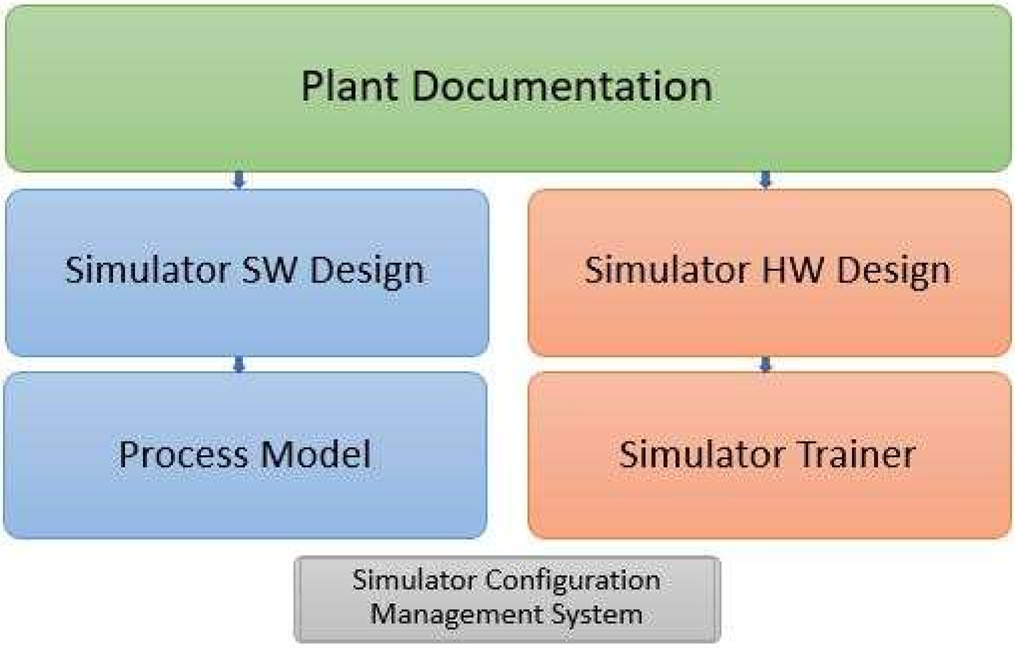

FIG. 14. How to implement an integrated configuration management system for all simulator documents.

Leading developers of simulators use automated configuration management systems during the development phase and include the appropriate software in the scope of delivery of simulators for subsequent use by the End Users of simulators.

8.1.3. Periodical testing

Like every complex engineering product, the simulator must undergo periodic non-regression testing to ensure that its functionality/fidelity does not degrade over time. Testing the simulator hardware should not be particularly difficult and when planned properly, does not take much time. It can be carried out at any time, as identified and programmed in the simulator usage plan. There are standard simulator functions, such as the DORT (Daily Operational Readiness Test), which allows to test I/O system and panel equipment in a few minutes. Care should be taken to prepare meaningful automated tests for different types of equipment, such as synchro scopes, counters and other more complex equipment than single channel analogue or digital indicators. Computer equipment can be tested by standard utilities provided by the manufacturer or by means of the operating system. Automated alarm generation and collection of logs and diagnostic information to an external or dedicated facility should be considered to alert for detection of possible developing problems (loss of redundant components, early degradation warnings) and post-analysis of failures after total loss of equipment.

If no modifications have been made to the software, then the probability of degradation of the mathematical model is extremely low. However, it is impossible to realize such a scenario of simulator operation in actual practice:

- In the course of preparing and conducting exercises on the simulator, problems are identified that require correction of the model;
- Modifications are made at the prototype power unit, which must be considered on the simulator, which often require modifications of the simulator model;
- Changes in training programs require the development of new training scenarios, and sometimes even extension of the scope of modelling systems and processes. Findings are very typical when new scenarios are developed, and simulator engineers should be present or immediately available during new scenario development to record and analyse findings during new scenario preparation and validation. Effective simulator change and version management allows fast 'hot fix' changes during training exercise preparation activities, the changes should also be passed to the normal simulator change management routine for evaluation of the change is deemed to be a temporary implementation for just that training period or made permanent and properly documented and carefully tested implementation ensuring proper documentation and thoughtful implementation for the change.

Usually, every change in the model is carefully checked before it is introduced, but it is practically impossible to perform the full set of simulator tests after each change in the model. Individual changes should be packaged together for testing and releasing as new configurations together in reasonably sized small projects, perhaps once or twice per year typically. Testing records should always indicate what changes the test covers and which exact version of the simulator configuration it applies to and was performed on.

Over time, the number of model modifications increases, which can lead to unpredictable cumulative effects. Operational experience shows that the following negative effects are possible due to the massive changes in the mathematical model:

- The model becomes unstable in some modes;
- The model cannot maintain real time execution;
- Modifications in some systems have a negative effect on other neighbouring systems;
- Modifications work properly in the scenarios tested and considered but cause problems or improper behaviour in other scenarios not considered during testing;
- Incomplete knowledge of changes by the simulator users may cause wrongful use or expectations of simulator response (workarounds or avoidance of known previous deficiencies which have already been corrected for example).

In order to ensure the reliability of the simulator, many training centres use a periodic testing procedure (non-regression tests). Tests include the execution of a set of scenarios of normal operation, malfunctions, and accidents in fully automatic mode. The actions of the operator in the course of the scenario are either absent or are set automatically through a fixed script. This is necessary to exclude the influence of the human factors/inaccuracies on the dynamics of the processes being simulated. Thus, the trends of the key parameters when performing standard scenarios can be compared with previous tests, which allow one to draw conclusions about the absence or presence of model degradation. ANNEX VII shows example of non-regression tests for Boiling Water Reactors (BWR) and ANNEX VIII demonstrate example for Pressurized Water Reactors (PWR).

Modern software simulators allow full automatization of periodic testing, including comparison of trends and generation of the report in a user-defined format. Automation allows running tests at a time when the simulator is not used for training, for example, at night or on weekends. This is important for multi-unit stations, where the simulator serves several power units and is almost always occupied for training. Automatic pass/fail evaluation of tests saves on precious human resources reviewing the test results and reduces human error in the review.

Since the simulator model is constantly improving, there may be differences between the trends of the previous testing and the current testing. Such differences should be analysed and accepted by subject matter experts. When establishing these results as the new baseline for reference behaviour, care has to be taken in picking baseline data and reviewing the history of previous performance not to introduce creeping errors in results where small individual changes cumulate over time, and cause unnoticed drift in some parameters if only compared to the previous data.

8.2. SIMULATOR UPGRADE PROJECTS

Full-scope simulators have been utilized in many Member States to train control room operating personnel for the past 30+ years. During this time there have been significant changes in requirements for personnel training (scope and fidelity of process models and training scenarios), simulator equipment and software becomes aged, compromising the availability of the simulator for training. Many issues in maintaining simulator fidelity and keeping them up to date can be resolved by the customer's own simulator support team (using existing hardware and software tools). Significant upgrades of simulator hardware and/or software may be needed to fulfil new requirements for personnel training and ensure high levels of simulator availability. In such a case the realization for the need of a deeper upgrade project, with involvement of a simulator Vendor is now a common practice. Continuing increases in computing power and capability and of software development tools has led to decreasing the cost of simulator upgrade work and provided the possibility to use simulator engineering-grade models of plant systems, object-oriented simulation software modelling environments, and graphic-based simulator instructor stations. Despite all these advances the actual realization of a simulator deep upgrade project is a big challenge for both: customer and vendor. Especially the combination of a very wide scope of simulation, partly due to technical modelling capabilities and partly the high level of instrumentation and information systems on NPPs, and partly due to engineering grade models replicating accurately new forms of phenomena and behaviour previously attainable, the requirements for reference data have grown significantly in amount, complexity and coverage. This also greatly expands the complexity, amount and contents of V&V testing the changes and evaluating the very detailed test results by various subject matter experts.

8.2.1. Establishing the need for a simulator upgrade

Modernization of the simulator is a complex project, requiring significant expenditures of finance, human resources, and time. In addition, the simulator may be unavailable for training for a considerable amount of time to implement the changes and conduct debugging work on completion. Therefore, in order to start such a project, training organization need to fully understand the significance and justify the reasoning before starting such an undertaking:

— *Training needs* - the simulator requires upgrading to support additional training needs as identified through the implementation of the training programme;

— *New training requirement* - the simulator requires upgrading to comply with new Regulatory requirements and/or industry standards;
— *Simulator maintenance needs* - the simulator requires upgrading to maintain or increase simulator availability for training. This need is mainly caused by the ageing of equipment and software; with aging components no longer available on the market and old software no longer being supported by Vendor, but can also occur due to loss of knowledge and competence from the simulator owner, vendor or other supporting partner;
— *Modernization of NPP safety and control systems has to be reflected in FS simulators* (e.g. digital I & C modernization of reactor power and rod control systems);
— *Other than existing training applications of the simulator* - the simulator requires upgrading to perform additional functions (examples include plant emergency plan drills, engineering design change validation, plant operating procedure validation, use simulator model in a classroom environment, etc.);
— *Changes in the reference unit,* for example new plant systems, changing DCS platforms etc. large modifications.

Factors in each of these four categories are discussed in more detail in the following sections.

8.2.1.1. Training needs

The training programmes for control room operating personnel are continuously changing and evolving. At some point these programmes may run into the ‘limits of simulation’ on the simulator’s current hardware and software platform. This typically means that the simulator is incapable of simulating a required or desired malfunction or sequence of events. An increase in the number of these issues over time, particularly those related to the potential for ‘negative training’, may justify an upgrade of the simulator.

Simulator hardware and/or software problems that cause simulator behaviour to deviate from actual or expected reference unit behaviour are documented on simulator modification requests. Some of these requests may identity problems with the performance or capabilities of the simulator instructor station. Performance problems are typically discovered during simulator testing or during actual training sessions. It is undesirable to find simulator performance deficiencies during training or examination scenarios as they may have a negative impact on the outcome of those scenarios. Such problems also provide negative impact on trainee’s attitude to the simulator training.

Over time a backlog of modification requests will accumulate that cannot be resolved due to the hardware and/or software limitations of the existing platform or lack of knowledge and skills to change the implementation. A large backlog of unresolved items is undesirable as it undermines the confidence of the instructor staff and plant operating personnel in the performance of the simulator.

Over the operating lifetime of a nuclear power plant many design changes are implemented, and obsolete equipment is replaced. These design changes should also be implemented on the simulator to ensure that fidelity with the reference unit is maintained. It may not be possible to implement certain plant design changes due to the hardware or software limitations of the current platform. In this case the cost of a simulator upgrade could be included in the scope of the plant design change through a training needs assessment when the plant change is being planned. This issue relates especially to the replacement of obsolete control systems to DCS.

In summary, the analysis for a simulator upgrade based on training needs should include the following main factors, as being applicable:

- Limits in the simulation capabilities of the existing platform do not allow the use of some required or desired training scenarios in the operator training programmes;
- A large unresolved modification request backlog limits the use of the simulator and/or undermines the confidence of the instructor staff and plant operating personnel in simulator performance. Limitations in simulator hardware and/or software prevent the implementation of plant design changes on the simulator. This has a negative impact on simulator fidelity and in turn on training;
- An up to date lifecycle analysis of the simulator platform and the reference unit, considering the future need for operating a simulator and the expected lifetime of the existing and possible systems to be acquired.

8.2.1.2. Regulatory and industry requirements and standards

There are differing national standards for simulator management, generally based upon the ANSI/ANS 3.5-2009 [6] standard (or one of its predecessors). Since full scope simulators became an obligatory part of control room personnel training (and in turn - part of the operator personnel licensing process), these standards have been upgraded several times, each time bringing a new, stronger set of requirements for consideration in the scope and precision of simulator modelling, new improved training scenarios and more detailed simulator configuration management issues to deal with. While it is possible that upgrades to a simulator may be required due to changes in regulatory requirements, it is more likely that regulatory requirements affected the reference plant, which in turn affects the simulator. It is the responsibility of the training department to keep abreast of existing and new issues that may affect simulator management and even attempt to predict potential, future industry and regulatory requirements that may have an impact on simulator training and/or simulator management.

8.2.1.3. Simulator maintenance needs

A control room simulator is a complex system of hardware components and supporting software that age and become obsolete in much the same way as plant equipment. Computer systems, input/output system components and other hardware will eventually become less reliable over time, which will negatively impact the simulator’s availability to support scheduled training (i.e. increase simulator unavailability time). A decrease in equipment reliability results in an increase in maintenance and repair costs. This cost increase is reflected not only in the cost of replacement parts but also in the person-hours that are expended to affect repairs.

At some point it may become difficult or impossible to repair certain simulator equipment and systems because replacement parts are no longer available. Factors affecting parts availability include:

- The original vendor for the equipment is no longer in business;
- The original vendor considers the equipment obsolete and no longer supports it;
- Parts are unavailable in the secondary or surplus markets for obsolete equipment;
- Equipment does not cope with increased capacity needs due to incremental updates to the simulator over the years.

Another factor in the maintainability of old or obsolete equipment is the experience level of the simulator support staff. Personnel that leave an organization take their experience with them. If an organization's technical documentation and maintenance procedures do not provide adequate detail, new personnel may find it difficult to maintain the equipment.

Therefore, the analysis for replacement of simulator hardware (computer systems, I/O equipment, etc.) should include the following factors as applicable:

— Equipment obsolescence and cost of long-term maintainability;
— Spare parts availability and cost;
— The impact of equipment out of service time on scheduled training;
— Experience level of the simulator staff in maintaining old equipment;
— Insufficient computing power that limits the ability to fix modelling problems or enhance the scope of simulation;
— Separate handling of specialized or unique equipment verses regular Off-The-Shelf compatible systems.

Simulator software should be maintained over the operational life of the simulator. This software includes:

— The operating system;
— The simulator executive system;
— The software development environment;
— The instructor station software;
— The plant system models;
— Communication links to possible external systems;
— Current configurations and settings for the above.

While software does not 'age' and break down like hardware it can become obsolete. At some point old versions of computer operating systems and simulation executive systems will no longer be supported. The only choice in this case is to live with the current system or upgrade to a newer version of the software and possibly other connected systems which no longer are compatible with the renewed part.

Older simulators may have plant system models that are coded in assembly language via a higher-level programming language such as FORTRAN or C++. These models are typically more difficult to maintain and upgrade than models developed with more modern software tools. Moving to a more modern software environment should save time and effort in the development and maintenance of plant system models. Also, software engineers who are skilled and capable to deal with older/obsolete programming languages are retiring/leaving work.

8.2.1.4. Other than training simulator applications

While the primary purpose of a full-scope control room simulator is to train control room personnel, other uses for the simulator have evolved over the years. Some of these uses include:

— Emergency response drills and exercises;
— Plant operating procedure validation;
— Plant design change validation;
— Training of non-control room operating personnel (e.g. plant engineering staff);
— Implementation of 'simulator in the classroom' capabilities;

— Distance self-study (remote access to the simulator).

Some of these additional uses for the simulator may require that the simulator be upgraded to support these applications. For example, in order to support emergency drills and exercises a model and network connections upgrade may be required to simulate a desired accident sequence of events; and transfer simulated parameters to the emergency control centre.

Engineering applications of a simulator may require upgrade of thermo-hydraulic and neutron kinetic models to reach required fidelity of simulation.

8.2.2. Typical works in frame of simulator upgrade project

Despite the variety of simulators and modernization projects, all such projects consist of a set of typical tasks as listed below.

8.2.2.1. Hardware upgrades

— Computer system upgrade or replacement (re-host);
— Plant process computer upgrade or replacement;
— Input/output system upgrade or replacement;
— Control panel modifications;
— Replacement or upgrade of audio/video (A/V) recording systems;
— Replacement or upgrade of control room communication systems.

8.2.2.2. Software upgrades

— Implementation of new process and logic models (severe accident models, digital control or protection systems, etc.);
— Replacement thermo-hydraulic models – based on engineering-grade best estimate or advanced codes;
— Enhancement of existing process models;
— Instructor station upgrade or replacement;
— Implementation of 'simulator in the classroom' capabilities;
— Implementation of modern development tools (object-oriented with graphical interface);
— Implementation of new malfunctions;
— Implementation of modern configuration management software.

8.2.3. Project development

8.2.3.1. Establishing the upgrade project requirements

The technical and administrative requirements for a modernization project should be clearly stated in a project specification document. This document should include information on project goals, schedule, estimated costs, priorities, and general acceptance criteria. In order to optimize future resource expenditures for simulator upgrade and modernization projects it would be helpful to have a 5 to 10 year 'look ahead' schedule of the major modifications which may be implemented on the simulator. This schedule would consider such factors as new training needs, extensions of simulator model scope, plant design changes, and projected hardware and software upgrades.

The responsibility for collecting this information and completing the specification may vary, based upon organizational structure; usually it is the training centre operating the simulator, however, it is recommended that plant personnel from the operating and engineering departments be involved in the project development process to establish correct/aligned goals, priorities and acceptance criteria.

The project implementation schedule should take into consideration:

— Scope and complexity of work;
— Availability and quality of technical documentation;
— Simulator training schedule;
— Simulator maintenance schedule;
— Accessibility to the simulator for vendor (evening and night shifts);
— Any other activities on the simulator planned during the project implementation time frame.

Therefore, it is a good practice to develop an integrated simulator schedule that delineates simulator usage for several years (at least during the simulator upgrade project implementation plus warranty period).

8.2.3.2. Assessment of technical solutions

Assessment of technical solutions means to determine the effects of the potential technical solutions on the final schedule and cost of the project. The process of assessing various solutions can be broken down as follows:

— Determine possible solutions and evaluate each option;
— Assess the risks involved for each solution;
— Choose a solution with the best technical, cost, and schedule basis.

Technical factors associated with the selection and implementation of a hardware and/or software solution and may include the following:

— *Functionality*: the ability of the solution to meet the intended need;
— *Quality*: the ability of the solution to meet the required quality standards;
— *Reliability*: the ability of the solution to meet established reliability and stability requirements;
— *Maintainability*: the ability of the solution to be maintained by the simulator support staff;
— *Expandability*: the ability of the solution to support additional hardware or software that may be added to the system in the future;
— *Knowledge preservation*: the ability of the solution to preserve the existing knowledge of the simulator support staff.

Various cost factors are associated with project implementation and may include:

— *Budget*: The ability to implement the project within the budget allotted;
— *Realism*: The ability to predict accurate cost based on project scope and assumptions;
— *Variable costs*: The ability to manage unpredictable project costs. These costs may be incurred when various elements of technical scope are unknown, not well understood, or the exact nature of project tasks are difficult to define;
— *Future commitments:* in forms of yearly membership or support agreement payments.

Other factors that affect project cost could include monetary exchange rates or operational costs after the project is completed. These costs are not addressed in this report.

Schedule factors associated with the project implementation and may include the following:

— *Flexibility*: the ability of the schedule to be accelerated or extended based upon unforeseen factors (i.e. project implementation problems);
— *Milestones*: the ability of available resources to meet the milestones established in the schedule;
— *Implementation*: the ability of the schedule to reflect task performance time frames with accuracy.

The importance of technical, cost and schedule factors may vary greatly based upon the nature of the project being considered and should be determined in advance of the solution validation process.

8.2.3.3. Assessment of hardware changes

The most likely hardware system to be upgraded during the simulator life cycle is the simulator computer system. The solutions of interest for a computer system hardware change can be divided into the following three categories:

— *Category 1:* Change to a new hardware platform and operating system (e.g. replacement of a legacy system with a more modern system). This type of upgrade typically requires the most work to 'port' the simulation models to run on the new operating system as well as implementation of a new simulator software environment;
— *Category 2:* Replace the existing computer system with a newer system of the same type. This newer system may run the existing version of the operating system (OS) or require an upgrade to a newer version of the same OS. This type of upgrade is justified when a vendor stops supporting the existing computer system;
— *Category 3:* Expand the capability of the existing computer system by adding computer hardware of the same type. This type of upgrade is justified if the additional required computational resources can be met by the addition of more computers of the same type currently in use.

A Category 1 upgrade typically requires implementation of a new operating system while a Category 2 upgrade may require implementation of a newer version of the existing operating system. In both cases, the risk factors imposed by the hardware change are less critical than those imposed by the required software migration. The operating system change may lead to a migration of application software packages and hence parts of the simulator software development environment may need to be migrated as well. For Category 1 upgrades the entire software development environment should be migrated or replaced with a new environment.

Therefore, Category 2 and 3 solutions are typically of lower technical risk than Category 1 solutions. With respect to Category 2 solutions, an option may be to request an extension on the support agreement with the computer vendor if the existing system can fulfil short-term future requirements. This only makes sense if the cost of the support contract is not higher than the cost for other solutions.

For Category 3 solutions the risks implied by system reliability should be investigated in detail. The computer systems being added by this type of project may have the same aging and obsolescence considerations as the existing computers systems. This will eventually impact overall system reliability and stability. It also should be noted that this option does not always provide expected increase of computational capability, since not all models and OS support parallel computing.

The technical factors and risks for replacement or upgrade of the Input/output (I/O) system are mainly related to the functionality, maintainability, and expandability criteria:

— Required functionality is determined by the number of devices communicating with the main simulation computer, required communication frequency, simulator executive system (e.g. the scan and transfer rate), and the I/O override capability of the instructor station;
— The maintainability criterion reflects the ability of the new I/O hardware to be maintained by the simulator staff. If special control room hardware (such as stimulated equipment) is necessary, the impact of a change to the driver software should be investigated as this may require vendor proprietary information. In addition to the technical risks the schedule risks related to meeting project milestones based upon the vendor's ability to deliver parts and components should be assessed;
— The expendability of the I/O system is related to the implementation of control panel modifications.

Factors and risks that are implied by other hardware changes, such as computer network or peripheral device upgrades are mainly associated with the reliability and expandability criteria. A change in network equipment may influence communication timing behaviour requiring a compensatory software modification. The main contributor to the need of an upgrade of a network is stimulated systems (DCS, PPC). Additions of new peripheral devices such as printers typically require software driver changes due to different options and/or page formats.

8.2.3.4. Project implementation

The approach to the implementation of the project, for the modernization of the simulator, in principle does not differ from the generally accepted approach to the implementation of any other engineering project. The whole amount of work is divided into separate tasks, for each task time, human and financial resources are allocated. It is necessary to establish criteria for accomplishing tasks and to identify the critical tasks on which the progress of the project depends. However, it is necessary to consider the exceptional technical complexity of the modelled object, which often leads to the need to develop and apply non-standard engineering solutions, as well as the need for an operative change in resource allocation and work schedule.

A software upgrade project will typically include the following phases (FIG. 15).

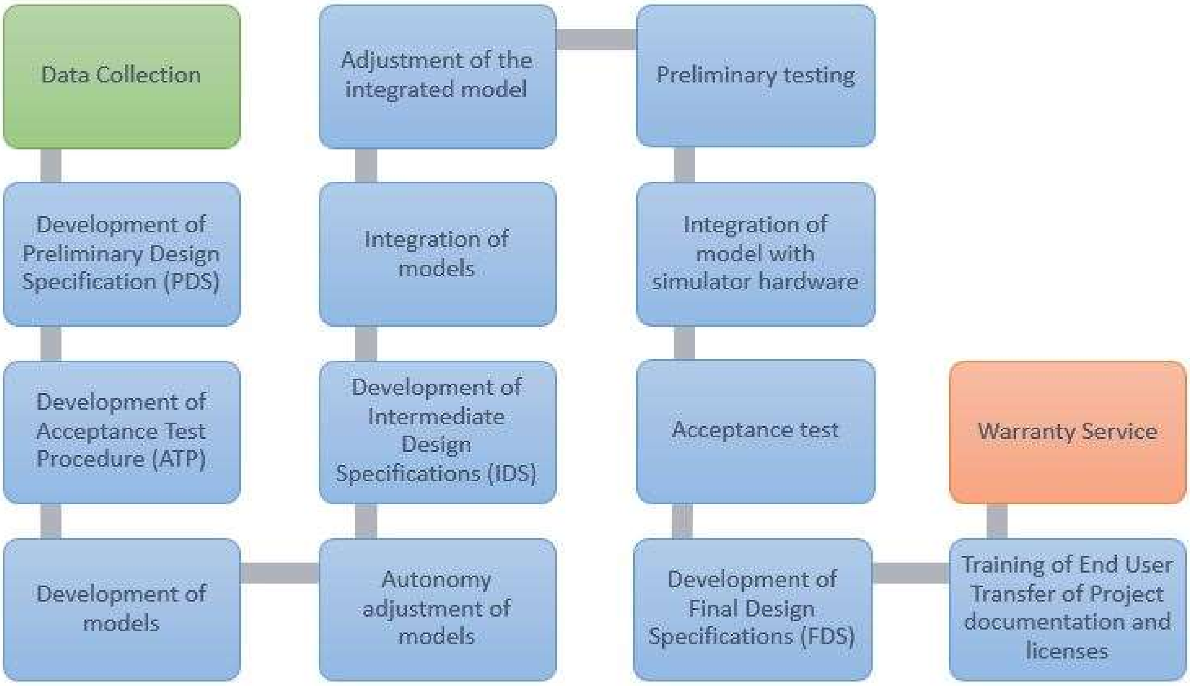

FIG. 15. Simulator modernization project outline.

Even though the hardware and software of the simulator work together, the modernization of these parts can be performed as independent tasks. Of course, at a certain stage of the project, the hardware and the mathematical model must be integrated, and then they will be considered as inseparable parts of the simulator (these stages are highlighted in orange in FIG. 16).

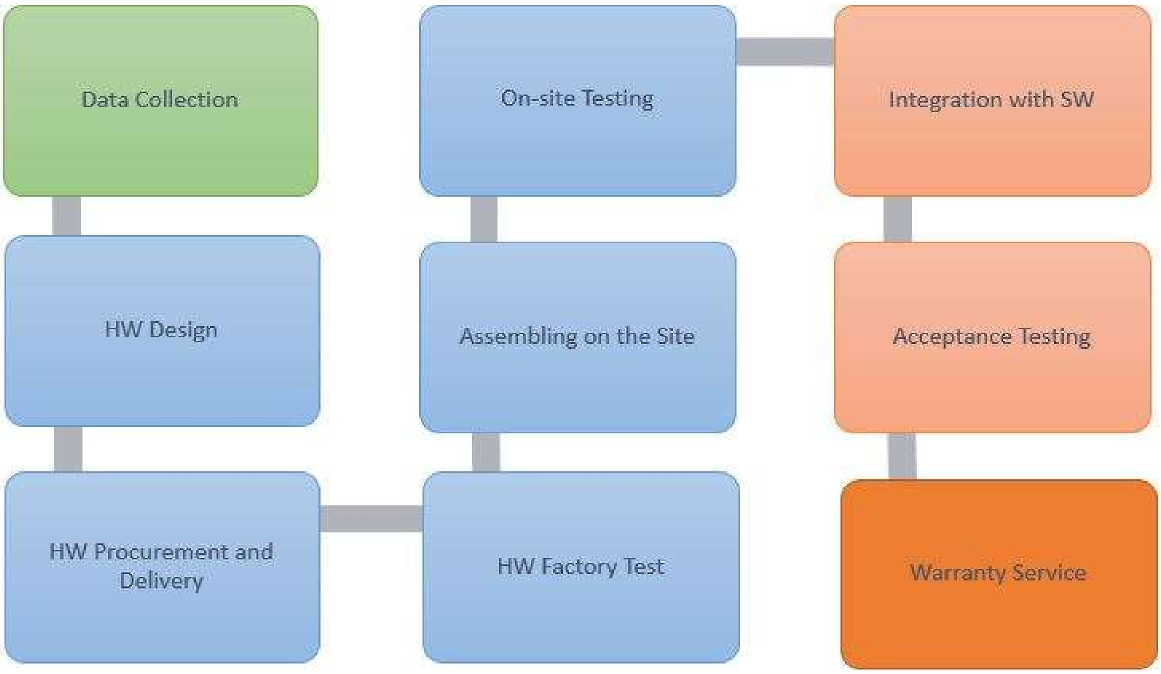

FIG. 16. Typical phases of the simulator upgrade project (hardware).

8.2.4. Key points for project success

In order to ensure the success of a simulator upgrade project the following factors should be considered:

- The new requirements and needs for the upgrade should be clearly identified and understood by customer;
- Full access to required reference plant documentation (design and operating) including reference plant transient data should be provided to the vendor, application and referencing this data should be carefully tracked and documented;
- Support from relevant plant subject matter experts should be provided to the vendor;
- New technicians to learn about the process;
- Simulator software and hardware configuration management systems should be established from the beginning of the project and run during the project to completion;
- The project team (customer + vendor) should be integrated and should include both development and testing personnel. A clear and efficient means of communication should be established between all team members. This is particularly important during the acceptance testing phase of the project;
- It is beneficial to have a comparison baseline to use for model acceptance testing. An engineering model of the reference plant may be used for this purpose;
- Achievable and representative acceptance criteria should be identified and agreed as early as possible;
- Availability of an automatic or semi-automatic validation tool (if included with the model) makes it possible to significantly reduce acceptance testing time and cost.

8.2.5. Project implementation considerations

Factors to consider at the preparation phase:

- Development of a detailed project specification as well as compilation of required documentation and data. If a vendor is involved in the project, a bid specification should be developed from the project specification;
- Acquisition of and familiarization with the new software development tools and simulation environment. If the project is performed solely by a vendor, in-house simulator staff training may occur towards the end of the project. If the in-house staff is involved in the project (recommended approach), training should occur before the start of work.

Factors to consider at the model development and implementation phase:

- Difficulties — that have been encountered in some projects — in integrating new models developed with modelling tools with the rest of the simulation models;
- Reluctance of the instructors and trainees to accept plant behaviour different from that of the old models. The operators and instructors have been using the old models for years and are ‘conditioned’ to expect the behaviour of those models on the simulator. Typical example is the reactor core dynamic – in many simulators the core model is ‘static’ during many years while at the real plant significant changes may occur (modification of fuel assemblies, allocation of control rods in groups, implementation of self-burning neutron absorbers, etc.). This may lead to considerable changes in core dynamic and in turn in power unit response;
- The portability of the model source code or executable files as appropriate;

- The long-term availability of vendor support and portability of the work to future computer platforms;
- Availability of the simulator for development and testing. Development and testing must be completed on development or other secondary simulators and only after that installed on the FSS for final approval;
- 'Learning curve' associated with implementing and becoming proficient with a new simulation environment and associated software modelling tools;
- Co-existing projects changing the simulator make configuration control and identifying responsibilities more difficult if several changes must be merged during a long project. Alternatively, other projects or changes may experience significant delays while waiting in queue for another one to finish.

8.2.6. Project schedule

Once the project has been started, the detailed planning phase can begin. The following tasks will typically be performed jointly by Customer and Vendor during this phase:

- Evaluation of time required to implement proposed technical solutions and implementation methodology;
- Preparation of a detailed project schedule based upon project scope, and technical and quality requirements;
- Creation of a project team and establishment organizational procedures as necessary; determination of the hardware, software and manpower requirements; assignment of responsibilities;
- Establishment of required communications with outside groups or organizations;
- Establishment of temporary workplaces for vendor's employees as close as possible to the simulator.

Execution of simulator upgrade project will vary appreciably depending upon the following factors:

- Development team qualification and completeness;
- Previous experience in the use of the modelling environment selected;
- Degree of vendor involvement in the project;
- If more than vendor is involved, who will carry the main responsibility in the project delivery and work between the stakeholders, who subcontracts who etc.
- The number of systems to be upgraded or replaced;
- The amount of training required for the in-house simulator staff;
- Availability of plant data;
- Simultaneity with other projects (e.g. NSSS model upgrades, computer system re-host);
- Availability of the simulator during the development phase and the performance of Site Acceptance Testing;
- If the simulator is used for training multiple unit crews and the update is a significant change in operating the plant special arrangements may have to be taken to train different unit crews for different plant configurations during a multi-year project.

Industry experience indicates that the following considerations may impact project duration and should be factored into the project schedule:

- Scope of the simulator upgrade and completeness of technical requirements;

- Experience of vendor in upgrade of other simulators;
- Availability of the modern modelling tools and codes;
- Availability and form of plant data (paper or digital);
- Communication and collaboration with customer team. If the upgrade is due to a reference unit modification such as a new DCS, problems at the NPP project may delay the simulator implementation.

The duration of a simulator upgrade project may vary in a wide range depending (but not limited) on factors described above. For typical scope of such a project (including simulation computer re-host, transfer plant systems models into modern development environment, complete replace control logic models with stimulated or emulated DCS, upgrade of Instructor Station and I/O system) the project schedule may fit in to 1.5 to 2-year time frame.

8.2.7. Acceptance testing

Acceptance testing is the process that involves testing, correcting identified deficiencies, and re-testing to ensure discrepancies have been adequately resolved. Typically, there are three types of acceptance tests that may be conducted as part of any upgrade project: Pre-factory Acceptance Testing, Factory Acceptance Testing and Site Acceptance Testing:

- Pre-factory Acceptance Testing (Pre-FAT) is typically, only required when a vendor is involved in the project and a considerable amount of the work has been conducted at the vendor’s location. A Pre-factory Acceptance Testing typically requires performance of a pre-selected group of acceptance test procedures to verify that the simulator is ready for Factory Acceptance Testing. This testing should start once all software is integrated. The need to perform this type of acceptance testing is project dependent. In many cases only a Factory Acceptance Testing and/or Site Acceptance Testing are required. Often the nature of a pre-fat can be to find as many errors as possible in preparation of the actual acceptance testing, instead of proving that everything works correctly and finalize the official test protocols and tools used for more formal testing. This testing can be less formal, provides an opportunity for the customer personnel to get familiar with the new system, receive training on the new systems and still change some more cosmetic aspects of the system still somewhat under construction;

- Factory Acceptance Testing (FAT) is typically conducted after the vendor has completed the required software and hardware integration work. Factory Acceptance Testing may be conducted at the vendor’s site prior to shipment to the customer if all necessary interfaces and external systems such as stimulated or emulated DCS, process computer, soft panels etc. facilities are available for proper integrated operation (plant start-up, shutdown etc.). Consequently, this type of testing cannot test the hardware I/O interfaces of the simulator. This type of testing should involve both vendor and customer personnel. FAT h be as to be a formal, well-documented and planned effort performed of a single well-defined, unchanging configuration step of the project delivery. FAT should not be started if there are known open issues or the complete scope of work has not been verified in earlier technical tests or reviews. All findings, observations, errors, etc. must be clearly recorded, assigned and efficiently worked on to prevent delays in the project;

- If a Site Acceptance Testing (SAT) is performed following a Factory Acceptance Testing, it will typically consist of a sub-set of ATPs (Acceptance Test Procedure) that are determined at the closure of Factory Acceptance Testing. A Site Acceptance Testing may be the only acceptance testing required if the project is being implemented in-house. In this case the Site Acceptance Testing should include the performance of all developed ATPs. As the name implies, Site Acceptance Testing is conducted on the simulator. This type of testing is usually performed by NPP operating personnel (i.e. actual NPP operators or operator instructors) with support from vendor personnel (if applicable). No changes have to be performed on the simulator configuration during the tests as the intent is to prove that the configuration under test works as a complete, well-defined and documented configuration step.

Pre-factory Acceptance Testing and/or Factory Acceptance Testing should start once all software integration is completed at the vendor's site. The customers' project engineer and test operator, in consultation with simulator engineering personnel, are responsible for documenting and prioritizing the discrepancies discovered during testing. Each deficiency must be adequately documented so that the vendor can accurately resolve the problem. The individual who discovered a deficiency should be the one to re-conduct the test in order to evaluate the adequacy of the fixes that were made. It is important to have a clearly defined test lead engineer/ representative who is responsible for the conduct of the testing as planned into completion with proper documentation and follow-up of all issues raised. Any deviations from the test protocols have to be documented and approved by the test lead and customer representative before closure and acceptance of each test procedure.

Site Acceptance Testing can begin once the new hardware and software have been installed and integrated on the simulator. The testing should start with a power-up of the simulator computers and other equipment and start-up of the simulator software environment, performed according to written procedures how to do so, because it is possible that some last minute changes have been performed on the systems which are not persistent across reboots or restarts of systems. This also validates the written procedures for starting up and using the systems in a correct manner and provides a record on the state of the system at the start of testing. The ATPs for the Site Acceptance Testing should be run on the simulator control panels to ensure that the simulator I/O system and other interfaces are functioning properly. The Site Acceptance Testing may consist of a sub-set of ATPs that have been determined at the closure of Factory Acceptance Testing. If a vendor is not involved in the upgrade project, the Pre-factory Acceptance Testing and Factory Acceptance Testing are not applicable; and the Site Acceptance Testing should consist of all the ATPs that were developed to test the upgraded simulator. The supplier's project engineer, team leader and other system specialists have to be on-site for the Site Acceptance Testing to provide support and resolve discrepancies discovered during the testing and define the required re-testing scope for any corrections. The person responsible for the simulator configuration control and versioning should be present to ensure that the tested configuration steps have been implemented into the simulator configuration and version management systems and that appropriate references to the configuration are properly recorded during tests, corrections and re-tests.

A format for deficiency reporting should be established including an approval and tracking mechanism. This may be developed in-house or if a vendor is involved, the vendor's deficiency reporting system may be used. Proper deficiency reporting and tracking during the integration and acceptance test period plays an essential role in ensuring project success. Any changes to resolve deficiencies should be performed according to established configuration control and version control measures used throughout the simulator's life span. Alternatively, a pre-project scheme should be developed if one is not available for use from the regular simulator maintenance procedures.

The SAT phase may include a durability or trouble-free operation period, which proves the quality, stability and continuous usability of the complete integrated simulator platform.

This period may for example include one month of trouble-free normal operation of the simulator (creation of initial conditions, execution of ATP tests, other transients, training preparation activities and other evolutions representing normal productive use of the simulator as a training platform). It is often essential to provide a stable, trouble-free environment to the operator training needs as interruptions and delays in training licenced operators during their normal shift work can present a significant challenge.

Once the acceptance testing program has been completed successfully, the simulator can be declared ready for training and transferred to the training organization for use with careful recording of the simulator's complete configuration state which has been reliably backed up for future recovery needs and warranty claims and assures that the back-up and restore procedures properly cover the changed systems.

8.2.8. Practical considerations and examples

8.2.8.1. Simulator software upgrade

The simulation models are the key component of any simulator (FIG. 17). These models define the simulator's behaviour with respect to replication of the physical and logical processes that occur in the reference NPP. However, in order to develop and correctly run, a mathematical model of a plant process, additional software is needed. This additional software includes general configuration management tools, databases, modelling tools, operating systems, compilers, communication software, executive software, drivers, etc.

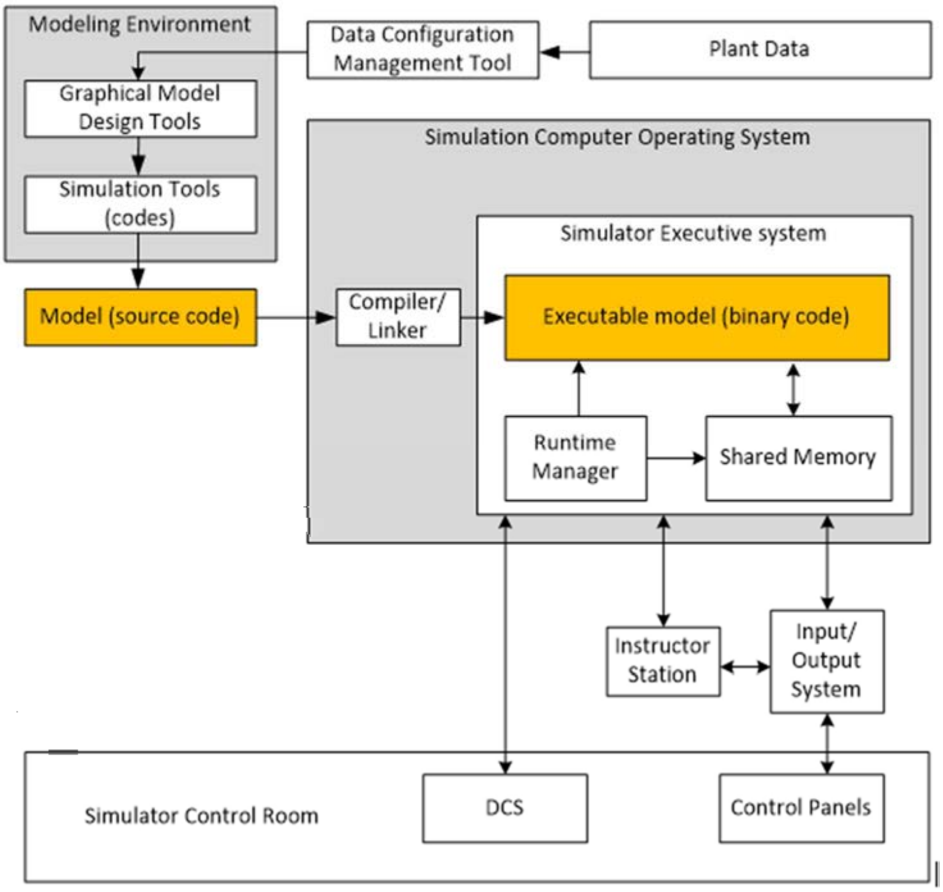

FIG. 17. Simplified typical structure of simulator software.

Therefore, simulation software upgrades may include a model upgrade, modelling software upgrade or (typically) both.

8.2.8.2. Process models upgrade

The various types of models that make up the integrated simulation require different considerations for upgrade and/or replacement. These models typically fall into one of the following categories:

- NSSS (Nuclear Steam Supply System) model – typically include both the core neutronic and primary circuit thermo-hydraulic models;
- BOP (Balance of Plant) model - typically include reactor auxiliary systems, turbine systems and common plant systems;
- Control logic model;
- Electrical distribution model;
- Possibly external systems such as off-site gas turbine or diesel power sources, external power grids or other external functional entities.

8.2.8.3. Nuclear steam supply system model upgrades

The objective of an NSSS model upgrade is to improve the fidelity of the reactor thermo-hydraulic and/or core neutron kinetic models. In current practice this typically involves implementation of advanced or 'best estimate' engineering modelling codes. This type of project might also include replacement of interfacing models, such as the reactor containment building model.

Advanced or best estimate codes were originally developed for engineering analysis of the transient thermo-hydraulic and neutronic behaviour of an NPP in a non-real time environment. These models are based upon complex conservation equations parameterized by means of data files that represent the actual geometry and characteristics of the plant. Until recently, these codes have been used primarily for engineering analysis at design phase and validation of plant modifications. However, the increasing computational power available from modern computer systems has allowed these codes to meet real-time simulation requirements. Consequently, they may also be used for simulator training purposes. Implementation of an advanced or best estimate model on a simulator typically requires minor modifications to include simulation functionality (i.e. run, freeze, backtrack, etc.). Adaptation to the simulator environment may also require minor modification to some specific model characteristics that do not considerably reduce the quality of the results. Advanced or best estimate codes typically consist of an executable file that solves the equations based upon an input data file that defines the reference plant design and initial conditions.

8.2.9. Rationale for NSSS model upgrades

The models originally delivered with a simulator were developed many years ago, when the available power of simulator computer systems was very limited, compared with what is available today. This resulted in the need to keep the thermo-hydraulic and neutronic models 'simple' in order to meet the requirements of real time execution. Consequently, the fidelity provided by these models was often questionable and, in some cases, unacceptable. These older models also placed a limit on the simulator's capability to simulate certain types of events or transients that occurred in the reference plant, thus making it unsuitable for training under certain conditions. Other situations where a NSSS model upgrade might be justified include:

— Core modifications necessitated by plant power uprates, extended fuel cycles;
— Employment of new types (for instance mixed oxide) fuel elements;
— Extension of the predictive capability of the simulator, allowing it to be used as an evaluation tool by the plant design engineering groups;
— Obsolescence or lack of vendor support for the existing NSSS models;
— Situations when new models would significantly reduce the cost and time required to implement plant modifications on the simulator (e.g. core model data updates);
— Need for running 'what if' scenarios with a reliable physical background with little or no operational or analytical data.

Best estimate simulation models are typically a 'black box' for simulator End Users. Such a model usually consists of two main components:

— Computational code (i.e. RELAP, CATHAR, etc.) containing a set of equations and solver;
— Input Desk containing constants and plant-specific design data.

This means that the modelling methodologies and techniques used in the model are proprietary and not meant to be modified by the Customer. A plant-specific model is typically developed by creating an input file that contains plant design data. In general, the larger the number of basic equations and nodes resolved by the model, the better the results will be. However, other aspects of the model, such as resolution methodology, numerical stability, constitutive correlations, are also important. Other considerations may include:

— How the model will interface with the other simulation models. This includes the core model and other interfacing models;
— The reluctance of the instructors and trainees to accept 'different' simulator behaviours following implementation of a new model. The operators and instructors have been using the old model for years and are 'conditioned' to expect the behaviours/characteristics of those models on the simulator;
— The portability of the model to other computer platforms, operating systems, and simulation environments;
— The long-term availability of support for the model. Will a vendor software maintenance or support contract be needed; or can the model be supported in-house with minimal vendor support?
— The completeness, accuracy, and 'user-friendliness' of model documentation;
— Availability of visualization tools, such as 3D viewers displaying different properties of the simulated systems in real-time.

8.2.10. Model selection considerations

Several factors should be taken into consideration in the model selection process. This may include:

— For thermo-hydraulic models:

  - The number and characteristics of the phenomena equations resolved in the model (flow and heat transfer regimes, sonic flow, counter-current flow, horizontal stratification, natural convection, etc.);
  - Ability to simulate the effects of non-condensable in steam, as well as radioactive and chemical species transport;

- Type and characteristics of boundary conditions;
- Malfunction capabilities;
- The degree of nodalization allowed, and the time step capability at the desired nodalization (both factors are dependent upon available computing power);
- The numerical methods used, ensuring the model's stability across the entire operating range including transients;
- The availability of analysis and debugging tools, as well as the capability to access all the variables calculated and parameters used by the model;
- Available fast time (acceleration) options;
- Multi-threaded execution allowing the use of a large number of CPUs for supporting more detailed nodalization and including more plant systems into the scope of simulation;

— For core neutronic models:

- The degree of horizontal and vertical core nodalization permitted by the model. It should be consistent with the characteristics of each core and if possible, match the nodalization used for online core monitoring software as well as offline core design tools when the simulator uses the same model family as the real plant, such as Simulate-3/S3R products from SSP;
- Simulation capabilities with respect to the reactivity effects of changes in moderator density, fuel temperature, control rod position, boron and fission product poisons such as xenon and samarium;
- Ability to simulate various core burn-up states and support several different core cycles depending on the initial condition loaded;
- Number of neutron precursor group calculations included in the model;
- Number of fission product groups used for decay heat calculation;
- Ability to simulate individual control rods;
- Ability to simulate in-core neutron flux detectors. Available fast time options;
- Availability of analysis, debugging, and model tuning tools, as well as the capability to access all the variables calculated and parameters used by the model;
- Ease with which the neutron and thermo-hydraulic models can be interfaced.
- The stability of the interface between the neutronic and thermo-hydraulic models and its capability to adequately solve fast transients;
- Ease with which the model can be updated with core reload data to reflect the behaviour of future cycle cores;

— For both thermo-hydraulic and neutronic models:

- Compatibility with the other simulation models and simulator hardware (portability of the model to other computer platforms and operating systems);
- Maturity of the model. Is it being used successfully on other NPP simulators? Is there enough of a user base for the model that a User's Group can be established to share experience?
- Stability in numerically extreme situations such as sub-atmospheric pressure cold shutdown conditions and outage states or solid operation of the RPV/primary loop;
- Synergy benefits if the same codes are used for the real-time simulator and plant analysis for fuel design, safety calculations or other analytics within the company;

— Future maintainability:

- Training and experience required to implement changes to the model. Significant training may be required if the model is maintained by the in-house simulator engineering staff. This may not be necessary if the model vendor is contracted to provide long-term support following project completion;
- Available post-implementation vendor support for the model, necessity in a long-term support agreement with the supplying vendor, if access to the source code is not available then.

Two model configurations that are typically found in a project of this type:

— Model executable code is provided that is specific to a reference plant; or
— An executable generic version of the code is provided along with a configurable input file that represents actual plant data.

For the first configuration, the customer cannot typically modify model parameters. For the second configuration, the customer may have the ability to modify the model input data file, thereby allowing a level of model 'tuning'. In this case, the following factors should be considered:

— Simplicity with which changes can be incorporated in the model:
— Availability of access to the model (input desk) source code.
— Clarity and sufficiency of model documentation.
— Availability of configuration input file (e.g. nodalization changes);
— Dependence of CPU consumption on the number of computational nodes;
— Capability of incorporating new malfunctions.

8.2.11. Implementation of severe accident modelling codes

Major parts of existing simulator models, e.g. NSSS and reactor building (containment) models do not currently support the simulation of severe accidents. On a typical simulator, the limits of simulation are usually reached when model fuel and cladding temperatures approach a value where fuel damage is expected to occur. Therefore, most simulator models cannot support the dynamic simulation of core damaging events and post-core damage consequences (in-vessel and ex-vessel phases of severe accidents).

In the past, such accidents were generally not considered in designs. As such, operators in control rooms were not equipped to train for these severe types of event; no simulated means to control extreme parameters, no procedures to manage (mitigate) severe accidents and no equipment capable of working in the extremely harsh environments, usually associated with the progression of severe accidents. However, several severe accidents have occurred at NPPs and this has led to significant changes in plant design and operational approach to these extreme events. Nowadays almost all nuclear power units are equipped with special instrumentation and equipment to control severe accidents and mitigate consequences. Operators have SAMG. All these improvements have led to a requirement to train operators on how to operate/manage reactor installations during severe accidents. Severe accident simulation codes and models were originally designed for engineering purposes, to run long-term transients that lead to fuel damage, cladding oxidation and failure, hydrogen generation, core melt, reactor pressure vessel failure, and containment building failure leading to a significant fission product release to the environment.

8.2.12. Implementation of Severe Accident Simulation

Utilities of Member States need to consider enhancing their simulator capabilities with the addition of severe accident simulation. All current simulators are designed to simulate, with accuracy, Design Basis Accidents (DBAs) considered in the design and licensing of NPPs. In addition, most current simulators can simulate adequately Beyond Design Basis Accidents (BDBAs) not involving the melting of the reactor core. In fact, most simulators are configured such that the limit of simulation (i.e. simulator confidence) is reached when the fuel/cladding temperature exceeds a specific value.

Several engineering-grade Severe Accident Codes (SAC) have been developed over the years to predict the plant response under severe accident conditions, such as MAAP[3] and MELCOR[4], to name a few. The SAC typically includes detailed modelling for the NSSS (including the reactor vessel and its internals), the containment and the spent fuel pool. The SAC can also predict offsite radiation dose based on environmental conditions (i.e. wind direction, wind speed, etc.). These models are typically coupled to other high-fidelity simulator models in order to produce a realistic plant response under severe accident conditions. The SAC can handle the following extreme conditions:

- Degraded Reactor Core (i.e. fuel melting, cladding oxidation, hydrogen generation and vessel failure);
- Containment Failure;
- Fission Product Release.

FLEX is a diverse and flexible coping strategy for the restoration of core, containment and spent fuel pool cooling, considering the most likely risks from severe natural events at each NPP.

After the Fukushima-Daiichi nuclear accident, most NPPs around the world underwent in-depth design review, resulting in the implementation of FLEX plant modifications:

- External power sources;
- External water sources;
- Remote monitoring of plant parameters for potential high radiation areas;
- Remote operation of equipment for potential high radiation areas;
- Hardened containment vents, etc.

Utilities of Member States are recommended to base their decision on implementing or not implementing severe accident simulation and/or FLEX plant modifications on their simulators using the training needs assessment process prescribed by ANSI/ANS-3.5 simulator standard [6]. In the case of Japan, the JEAC 4805-2014 simulator standard requires the incorporation of severe accident simulation.

There are several factors to consider before implementing severe accident simulation for training purposes:

- Intended training audience: operators, Emergency Response Organization (ERO), plant management, etc.;
- Required type of simulator: FSS, classroom/portable simulator, engineering simulator, etc.;

[3] Name of a Severe Accident Code
[4] Name of a Severe Accident Code

- Required external interfaces: technical support centre, onsite/offsite emergency operating facilities, local government facility, regulator facility, etc.;
- Required Emergency Preparedness (EP) drill scenarios: determine benchmark testing and decide if spent fuel pool scenarios are required;
- Operator interface: FSS equipped with panel instruments or soft (virtual) panels;
- Existence of stand-alone SAC already in use by engineering: benchmark the simulator against the stand-alone SAC, possibility of shared licensing;
- Feasibility of integrating the selected SAC into the existing simulator software: real-time, fast-time capability for long transients, support of simulator commands (e.g. freeze/run, etc.) considerations;
- Benchmark other utilities that already implemented SAC;
- Consult with simulator vendor(s) for available technical solutions;
- Reference unit type, preparation and systems for severe accidents and the general expected path of a severe accident progression. Some designs may have very little facilities in the MCR for a simulator to represent. Also, modern reactor types may present extremely slow evolutions leading to SA cases, leading to scenarios lasting for days if running at real time;
- SA management is first and foremost a large-scale operation between emergency response teams, plant personnel, public and governmental agencies etc. dependent on their inter-communication and situational awareness. Coupling all this to a simulation is largely external to the actual simulation scope attainable;
- Severe accident simulation can be augmented by 2-D and 3-D visualization, which helps plant personnel better understand severe accident phenomena.

Several utilities of Member States have already implemented severe accident simulation on their FSSs and/or as stand-alone simulators. It is expected that the implementation of severe accident simulation will increase as the nuclear industry matures further.

This subsection describes general approaches and considerations regarding the integration of severe accident models into the simulator environment.

When considering the implementation of SAC models on a simulator, the following factors should be evaluated:

- Typically, severe accident model scope is limited to the reactor core, the primary system, the containment building and parts of the emergency core cooling systems. Therefore, an interface must typically be developed between the SAC and the interfacing secondary plant and other models in the normal simulation load;
- If the NPP engineering group uses a particular SAC for plant safety analysis, it is recommended that this code be implemented on the simulator to reduce licensing costs. Additionally, analysis results from the plant engineering model will be useful in acceptance testing of the model following integration on the simulator;
- Most SAC models are not designed to run in real time. Consequently, a method of controlling the time step execution of the SAC model should be developed to ensure smooth operation with the interfacing simulator models. The methodology chosen should control the execution of the SAC model while ensuring that it does not result in instabilities and inaccuracies in SAC results;
- The SAC may require modification in order to support simulator operational features such as Run, Freeze, Step, Backtrack, Snapshot and Reset.

Scope of implementation of severe accident models on the simulator should be analysed from a feasibility-reasonability perspective. This means that despite the latest improvements in plant design the operator is still limited in means for SA control and mitigation. Therefore, the SA model should be enough to support training on SAMG procedures and processes and run in real time or faster. There is no reason to implement an operator training simulator as detailed as an engineering SA model; since the operator trainees are not required to see, on the simulator, major parts of the model's outcomes required of the engineering simulators. The cost to implement severe accident models should be weighed against the low probability of occurrence of severe accidents. Since severe accident mitigation strategies involve the operation of plant equipment that is used infrequently (or never used), nevertheless training is important to increase plant personnel preparedness for beyond design basis events.

8.2.13. Modelling software upgrade

Different types of modelling software usually integrated in modelling environment. Typically, such an environment includes:

- Configuration management tool;
- Graphical modelling tool for thermo-hydraulic systems;
- Graphical modelling tool for I&C systems;
- Graphical modelling tool for electrical systems;
- Graphical tool for Instructor Station;
- Executive simulation software;
- Communication (I/O) software;
- Work and deficiency management system (tickets, work orders, discrepancy reports);
- Third party software (operation systems, compilers, database managers, debuggers, etc.).

The objectives of a modelling software upgrade are:

- To improve the fidelity of simulation;
- To improve maintainability and configuration management of models;
- To ensure possibility for further model upgrades by plant training personnel;
- To reduce dramatically time for model development.

Leading simulator vendors have their own graphics-based and object-oriented software tools capable of modelling various plant processes and systems. The development environment may include icons or graphic objects that represent plant components, piping, relays, etc. Typically, a logic or dynamic system can be modelled by using the tools to draw the system or diagram being simulated. This is a significant advance in technology when compared to manual coding methods and the resultant model drawings can be used for other purposes, such as classroom training. Also, the simulator customer, after relevant training of staff, can implement changes in models as the graphical models are user-friendly and facilitate an ease of alterations.

Automated data generation from digital documents of the reference plant could present gains in producing the bulk of drawing and manual work for initial model development. Translation of I&C systems from plant data to simulator models could provide fast, reliable automated generation of new I&C revisions.

8.2.14. Rationale for modelling software upgrades

System models originally delivered with the simulator were developed many years ago when the available computing power was significantly less than it is today. Consequently, many of the models were relatively 'simple' and were developed in assembly language or other lower level programming languages in order to ensure real time execution. The quality and fidelity of the results provided by these models today may not be adequate to support the levels of training now required from our simulators. Additionally, limitations in these models may make the simulator incapable of accurately reproducing certain plant events or transients. This could result in the simulator being unsuitable for operator training under certain conditions. |Other situations where model upgrades may be justified include:

- A model upgrade may be required as part of a simulation computer re-host project. It may not be possible to directly migrate older models from one computer platform to another. This may be additionally complicated, due to obsolescence or lack of vendor support for the existing models and/or modelling environment. Therefore, it may be necessary to re-create these models in a new software development environment;
- Plant modifications or implementation of new systems requires relevant upgrade/ extension of the existing simulator model;
- High fidelity models allow the use of the simulator as a validation tool for new operating instructions and/or an engineering tool for plant modifications;
- Accurate representation of physics allows 'automatic' observing of functions such as effects of different elevations and static head and other natural occurrences in fluid systems which are completely absent from very simplified models;
- Significant reduction of cost and time in the incorporation of changes to the simulator;
- Input data and files for generated model code may not have been retained or kept up to date preventing changes to generated models;
- Keeping instructor station graphics files for process diagrams up to date in model changes is additional manual work which has to be done after model changes. Newer systems may be able to utilize the graphical model drawing directly as an instructor station drawing, thus removing the need for maintaining separate graphic pages.

8.2.15. Modelling software selection considerations

Some factors to consider when choosing a software development environment may include:

- The simplicity of using modern graphical software development tools for modelling of plant control logic and thermo-hydraulic systems, makes them desirable for a model upgrade project. These tools enforce consistency in model development and typically require minimal computer programming experience. They may also decrease the time needed to create and test a model, which could reduce overall project duration. Models developed with graphical software tools are typically easier to troubleshoot and maintain than compiled code;
- Selection of software engineering environments that integrate modelling tools, the simulation executive, the instructor station, and other software (e.g. widely used third-party text processors and databases) is recommended;
- In their current state of development, simulation modelling tools are typically not adequate for precise simulation of the specific processes (i.e. core neutronic and reactor coolant system thermo-hydraulic). However, some simulation packages can provide a graphical interface to the key variables in such specific models, which enables an easier troubleshooting process.

8.2.15.1. Capabilities for modelling of plant technological models

— The number and characteristics of the equations resolved in the model, including resolution method, stability, and time step capability. Important non-homogenous nodes have to especially be considered for the containment, suppression pool and main condenser nodes where steam pressure is suppressed with water spray, steam is sprayed under water for quenching or thermal stratification of a pool or room volume is important. Correct response is typically not achieved with regular modelling tools using homogenous properties within nodes, additional measures have to be considered for these special cases. Normal operational effects such as heating up main steam lines from cold state may require additional modelling to display consistent behaviour until saturated conditions are achieved, etc.;
— Ease of use of graphic interface of modelling tools;
— Scope and characteristics of the available equipment components library (i.e. types of pumps, valves, etc.). Type and characteristics of model boundary conditions;
— Capability for easy extension of the components' library (adding new objects and modification of existing components);
— Number of permissible modelling nodes and their impact on available computational power;
— Number and characteristics of system and component malfunctions.

8.2.15.2. Capabilities for modelling of plant control logic and electrical power supply models

— Ease of use of graphic modelling tools;
— Compatibility with the rest of the simulation models:

- The link to the rest of the simulation models (especially the NSSS model) and, in general, the adaptability of the new models to the architecture of the rest of the simulation;
- Generation and maintenance of the Input/output system interface with control panel instrumentation;
- Availability of components in the standard library or additional available libraries which cover the existing necessary plant equipment;
- Quantity and quality of documentation of the standard object library included with the tool;

— Possibility to stimulate/emulate plant I&C software (especially DCS).

8.2.15.3. Long-term maintainability

— Total software configuration control starting from plan data and up to executable models. This will ensure stable quality of the models' documentation;
— One database for the whole simulation environment;
— Portability of the simulation environment and developed models to existing and future computer platforms and new or updated operating systems.

It is recommended that a 'user group' be established for users of the same simulation environment to allow for a free and open exchange of information and experience.

8.2.16. Simulator input/output system replacement or upgrade

The main objective of a simulator Input/output system replacement is to improve the operational reliability of the simulator by replacing obsolete components. The scope of this type of project may vary greatly from a complete re-wiring of the simulator panels to the replacement of only a few system components. Project scope is defined by the basis for the upgrade as defined in the project specification document.

8.2.17. Basis for simulator input/output system replacement or upgrade

Example conditions that contribute to the justification of the replacement or upgrade of the Input/output (I/O) system may include (FIG. 18):

- The I/O system originally delivered with the simulator is now obsolete;
- Spare parts are not available from the original vendor and after-market parts (used or refurbished) are becoming scarce, expensive, or unavailable;
- Simulator unavailability time has increased due to frequent failures of I/O system components;
- New I/O system designs provide increased functionality to facilitate troubleshooting and repair of system components. It may also be possible to improve the diagnostic and troubleshooting capabilities of the existing system by adding new components;
- DCS implementation requires a higher data transfer rate between simulator and control room.

FIG. 18. Master and slave, I/O chassis from Grafenrheinfeld Simulator (Germany).

8.2.18. Equipment selection considerations

Some factors to consider when choosing replacement hardware for the project might include:

— Technology:

- The equipment should be state-of-the-art (widely used and not nearing the end of its life cycle) to forestall future obsolescence. It is recommended to contact other simulators that have installed the equipment under consideration to determine their satisfaction with the product;
- The equipment should be compatible with existing panel hardware (switches, controller, etc.) and simulation software. This minimizes cost by eliminating the need to create special purpose hardware and software interfaces between the new and existing hardware. System features should facilitate installation and integration;
- Evaluation of the compatibility of new or upgraded I/O system hardware, not only with the current simulator computer systems but also with potential replacement systems that may be implemented in the future is recommended. Systems that are compatible with existing standards, such as Microsoft Windows©, UNIX, LINUX, Ethernet, TCP/IP, CAN bus; will typically provide more flexibility and future upgrade capability than systems that are not;
- The system should be expandable, with adequate I/O connections available to support existing needs, as well as allow for future control panel modifications;
- The system should be designed to accommodate the required data transfer rates that may result from DCS upgrades which may possibly be implemented in the future;
- When equipment is installed in the MCR, perhaps inside the operating panels, low noise level equipment should be preferred to prevent creating a noisy control room environment. Loud power supplies or computing gear could be moved behind walls or other structures to isolate noise sources from the MCR space;
- A spacious, well-lit working environment behind the panel makes installation, maintenance and troubleshooting easier and safer than cramped cabinets;

— Maintainability:

- Avoidance of 'black box' hardware that creates long-term dependence on the equipment supplier for maintenance support is recommended;
- The new or upgraded system should have features that make it easy to troubleshoot and repair in-house, or with minimal vendor involvement, for example:

  - ▪ Monitoring and remote control of power supply modules: remote on/off, voltage and current measurement in real time, etc.;
  - ▪ Protection and detection of hardware faults with real-time information for the simulation software, such as: open circuit (especially useful to detect blown bulbs) or short-circuit situations;
  - ▪ Hardware self-test functions implemented in each card (Built-In-Test Equipment feature, with testing of 100% of the card functionality). Ability to repair equipment in-house at the board or even the IC chip level that is important for long-term maintainability and cost savings;
  - ▪ Procurement of suitable testing tools such as test jigs, card extenders, cable and connector testers, logic analysers, oscilloscopes etc. gear which makes testing fast and reliable helps reduce down time and identifying unreliable equipment;
  - ▪ An adequate supply of spare parts to be included in the initial purchase, and parts to be readily available from the system vendor for the foreseeable future;

- Proper markings and layout of equipment is essential for efficient working, this equipment will be used for decades and looked after by different people;
- Use of ‘obscure’ connectors or parts from another part of the world can be hard to get, expensive, unfamiliar and ill-suited for the tools and skills available locally;
- Electrical distribution and safety features should be designed and procured locally in the country the installation will be used;
- A modular system where modules can be quickly exchanged with connectors should be preferred over fixed-wire installations where equipment replacement requires powering off sections of the system and qualified electricians with suitable tools and dismantling of protective materials before disconnecting/connecting equipment;

— Knowledge transfer:

- It is important to ensure that knowledge transfer occurs to the technicians, from the vendor, who is to be responsible for the maintenance of the new simulator equipment. This is best accomplished by ensuring that the equipment supplier provides training. This training should be specified in the initial project contract.

The technicians responsible for equipment maintenance should be involved in project specification development, as well as installation of the new equipment (if the project contract allows). Some overlap in knowledge between the system engineer for the I/O system logic and the technicians handling the hardware helps working with the system. Ideally there has to always be one responsible person available who understands the whole functional chain of operation from the buttons to the model variables and back, otherwise debugging and planning for changes will be more difficult and prone for errors. Consistent unified documents detailing the whole chain at least in principle if not in per-signal format is always useful but may not be included in the standard delivery of a system vendor who often designs his system to be constructed and assembled in separated parts. Also, initial vendor design and documentation may not have provisions for future maintenance, extension and additions and may not be available for the customer to take over, update and maintain in its native form. If several vendors are involved in the design, build and delivery of as system there should be one responsible party for the design and documentation process, naming conventions etc. so that documents are produced in a uniform and centralized way instead of every supplier delivering their own part with little regard on what is ‘on the other side’.

8.2.19. Project implementation considerations

The I/O system is a critical simulator system; and the process of choosing new equipment and the strategy to implement the new equipment should be carefully analysed. The following factors should be considered:

— The new or upgraded system must be linked with the simulator computer platform, preferably provisions have to be made to cross-connect platforms such as the FSS and BSS or a spare hardware platform quickly and easily for disaster recovery or change testing needs;
— Methods of communication should be established between the new equipment and the equipment that is not being replaced;
— A window in the simulator training schedule should be identified where the simulator can be de-energized to facilitate equipment replacement and testing. In some cases, a ‘phased’

replacement approach may be utilized where equipment is replaced one section at a time. This approach maintains full functionality of the simulator over the course of the project. It is important to perform a partial acceptance test for each section of the I/O system that is replaced in order to ensure that the response of the simulator is correct;

— If problems are encountered during installation and testing of the new equipment, the project plan should include contingencies for re-installation of the old equipment to minimize simulator unavailability time. In some cases, this may not be possible if wiring or other permanent changes have already been implemented;
— Simulator wiring diagrams (or a wiring database) are fundamental information needed to support an I/O system replacement or upgrade. It is recommended to ensure that diagrams and/or the database are updated and well understood to reflect the new configuration. A single unified data base with all relevant information for the I/O system and all signals (hardware, software and virtual panels) is recommended over several separate records.

8.2.20. Computer system re-host projects

The main objective of a computer system re-host project is to upgrade the simulator computer system that runs the simulation models and/or the software development computer system. This type of project may also include replacement or upgrade of other facility equipment, such as the simulator Ethernet network, and the instructor station computers.

8.2.20.1. Basis for computer system re-host projects

A re-hosting project may be necessary if the existing simulation or software development computer system does not fulfil certain basic requirements for computing power, connectivity, and maintainability. For example, inadequate computing power may prevent the running of certain training scenarios. Inadequate computing power may also prevent implementation of a model upgrade project. Not having adequate space available on the system hard disk, limits the number of initial conditions sets available to the instructors as well as the number of different simulations loads that can be installed on the system.

The requirement of high simulator availability for scheduled training may be difficult to satisfy if spare parts for old computer systems are no longer available. Typically, a computer supplier will not support a hardware platform for a long period of time. The same is typically true for computer operating system support.

Additionally, it may be necessary to periodically upgrade the capability of computer system peripheral devices. For example, it may be desirable to upgrade the computer system network speed by upgrading network equipment to support faster data transfer rates and create redundant network connections for critical parts. In many cases new peripheral devices are not supported by old computers or operating systems.

8.2.21. Computer system selection considerations

Once the need for a computer system re-host project has been identified, it is then necessary to evaluate the available options for computer systems and associated operating systems. From the point of view of the hardware, it is important to assess the capability of connecting a new computer system to other computer systems or equipment connected to the simulation computer including; Digital Control Systems (stimulated or emulated), Manual/Auto (M/A) controllers or control stations, plant process computers. The new equipment should provide adequate flexibility when establishing a link with any component or peripheral.

The ability to connect the new computer system with the I/O interface system for the control panels should also be considered. In some cases, a simulation computer re-host project may also require an update or replacement of the I/O system. If the decision is made to update only the simulation computer system, consideration should be given to the type of link that will be established with the old I/O system. It is possible that problems will be encountered when establishing this link because of a lack of compatibility with old hardware or software.

It is also important to assess the long-term availability and maintainability of the computer platform selected. While no computer platform is 'obsolescence proof', state-of-the-art technology should typically be chosen to ensure long-term viability. Another factor to be considered is the operating system software that can run on the selected platform. The ability to run several operating systems or different versions of the same operating system without significant hardware upgrades is desirable. The computers purchased for the project should have significant computing power, available memory, and disk space to support other planned upgrades for many years into the future.

From the point of view of the operating system, a re-hosting project is the most suitable time to move away from old proprietary computer operating systems. Selection of more open and widely accepted operating systems such as UNIX, LINUX, or Microsoft Windows© is recommended. A change in operating system may involve more than re-compiling and minor adjustments to the simulation software. Therefore, it is important to assess the ease with which the simulation software can be migrated to the new system. This software includes the system models, the real time executive, databases, graphics systems, auxiliary software and the instructor station. Different computers may also run different operating systems as required for the particular use of the machine. For example, simulator executive servers could run LINUX but instructor workstations could be using a newer version, different distribution of Linux or even MS Windows.

In order to become more hardware independent, the re-host project could be set up in a way to virtualize the simulation computer and development system. Simulation models are running on virtual machines. Virtualization of computer systems provides the possibility to easily set up instances of simulator and development loads and minimizes administrative effort in case of hardware changes. Virtualization may become the only re-hosting strategy in a case that the operating system does not run under a new hardware system. Virtualization also enables higher availability of the simulator computer system through automatic redundancy of storage, computing capacity, network connections and other resources.

Other factors to consider include:

— The existence of corporate commercial agreements which hardware suppliers may impose;
— Given equipment line and operating system on the project from the very beginning. Corporate licensing for third-party software may also be a determining factor in the operating system selected;
— The cost of the new computer system should also be considered; however, the price of computer equipment has decreased significantly over the years and typically now comprises a relatively small portion of the overall budget for a computer upgrade. Enough funds should be included in the project budget to allow purchase of at least one development computer system;
— A complete spare server for the main simulation server mirroring the master server configuration can provide disaster recovery in minutes when planned properly and allowed by the software licensing scheme;

— The experience of the simulator staff with the new computers and operating system should be evaluated, as this will determine how much staff training will be required;
— Performance requirements of a virtualized simulation computer should be determined from the very beginning;
— Planning the simulator systems network structure and possible expansions early and comprehensively helps to establish a secure and well-known environment. Network segments can be separated for security and performance reasons. External connections and additional services such as web servers, configuration management and bug tracker interfaces can be conveniently provided. Every host attaching to the simulator network complex have to be managed by a single entity (preferably by the simulator owners dedicated person) who assigns networks, host IP addresses and other network properties in a central fashion. Contracts have to be written such that any suppliers delivering equipment connecting to the network will obey these rules set by the network administrator. Modern network services such as routing, DHCP service, DNS resolvers and human-readable documented domain names needs to be set up with careful planning from the very start. Modern computer systems have not to rely on static '192.168.1.x' IP addresses set by each vendor by their own will. Separate networks and connections for real-time process data and user connections should be set up. Web browsing, version control system access or remote desktop sessions do not belong to the same network connections with real-time process data such as DCS data connections or simulator executive or I/O system connections.

8.2.22. Project implementation considerations

A computer system re-host project can typically be broken down into the following major tasks:

— Migration of the simulator models, real time executive system software, and the simulation development environment to the new computer system. This may require recompiling, and in some cases re-writing, some of the simulation models, the executive system and related subroutines;
— Installation of a compatible revision of the I/O interface driver software on the new computer system and performance of basic functionality testing by using I/O system testing software (if necessary);
— A Site Acceptance Testing (SAT) should be performed on the integrated system.

The following factors should be considered in the development and implementation of the project:

— If adequate documentation is unavailable for the existing real-time executive software, it may be preferable to develop or procure replacement software rather than migrating the existing software to the new computer platform. This should ensure that adequate documentation and source code is available to the simulator support staff upon completion of the project;
— The portability of other software files, such as Initial Condition sets, switch check files, simulation databases, should also be considered in project design. It is also important to assess the costs involved in the installation of the administrative applications for these files;
— Development of a thorough test plan is important to the success of the project. All the migrated software should be tested in an integrated environment. If the upgrade path consists of a newer computer running the same operating system (i.e. the existing software

easily migrates to the new system with little or no changes required), then less testing will typically be required than an upgrade where the computer platform, operating system, and simulation environment are completely different from the original system;

- The primary factors that impact the schedule for this type of project are determination of a 'data freeze' date and the availability of the simulator for performance of acceptance testing. In the case of a 'data freeze' a decision should be made to incorporate required software changes prior to acceptance testing or shortly after the re-host project is complete;
- There need to be a comprehensive (graphical) representation of the simulator systems complex for the hardware, software and networks detailing existing and planned features and components for more effective understanding of the entire facility by all parties involved in the project. This document has to be managed and maintained by the simulator owner, unless the vendor is contracted to produce such a document.

To support simulator testing, it is recommended that a 'switching' mechanism be developed so that the control panel I/O and other connected systems can be efficiently swapped between the old and the new computer systems. This will greatly facilitate acceptance testing while minimizing the project's impact on scheduled training while also providing disaster recovery options later. Acceptance testing will typically require a certain number of transient tests to be run, to compare against baseline results on the old system. The availability of automated testing tools facilitates the performance of this testing.

A computer re-host project often entails replacement of the instructor station computers and software. This will have an impact on the simulator instructor staff as a new instructor station typically requires them to learn the HMI of the new system.

If the simulator support staff does not have adequate knowledge or experience with the new system, a training plan will be necessary. Their participation in the re-hosting project itself will provide valuable operational and maintenance experience.

8.2.23. Digital Control System implementation

The objective of a simulator DCS implementation project is to install and integrate a DCS that replicates the functionality of the system installed in the reference plant in order to comply with simulator criteria for physical and functional fidelity and as well as provide quick and easy implementation of updates to the DCS without significant work implementing said changes in simulations.

8.2.24. Digital Control System implementation options

The different options available for DCS implementation on a simulator should be assessed to determine the best solution for a project. The options currently available and their potential advantages and possible disadvantages are discussed in the following section.

8.2.24.1. Stimulation

Potential advantages are:

- The same equipment as that installed at the reference plant;
- Strict compliance with physical and functional fidelity. Development and start-up time shorter than other options;
- Facilitation of start-up and 'tuning' to system design data or actual plant data;
- Early review of human factors;

— Continuously working with the stimulated systems can improve the skills and confidence of workers compared to only working with plant systems 'as little as possible as infrequently as possible'. Especially on secondary simulators where mistakes do not have severe consequences. Indeed, an engineering simulator environment can be a very effective and cost-efficient training environment for plant technicians and engineers compared to a stand-alone training setup for the plant only.

Possible disadvantages are:

— Difficulties in implementing simulator-specific functionality (e.g. Run/Freeze, slow/fast time, time required for IC loading);
— Restricted or non-existing initial condition maintenance functionalities;
— Inability to implement control system malfunctions;
— High hardware acquisition cost (including the cost of software licenses). Instrumentation and control maintenance issues;
— Plant equipment may not be the most suitable for simulator use (outdated, underperforming equipment, obsolete operating systems etc.);
— Inability or limited ability to connect a software development system to the stimulated DCS for troubleshooting;
— Dependence on the DCS vendor for technical support and possibly for maintenance support;
— Limitation of 'simulator in the classroom' functionality;
— Problems with the link between the DCS and the simulator server, which might cause real time simulation problems and interruptions in training;
— Limitations to run DCS system on virtual machines or in several instances;
— Non-reproducible simulator behaviour;
— System response times and procedures for starting up, loading an IC, etc. procedures may be slow and difficult compared to a simulated or emulated system acting much faster;
— Configuration and version control may not be well integrated with the main simulation or require separate systems;
— Time handling inside the DCS system may be limited leading to loss of historical archive data for initial conditions.

8.2.24.2. Emulation

Potential advantages are:

— Strict compliance of HMI with physical and functional fidelity requirements;
— Lower licensing cost;
— Hardware solution independent from DCS vendor;
— Fully integrated IC maintenance functionalities;
— Reproducible simulator behaviour if the emulation runs under the simulator executive system on the simulation host computer;
— Possibility to run DCS system on virtual machines or in several instances;
— Often quicker start-up times and responsiveness;
— Configuration and version control may be integrated with the main simulation.

Possible disadvantages are:

— Need for development of a DCS emulator for the simulator environment;

- Emulation vendor support may degrade or disappear while the DCS vendor is still active;
- Possible real-time simulation issues, if the emulation runs on a computer system other than the simulation host computer;
- Need for software documentation from the DCS vendor;
- Reduced scope of simulation due to non-emulated DCS functionalities;
- Compared to stimulation, wider and deeper testing is required to ensure complete correctness of the emulated systems.

8.2.24.3. Simulation

Potential advantages are:

- The environment known to the developer and the simulator maintenance team;
- Minimal or no license cost from DCS vendor;
- Ability to add postulated DCS malfunctions into the software design;
- Hardware and software solution independent from DCS vendor;
- No problems associated with implementation of simulator functionality;
- Fully integrated initial condition maintenance functionality;
- Possibility for extremely good responsiveness (quick start-up times, IC loading and storing);
- Configuration and version control fully integrated with the main simulation;
- Possibly the only implementation method if engineering data from the plant is not yet available.

Possible disadvantages are:

- Longer development and implementation times;
- Needs in comprehensive verification and validation of functional fidelity (control and HMI functions) for the initial deployment and updates during the life cycle of the systems;
- The nature of ‘proprietary information’ with respect to DCS functionality, that may vary from vendor to vendor, but could be a significant stumbling block to this implementation method;
- Need for detailed software documentation from the DCS vendor;
- HMI look will be different, faithful reproduction of graphical look and feel may be impossible due to copyright issues.

Note: Combinations of the three implementation methodologies are possible (e.g. emulation of the DCS I&C functions and stimulation of the HMI).

8.2.25. Methodology selection considerations

The DCS to be installed is selected by the NPP based on its needs and requirements, however the NPP need to include the features of the DCS system in regards of training possibilities and simulator compatibility in its evaluation of requirements and capabilities. Therefore, the possible simulator implementation methods may be pre-determined or restricted by this decision. For example, selection of a specific DCS may limit the implementation method to stimulation if the vendor is unwilling to provide the proprietary information necessary to emulate or simulate the system.

Another factor to be considered is which implementation method results in the best fit with the simulator environment. The simulator environment may not be able to support an implementation method without modification to either the simulator or DCS hardware or software. For example, digital control systems are designed to run reliably in real time in order to perform their plant process control and monitoring functions. Simulator-specific features such as run, freeze, reset, backtrack are not typically supported by a DCS. Therefore, this would be a significant consideration for the simulation implementation method, as some means of integrating these features into the DCS should be developed.

The simulator real-time executive system controls the execution rate of all tasks that run on the simulation computer. If stimulation is chosen as the implementation method, a communications link should be established between the simulator real-time executive and the DCS. This data link should be fast enough to ensure that data is exchanged between the simulation computer and the DCS in real time. This is particularly important for systems that must deal with fast transient behaviour (e.g. turbine control systems). Establishing this link may require the implementation of customized software on the simulator side, the DCS side, or both. This problem is typically not a concern for emulation or simulation because the actual DCS system hardware is not involved. In the case of emulation or simulation, the associated software normally runs on the simulation computer, and the simulator real time executive controls its execution.

Most digital control systems include a proprietary Human-Machine Interface (HMI) for operation of the system and monitoring of controlled process variables and system alarms. In many cases, the HMI can be customized to the specifications of the NPP. The HMI on the simulator should have the same "look-and-feel" and response time as the actual plant system. This is typically not a concern for stimulation as that implementation method utilizes the same hardware and software as the reference plant. This is a concern for emulation and even more so for simulation as detailed proprietary information is typically required to accurately reproduce the various HMI control screens, as well as the screen navigation logic and functions. If the DCS vendor is unwilling to provide this information as part of the project contract, then the simulation implementation method may not be a viable option. This same consideration is also applicable to the logic and control functionality of the DCS. If the vendor will not provide access to the functional control blocks or ladder logic for the system, then it may be impossible to emulate or simulate the system.

The ability to integrate an implementation method into the simulator software development and maintenance environment should also be considered in the selection process. This consideration mainly concerns the debugging capability of the DCS (e.g. for testing and fixing problems with the system logic, HMI, and other functions). Adequate software debugging tools on both the simulator and DCS sides of the system are necessary in order to ensure fast turnaround when fixing bugs or implementing system changes. For the simulation and emulation implementation methods 'translators' should be provided or developed in order to automate the process of updating the logic and HMI of the DCS when changes are made to the system in the reference plant. This is typically not a concern for stimulation in that changes made to the plant system should be directly transportable to the simulator system.

The ability to easily update simulator initial condition data when changes are made to the DCS software is also a selection consideration. In many stimulated systems IC data is stored on both the simulator computer and the DCS computer, making the update of IC data more complicated. Emulated and simulated systems typically store IC information on the simulation computer. In both cases, having software tools available to automate the update of IC files following changes to the DCS software is very desirable as stabilizing and re- snapping each IC is a time-consuming process.

Many simulators have at least two separate and redundant computer systems. One system is used to run the simulator for training and the other is used for software development and testing. This development system may also be configured as a backup training system if problems are experienced with the primary system. Therefore, the ability to connect to or run the DCS software from the development system is another selection consideration.

For a stimulated implementation, the DCS hardware should be switchable between the primary and the development system, or a redundant set of DCS hardware could be purchased, with the latter being the more costly option. In this regard emulation and simulation have an advantage in that the DCS software runs on the simulation computer. Therefore, a method of hardware switching, or the purchase of additional DCS hardware to implement the desired redundancy is unnecessary.

Some additional factors to consider in the selection process may include:

- Are the simulator models being used or will they be used in a classroom environment? If so, stimulation may not be a feasible option.
- What is the overall cost comparison for each option, and what are the future maintenance and support requirements and costs?
- How will DCS alarm and trending functions be implemented on the simulator?
- What type of physical changes to the control panels, operating consoles, etc. will be required in the reference plant and consequently the simulator?
- Does the DCS system support multiple versions of the system software and especially application data on the same system? Often it is desirable to have at least a training and testing 'load' which can be switched quickly. Additional loads may be necessary for training different plant units with slightly different implementation or different stages of updates.

8.2.26. Digital Control System verification and validation

The hardware and software verification and validation (V&V) that is accomplished as part of system acceptance testing (Factory Acceptance Testing (FAT), Site Acceptance Testing (SAT), etc.) is important to the success of a DCS implementation project. The process of DCS V&V is dependent upon the selected implementation method, the schedule for installation of the system on the simulator and in the reference plant and upon requirements from the authorities.

In the case where the simulator DCS installation occurs after DCS installation in the reference plant, V&V testing should be based upon a direct one-for-one comparison of the simulator system with the plant system (i.e. physical and functional fidelity). Simulator V&V test procedures can be based upon actual system operating and test procedures. This should be the case regardless of the DCS implementation method selected for the simulator. In the case of stimulated and possibly emulated systems, it will also be necessary to test the simulation features incorporated into the DCS. For example, the ability of the DCS to support simulator functions such as Run, Freeze, Reset, Backtrack, IC snap and restore, malfunction insertion should be included in the test plan. For simulated systems it is also important to test the ability to update the DCS models when changes are made to plant design.

Irrespective of regulatory requirements from the authorities there are several further advantages to installing a DCS on the simulator, prior to installing it in the reference plant:

- The ability to train plant operating personnel with DCS system operation in advance;

- The ability to use the simulator as a 'test bed' for operating or commissioning procedure validation, prior to the start of the hot commissioning tests on the reference plant;
- The ability to use the simulator as a 'test bed' in the preliminary and final design stages of the project in order to identify and correct hardware and software design and installation issues, prior to plant installation. This type of testing is beneficial regardless of the implementation method selected for the simulator;
- Minimizing project risks during the commissioning phase of the plant and possibly of shorter outage time of the plant. A proper virtual commissioning of the full system in all plant operating modes on the simulator can greatly reduce the changes required to the system during plant commissioning.

In the case where the simulator DCS installation will occur prior to plant installation, the simulator should become part of the engineering process of the DCS vendor and should serve as a test bed for pre-testing the DCS prior to commissioning the DCS on the plant. Therefore, plant and simulator projects should be synchronized from the very beginning in order to minimize project risks for the plant. This becomes even more evident if the operating personnel from the plant must be trained with the new DCS on the simulator, prior to system operation on the plant.

A common project schedule, including test and data delivery plans for the simulator should be contractually agreed upon between the NPP and DCS vendor (FIG. 19). For example, the project schedule of the commissioning of a DCS in the NPP should consider completion dates for the V&V on the simulator and, if requested, operator training on the simulator, prior to the operation of the DCS on the plant. It depicts the principal dependencies between the NPP and simulator projects.

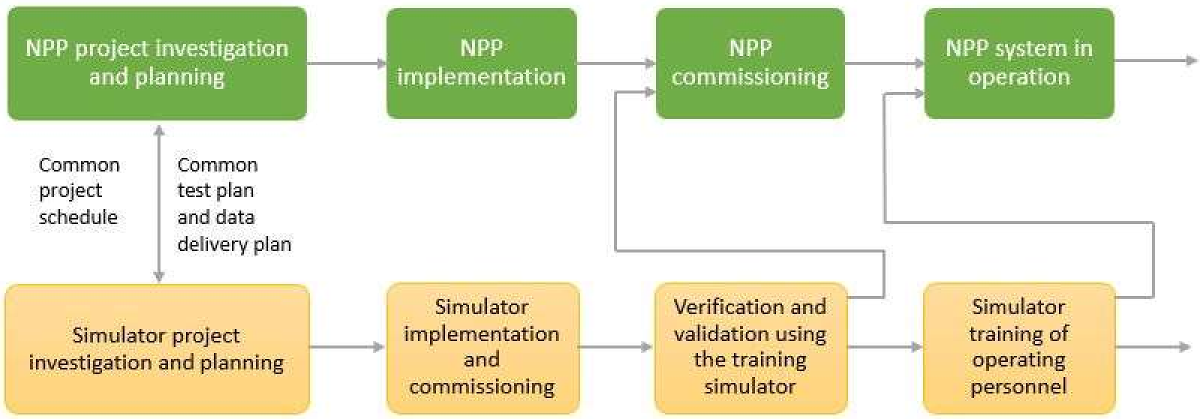

FIG. 19. A common simulator project schedule, including test and data delivery for the simulator.

The acceptance test program should include a broad spectrum of tests that exercise both DCS functionality as well as simulator integrated operation in order to assess the overall impact of DCS installation on simulator operation (FIG. 20). Examples of these tests include steady-state operation, transient behaviour, and response to selected malfunctions. A durability or trouble-free operation period is recommended to ensure robustness and high availability for training activities. Once the simulator SAT is complete, operator training may be conducted.

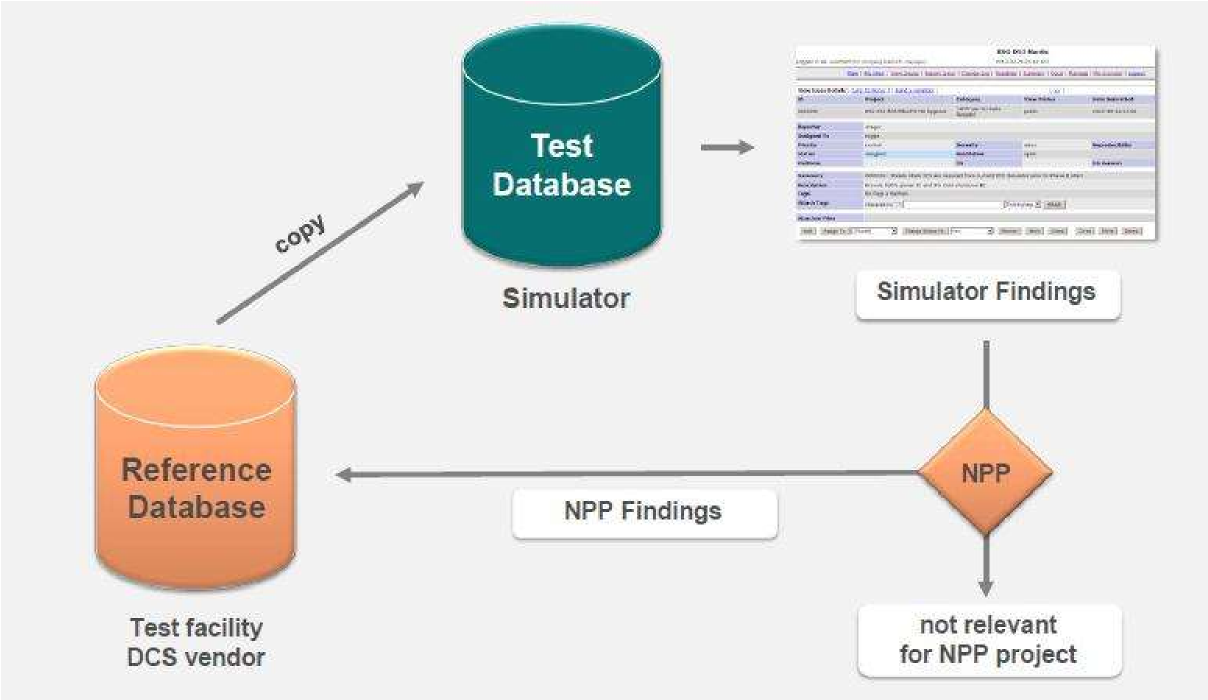

FIG. 20. The acceptance test program should include a broad spectrum of tests that exercise both DCS functionality as well as simulator integrated operation in order to assess the overall impact of DCS installation on simulator operation.

Since it is possible for changes to be made to the DCS design after installation on the simulator and prior to installation in the plant, it is recommended that an 'as-built' verification be conducted following plant installation. Any differences noted should be corrected on the simulator as part of the normal software configuration management process.

8.3. PLANT PROCESS COMPUTER SYSTEM UPGRADE OR REPLACEMENT

A Plant Process Computer (PPC) system is a data acquisition, analysis, and display system that typically has no process control functions. The objective of a simulator PPC upgrade or replacement project is to replicate the functionality of the system installed in the reference plant in order to comply with simulator criteria for physical and functional fidelity.

8.3.1. Basis for upgrade or replacement of the simulator plant process computer system

Much of the information discussed for DCS implementations is also applicable to an upgrade or replacement project for a PPC. For example, the possible implementation methodologies are similar, along with their attendant advantages and disadvantages. PPC upgrade or replacement projects are typically initiated by the reference NPP, based upon one or more of the following factors:

- The existing system is functionally obsolete and expensive to maintain and repair;
- The PPC vendor is no longer in business and the system is unsupported;
- Repair parts are not available from the vendor, obsolete, unobtainable or scarce in the secondary market;
- The enhanced capabilities and features of a newer PPC will improve the operational environment of the NPP.

If the existing simulator PPC is a simulated or emulated system, then it is possible for the simulator system to be upgraded, even if no changes are planned to the system on the reference plant. This type of project typically upgrades the computer system that runs the PPC simulation and has no impact on the HMI or functionality of the system itself. If the PPC simulation runs on the main simulation computer, then replacement or upgrades of that system could be included in a computer re-host project.

8.3.2. Methodology selection considerations

As discussed in the previous section, a PPC upgrade or replacement project is typically initiated by the NPP based upon its operational needs and requirements. Therefore, the possible simulator implementation methods may be pre-determined or restricted by this decision. For example, selection of a specific PPC system may limit the implementation method to stimulation if the vendor is unwilling to provide the proprietary information necessary to emulate or simulate the system.

As previously mentioned, PPC implementation methodologies are like those discussed for DCS implementations. Therefore, factors to be taken into consideration for selection of a PPC implementation method might include:

- How well will a method fit with the simulation environment, i.e. how will it support simulator-specific features such as Run, Freeze, Reset, Backtrack?
- For a stimulated PPC, how will be the link to the simulation computer established?

Most PPCs have a customizable HMI. If simulation is chosen as the implementation method, then the simulated HMI should be tested thoroughly to ensure the ‘look and feel’ and functionality of the system adequately replicates the actual system:

- How well does the chosen implementation method fit into the simulator software development and maintenance environment?
- If the system is simulated, will ‘translators’ be provided or developed to automate the process of updating the simulator software when changes are made in the reference plant?
- Where will IC data be stored, and how easily existing ICs can be updated when changes are made to the system?
- What type of physical changes to the control panels, operating consoles, etc., will be required in the reference plant and consequently the simulator?
- How will a chosen method interface with the simulator development computer system? For example, if the PPC is stimulated, will it require a hardware switch to enable connection to the simulator computer, as well as the development computer, or should a second set of PPC equipment be purchased for this purpose?
- Will ‘simulator in the classroom’ functionality be required? If so, then stimulation may not be a feasible option.
- What is the overall cost comparison for each option and what are the future maintenance and support requirements and costs?
- Which method will result in the least simulator ‘downtime’ during installation, i.e. which method will have minimal impact on scheduled training? Is it possible to switch between the old and the new systems to support training and still allow the necessary testing to be conducted?

8.3.3. PPC verification and validation

The hardware and software verification and validation (V&V) that is accomplished as part of system acceptance testing (Factory Acceptance Testing (FAT), Site Acceptance Testing (SAT), etc.) is important to the success of a PPC upgrade or replacement project. The process of PPC V&V is dependent upon the selected implementation method and upon the schedule for installation of the system on the simulator and on the reference plant. An integrated test plan should be included in the project schedule.

In the case where the simulator PPC upgrade will occur after installation in the reference plant, V&V testing should be based upon a direct one-for-one comparison of the simulator system with the plant system (i.e. physical and functional fidelity). Simulator V&V test procedures can be based upon actual system operating and test procedures. This should be the case regardless of the PPC implementation method selected for the simulator. In the case of stimulated and possibly emulated systems it will also be necessary to test the simulation features incorporated into the PPC. For example, the ability of the PPC to support simulator functions such as Run, Freeze, Reset, Backtrack, IC snap and restore, Malfunction insertion should be included in the test plan. For simulated systems it is also important to test the ability to update the PPC software models when changes are made to the reference plant system.

In the case where the simulator PPC upgrade or replacement will occur prior to plant installation, V&V testing will be based upon system design data. This information is typically obtained from the NPP engineering group or directly from the PPC vendor. It is recommended that a member of the simulator support staff is involved in factory acceptance testing, and that NPP engineering and PPC vendor personnel are involved in simulator acceptance testing.

Once the simulator SAT is complete, operator familiarization training may be conducted.

Since it is possible for changes to be made to the PPC design after installation on the simulator and prior to installation in the plant, it is recommended that an 'as-built' verification be conducted following plant installation. Any differences noted should be corrected on the simulator as part of the normal software configuration management process.

There are several advantages to upgrading or replacing the PPC on the simulator prior to making modifications to reference plant, including:

- The ability to familiarize plant operating personnel with system operation;
- The ability to use the simulator as a 'test bed' in the preliminary and final design stages of the project, in order to identify and correct hardware and software design and installation issues, prior to plant installation. This type of testing is beneficial regardless of the implementation method selected for the simulator.

8.3.4. Instructor station upgrade or replacement

The Instructor Station (IS) is a computer system or other dedicated device that is utilized by the instructional staff to control the simulator. The objective of an IS upgrade or replacement project is to improve the capability and/or flexibility of the system.

8.3.5. Basis for upgrade or replacement of the simulator instructor station

Typical justifications for replacement or upgrade of the simulator instructor station may include:

— The IS computer platform is obsolete and/or is no longer supported by the supplying vendor;
— The system has become troublesome and expensive to maintain. Parts may be difficult or impossible to obtain;
— A simulation computer system re-host project requires implementation of a new Instructor Station;
— The existing capabilities of the instructor station are inadequate and/or the interface is inflexible or difficult to use. For example, the number of initial conditions supported by the current system is inadequate.

8.3.6. Instructor station upgrade or replacement project considerations

Factors for consideration on a simulator instructor station upgrade or replacement project:

— Unless the instructor station interface is outdated, or the system is troublesome or difficult to use, the instructional staff may resist replacing it with something 'different'. Existing IS features such as system and panel graphics, malfunction lists, pre-scripted scenario files, that can be 'replicated' in or ported to the new instructor station will simplify the learning curve for the instructors on the new system;
— Most modern simulator instructor stations are highly customizable by the user. Involving one or more experienced instructors in the design stages of the project will ensure that the product meets the customer's needs;
— 'Ease of use' is an important selection consideration for a replacement IS. Most modern instructor stations make excellent use of graphics capabilities to display information and simplify simulator operation. Examples of desirable graphics capabilities include:

- Dynamic piping and instrumentation diagrams that display process information and allow malfunction insertion and remote function control, directly from the system diagrams;
- Dynamic virtual control panels (also called 'soft panels') that are graphical representations of the actual control panels, including their associated controls and instrumentation. Soft panels enable control of simulated systems via manipulation of the graphic objects that represent the actual panel controls. Some advantages of soft panels include:

  - The ability to enable or disable plant controls via insertion of malfunctions or I/O overrides directly from the soft panels;
  - The ability to operate the simulator when the simulation computer is not connected to the control panel I/O. This capability can be beneficial for software troubleshooting, off-line training scenario development implementation, for 'simulator in the classroom' capabilities if desired;
  - Extensive charting and trending capabilities;
  - The ability to export graphics files in various standard formats is a valuable tool for data analysis and simulator testing;
  - IS support for a simulator remote control device allows the instructor to control the simulation from the simulator floor while maintaining close contact with the trainees;
  - The new IS should fit well into the existing simulation environment to ensure long-term maintainability;

- The ability to record and playback the control panel manipulations performed by the trainees is a useful tool for trainee evaluation as well as for simulator troubleshooting;
- The ability to create 'scenario' or 'script' files to automate various IS functions is a desirable time saving feature. For example, this feature could be used to activate one or more malfunctions simultaneously, or to automate routine simulator testing;
- The ability to automatically generate links between IS functions and the simulator database for malfunctions, remote functions, I/O overrides, etc., would save a significant number of project man-hours as compared to manually generating these links;
- Developing a method of switching simulator control between the old and the new instructor station will facilitate system testing;
- Training on the operation of the new IS should be provided to the instructional staff prior to releasing it for use.

8.3.7. Instructor station verification and validation

Thorough acceptance testing of the new instructor station is critical to the success of the project. It is recommended that one or more members of the instructional staff be assigned to participate in IS testing. A detailed SAT should be developed that tests the entire scope of IS functionality. This testing should include the following:

- Function of all basic features such as run, freeze, reset, backtrack, snap IC;
- Linkage to all control panel I/O addresses;
- Control capability of all malfunctions, remote functions, I/O overrides, etc. linkage of all IS graphics objects with simulator database variables; function of all new IS features.

8.3.8. Modification of simulator control panels

The need to modify the simulator control panels is based upon the requirement to maintain physical and functional fidelity with the reference NPP. Projects to modify the simulator control panels may vary considerably in scope and complexity. Factors that should be considered in a project of this type are discussed in this section.

8.3.9. Basis for modification of simulator control panels

As discussed above, the primary basis for performing significant modifications to the simulator control panels is the need to maintain physical and functional fidelity with the reference NPP. This report does not address minor modifications of panel hardware (e.g. replacement of an individual meter or switch) which should be implemented as part of the normal simulator hardware configuration management process. Examples of reasons for major panel modification projects might include:

- Installation of a new DCS, PPC, or some other instrumentation and control system in the reference plant requires significant modifications to the existing control panels or installation of new panels;
- The original installation of the simulator control panels was limited in scope and the modification project extends the scope of simulation. For example, installation of the remote shutdown panels or other auxiliary panels;
- Obsolete panels in the reference plant are being removed or abandoned necessitating similar modifications to the simulator;

— New or upgraded communication systems (e.g. telephones systems, wireless communication systems, plant paging systems) are being installed in the reference plant and therefore must also be installed on the simulator;
— There has been a change to the reference plant for the simulator. For example, the simulator reference plant is currently Unit 1 for a NPP, and it has been decided to change the reference plant to Unit 2 or 3.

8.3.10. Control panel modification project considerations

Some factors to consider for a control panel modification project (FIG. 21) might include:

— Does the project schedule minimize simulator unavailability time during implementation of the panel modifications? Most panel modifications will require that work be performed during a 'simulator outage' where the simulator will be unavailable for training.
— If possible, include the simulator upgrade cost within the overall project cost for the NPP panel modification.
— Does the simulation facility have adequate infrastructure to support installation of new panels and associated equipment? For example, is there a enough and stable electrical supply; and is access to the installation adequate, without requiring major building modifications (e.g. knocking down walls)?
— If the project is adding new panels or new equipment to existing panels, does the simulator I/O system have an adequate number of spare connections to support the installation or will an I/O system upgrade be required.
— If a vendor is involved in the project, a detailed project bid specification should be developed. A vendor's experience with similar projects should be a consideration in the vendor selection process.
— Will the simulator be used as a 'test bed' for reference plant modifications? If so, the simulator work should not be performed until the plant design is finalized. If this is not feasible, then a design data 'freeze' may be necessary for the simulator work. If changes are made to the plant design after installation on the simulator, costly re-work may be required to match the installed plant configuration. Another option may be to create a full-scale mock-up or a virtual panel prototype for the project to test the design, prior to performing any modifications to the simulator or the NPP.
— If simulator modifications occur, following plant installation, then detailed 'as-built' data will be required from the NPP. It is recommended that high resolution photographs be taken of the actual control room panels in order to allow a detailed comparison between the plant and the simulator. This is particularly important for accurate equipment placement and labelling on the new or modified simulator panels.
— What changes should be made to the simulator software environment and/or the system models to support the new panels?
— Does the design of new panels include adequate maintainability features such as easy access for maintenance and compatibility with the simulator I/O equipment?
— Is familiarization training on the panel modifications for the simulator staff, the simulator instructors, and the plant operators included in the project schedule?
— Have adequate spare parts and consumables to support the control panels' modifications been included in the project cost estimate?

FIG. 21. Control panel modification project for Biblis B Full Scope Simulator (Germany).

8.3.11. Verification and validation of control panel modifications

Thorough testing of control panel modifications is critical to the success of the project. It is recommended that one or more members of the instructional staff be assigned to participate in acceptance testing. A detailed SAT should be developed that tests the entire scope of the functionality of all control panel modifications. This testing should include the following:

- Complete testing of all new I/O points and their associated memory addresses and database variables. The availability of an automatic or semi-automatic testing system should reduce the amount of time needed for this testing;
- Careful comparison of the simulator configuration with the 'as-built' reference plant configuration;
- Some amount of integrated testing (i.e. normal and transient plant operations) is suggested to verify the overall functionality of the panel modifications with the simulation models.

8.3.11.1. Upgrade or replacement of simulator audio/video recording systems

While not technically a part of the simulator in terms of modelling plant behaviour, the simulator's A/V recording system is a useful tool for monitoring operator performance. The instructional staff can utilize recordings of training or examination scenarios as an aide in the critique and feedback process in the operator training programmes.

Advances in A/V technology have made many of the recording systems originally delivered with a simulator obsolete. An evaluation of the performance and capabilities of the existing A/V system should be made to determine if it meets the needs of the operator training programmes. General recommendations for upgrading a simulator A/V recording system include:

- Involve the instructors or other current users of the system in the specification and selection of replacement equipment or systems. This should ensure that the replacement equipment meets the needs of the customer;

- It may be necessary or desirable to involve an experienced A/V vendor in the design, specification, and installation of new components if the in-house simulator staff do not have the requisite knowledge or experience;
- If only selected components of a system are to be upgraded (video cameras, microphone systems, or recording media), they should be compatible with the components that will not be upgraded;
- It needs to be clarified with the training department if the A/V recording system needs to be synchronized with the instructor station to incorporate simulator functionalities during recording;
- If the A/V recordings are planned to be used in de-briefing activities directly after a training session, good recording, synchronizing and management of the simulator replay functions, and the recorded A/V material need to be developed.

8.3.11.2. Considerations for use of simulator models in a classroom simulator

Extending simulation outside the simulator control room has many advantages that enhance plant personnel training. Examples include:

- Demonstration of theoretical concepts (e.g. reactor theory and thermodynamics) to reinforce traditional classroom training;
- Familiarization of control room operator trainees with the location and purpose of control board controls and instrumentation;
- Demonstration of plant system operational characteristics to support plant systems training in all plant training programmes. This is particularly beneficial for training of plant field operators (i.e. non-licensed operators) or other plant support staff who do not typically receive training on the simulator;
- Training of the whole crew of operators, including control room operators and field operators.

The ability to implement classroom simulator capabilities is highly dependent upon number of factors, including:

- Does the existing simulator instructor station support virtual control panels or soft panels? If not, it may be necessary to upgrade the simulator first to support this functionality. A classroom simulator could be included in the scope of a simulator upgrade project.
- Can the project be accomplished in-house, or will vendor support be required? If a vendor is involved in the project, then a detailed bid specification should be developed.
- Will the classroom simulator require an increase or a decrease in the scope of simulation? For example, is the scope of simulation for local control panels (i.e. those located outside the reference NPP control room) adequate?
- Will the simulation models be ‘served’ to the classroom environment over a network in a virtualized environment or will the simulation load run on a stand-alone computer?
- Will the classroom simulator be mobile (i.e. movable to different classrooms) or stationary?
- Will the classroom simulator fall under the simulator software configuration management program? If not, what method will be used to keep the classroom simulator software current with changes made to the control room simulator software?
- What display and interface technology will be used for the classroom simulator? For example, will the simulation be projected using a computer projector onto a screen or interactive whiteboard, or will individual computer monitors be used?

— If there are stimulated systems on the control room simulator (e.g. a DCS, PPC), then some method should be employed to simulate these systems on the classroom simulator or to limit the scope of the classroom simulator to exclude the stimulated systems.

9. CONSIDERATIONS FOR NEW BUILDS

9.1. TIMELINE AND TYPICAL SCHEDULE

Nuclear New Build Power Plants (NNB) are typically required to license/authorize Operators using a reference design full scope simulator prior to commercial operation, with the typical milestone for demonstrating the licensing/authorization of the shift crew complement being prior to fuel delivery to Site. The duration of an initial operator training programme, coupled with the volume of licensed/authorized operators required and the need to develop senior operators i.e. supervisors and shift managers, means that the overall programme to achieving the required number of licensed/authorized operators, prior to commercial operation, can be typically 3 or 4 years.

In addition to training the Operators there is a need to first develop a pool of trained operations instructors which can add another 2 or 3 years to this programme time.

Simulator facilities to commence the instructor training programme are therefore potentially required 5 to 7 years ahead of commercial operation.

Unless the NNB is a direct copy of an existing plant, then the availability of reference full scope simulation facilities 5 to 7 years ahead of commercial operation are impractical. Therefore, it is suggested that a phased approach is adopted which enables effective simulator training. This to commence on reduced scope simulator platforms but schedules periodic upgrades into the plan. It has to incorporate reference design modifications to both the simulator modelling and physical control room environment.

Following a scheduled simulator update, additional training may be required for those operators who have already completed training effected by a later update. This will be based on an assessed training need of the impact to subsequent training as a result of the latest simulator update. Hence Operator licensing/authorization being achieved by completing a base programme on the initial reference design simulator and a series of update training modules designed to capture any additional defined training needs (gaps in the earlier training resulting from later simulator updates).

Since licensing/authorization of Operators is expected prior to the completion of commissioning activities and prior to obtaining feedback from actual plant data, a further scheduled update is typically planned to capture learning from the commissioning and initial commercial operation activities.

Phases of Operator Training for NNB are therefore typically structured as (FIG. 22):

— Initial Instructor Training (based on reduced simulator platforms);
— Bulk Operator Training (based on initial reference design);
— Pre-Operation Update Training & Authorisation (based on updated reference design, during NNB design & delivery phase);
— Post Operation Update Training (based on updated reference design following commissioning and Initial Commercial Operation).

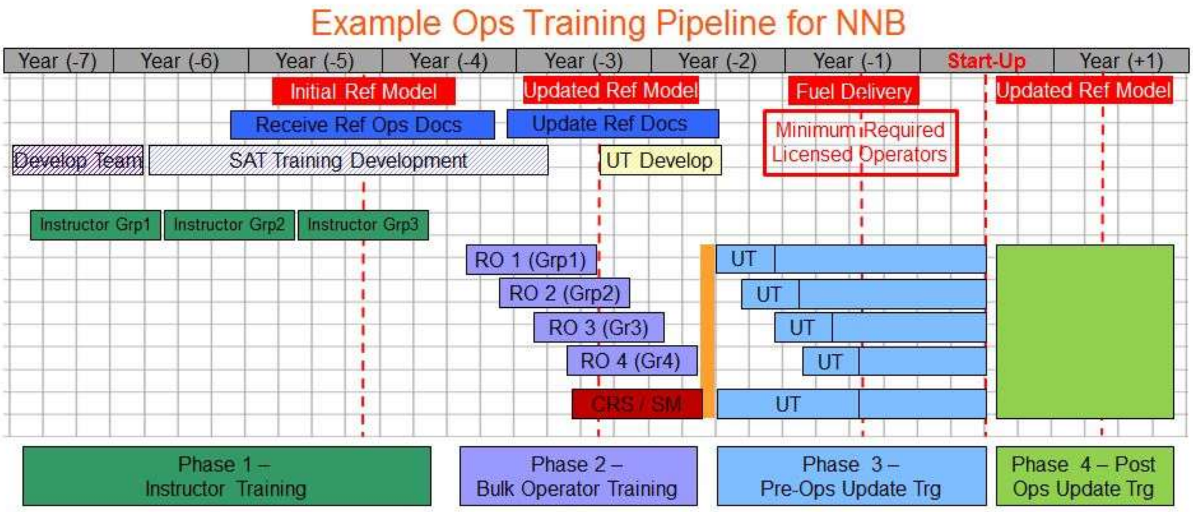

FIG. 22. Schedule example of operators training pipeline for NNB. Hinkley Point C, EDF Energy, United Kingdom.

9.2. MANAGING TRAINING NEEDS

The training of Operators needs to be managed effectively during all phases of the programme i.e. Design, Construction, Commissioning and Initial Operation.

The main challenges to ensuring the competence of the Operators prior to Commercial Operation of a New Nuclear Build are:

- Availability of a full scope 'replica' simulator running the reference design;
- Availability and training of Seed instructors;
- Incorporation of design modifications resulting from the design validation process, construction and commissioning activities;
- Alignment of training simulator modelling with engineering simulator requirements and development;
- Lack of real plant data to validate the simulator modelling;
- Availability of reference design Operational Documentation;
- Insufficient information to conduct an effective Training Needs Analysis and therefore late development of the Simulator training programme, both for the initial programme and subsequent update training;
- Lack of field experience to complement simulation training;
- Regulatory acceptance of modifications which are postponed to the post operation update phase.

For Initial Instructor Training, consideration should be given to utilising simulator modelling based upon the core reference design for the New Nuclear Plant, coupled with HMI (human machine interface) stations which enable key operator actions to be implemented in accordance with the associated Operational procedures. These HMI interfaces typically take the form of access to existing international core design simulator facilities or development of computer-based VDU or Soft Panel displays.

For Bulk Operator Training it is anticipated that an initial reference design, both in terms of plant systems and control room environment is available, along with the associated operations procedures, which can be used as the basis for developing and delivering an initial reference plant simulator platform. Depending on the scope of any anticipated updates it may not be practical or cost effective to conduct this training on a ‘replica’ Control room environment simulator, hence consideration may be given to extending the Instructor Training platform(s) or delivering an interim reduced scope platform. The present preferred practice, in the use of simulators on Nuclear Power Plants, is to have the modelling of the initial reference design simulator identical to that used for engineering purposes. Additional trends in control room operation from HMI being based on fixed IO (input/output) panels to computer-based operation, this may influence the type of reduced simulator platform chosen and the extent to which the training needs can be met (FIG. 23).

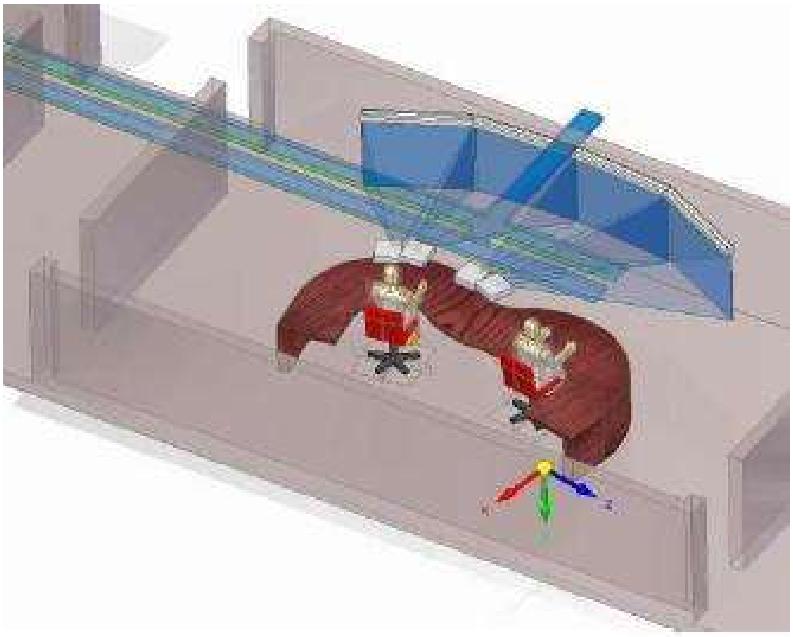

FIG. 23. Example of Initial Instructor platform. EDF Energy United Kingdom.

For Pre-Operation update training it is expected that there is a step or phased transition from any reduced/interim platform to a replica control room platform, which conforms to a relevant standard After each update, additional training would be provided to capture the training need associated with this update (FIG. 24). Licensing/authorization would be conducted following the last update, prior to commercial operation (FIG. 25) if the Operations training simulator modelling is aligned with the standard (i.e. ANSI-3.5 [6]). After each update, additional training would be provided to capture the training need associated with that particular update. Licensing/authorization would be conducted following the last update prior to commercial operation.

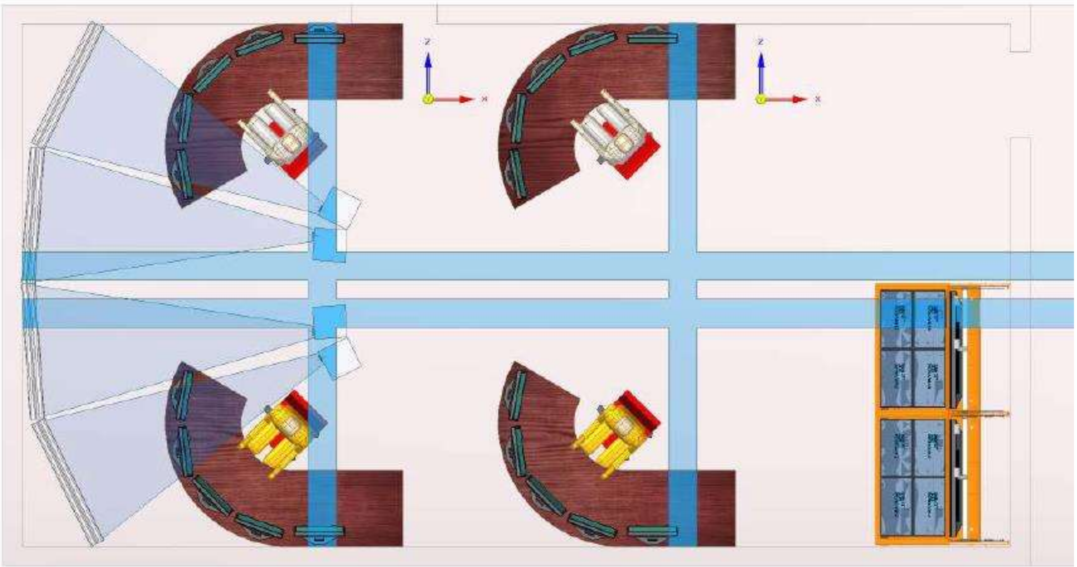

FIG. 24. Updated/Interim Platform to support BULK Operator Training.

FIG. 25. Full Scope Reference Platform for Update Training and Authorization, EDF Energy United Kingdom.

If the Operations training simulator modelling is aligned with the engineering simulator modelling, configuration control requirements and hence planned updates should be managed in an integrated manner, with the expectation that the engineering simulator modelling would incorporate design changes in an evolutionary manner and updates released to the training model at defined design configuration milestones. It may be necessary, to defer known design changes to the Post Operation update phase but it would be expected that any deviations to the relevant standard are justified to the licensing/authorizing body.

For Post Operation Update Training it is expected that the learning from the commissioning phase and initial operations phase, along with any deferred design changes are incorporated in a timely manner (typically within one year) and associated training needs incorporated within the continuing training programme.

10. SUMMARY

Operational experience shows human error as a great contributor when it comes to the risk of severe accident in a nuclear power plant. Following the Three Mile Island accident important improvements were made globally to reduce potential human errors. This was done through improved procedures and training of operators. The use of full scope simulators are vital in the efforts to reduce human errors. The training programmes for operators includes a large portion of training and retraining on the simulator and needs to integrate normal, abnormal and accident conditions. Simulator training is an integrated part of the operator's initial and continuing programmes. The importance of the simulator strictly characterizing authentic conditions and environment that would be practical in an actual situation is critical to the training and the expected outcome.

The use of simulators for the training and qualification of control room operating personnel is typically required by regulatory bodies of the IAEA Member States and has become a standard practice throughout the world. Simulators are used to develop, assess, and maintain the fundamental operator knowledge and skills required for safe and efficient plant operation.

The role of the simulator as a tool in training is to develop and reinforce knowledge of plant systems and their relationships; to apply plant procedures and the practical skills to operate the plant in different conditions. The simulator supports the development of supervisory skills and teamwork. Simulators are also utilized to conduct the authorization or licensing examinations of control room operating personnel.

Additionally, there is an increasing trend in the usage of simulators for non-training purposes including plant operating procedure validation, emergency plan drills and exercises, verification and validation of plant design changes.

The involvement of managers in all SAT phases is important factors to reach desirable behaviours in the field and has effect on both personnel and facility performance. Examples of involvement are to be part of the simulator training needs analysis and to observe simulator exercises.

Staff other than operators such as managers, field operators and technical support personnel also receives simulator training.

The simulator instructor selection needs to be based on both technical and human competencies and they receive initial and continuing simulator instructor training.

The simulator needs to be effectively maintained and upgraded when necessary to ensure that it continues to be a feasible training tool that accurately replicates the operational characteristics of the reference NPP. NPP management personnel — in conjunction with Training Department management, and simulator maintenance and engineering support personnel — have to continuously monitor and evaluate the performance of the simulator in order to identify the need for upgrade or modernization. The need for simulator upgrade or modernization may be derived from simulator training or operational requirements, regulatory requirements, system upgrades in the field or from the requirements of other simulator users.

To ensure project success, an upgrade or modernization of the simulator needs to be conducted based upon the proven project management principles and methods.

The project development process needs to consider all project management tasks including:

— Solution assessment;
— Identification of project constraints;
— Establishment of a project organization and assignment of responsibilities;
— Assessment of project performance.

The types of simulator upgrade and modernization projects most typically met for NPP simulators include:

— Simulation model upgrades;
— Simulator input/output system replacements or upgrades;
— Computer system re-host projects;
— DCS installations;
— Plant process computer system upgrades or replacements;
— Instructor station upgrades;
— Control panel modifications or upgrades;
— Implementation of supplemental simulation systems.

Effective methods for authorization of control room personnel includes SAT to validate the written, oral, and performance examinations used in the authorization process. This ensures both that the examinations are valid and reliable and that they are fair measure of the operators required knowledge, skills and attitudes (KSA).

Simulator examinations are a crucial tool to help ensure safe NPP operation and they need to be accurately resourced with well-informed training, support and assessment personnel, whose skills are normally in high demand throughout the organization.

Simulator instructors and assessors may be required to maintain or have held an authorization as an operator, or at a minimum ensure they receive the appropriate simulator instructor and/or simulator assessor training.

In general, the approach to the authorization process need to add values to the overall control room personnel training programmes and wherever possible, be helpful of training activities and continuous improvement. This will guarantee a positive relationship between the operating organization and the regulatory body.

APPENDIX.
SURVEY ON SIMULATOR-BASED TRAINING AT NPPS

A survey intended for managers responsible for simulator-based training at NPPs in all operating Member States (30) was sent in August 2018. The response rate was 50%, 15 responses from 13 operating countries responded.

The topics for the survey were about what group of staff the Member states train using different types of simulators such as basic principle simulators, full scope simulators, classroom simulators and multifunctional simulators.

The survey also included questions about the frequency of training and examination as well as different examination types in the Member states.

Finally, the survey explored the examination pass mark percentages for the respondents.

Information extracted from this survey is included in FIG. 26-*FIG. 30*.

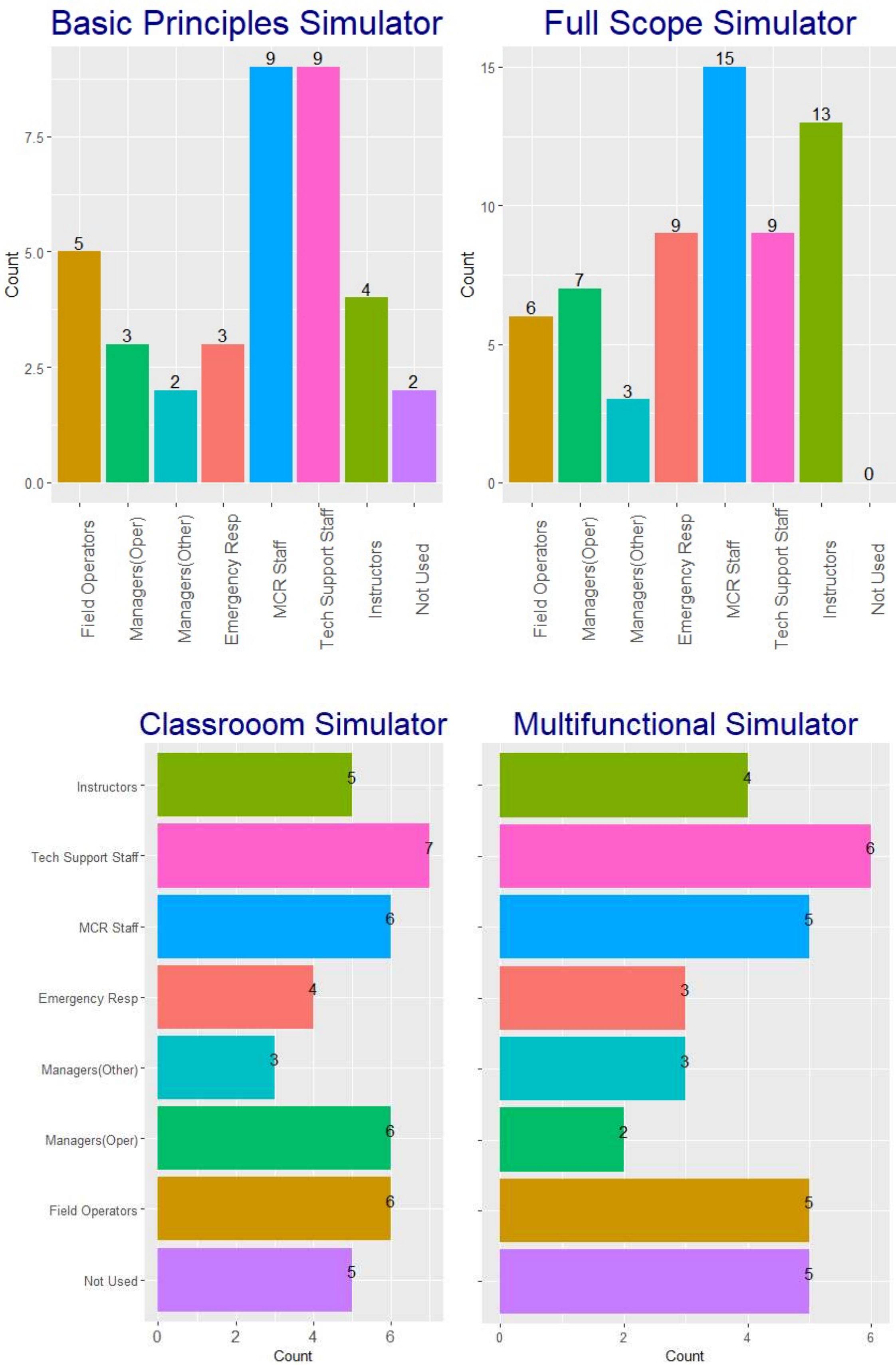

FIG. 26. Simulator types most widely used in different NPP departments in Member States

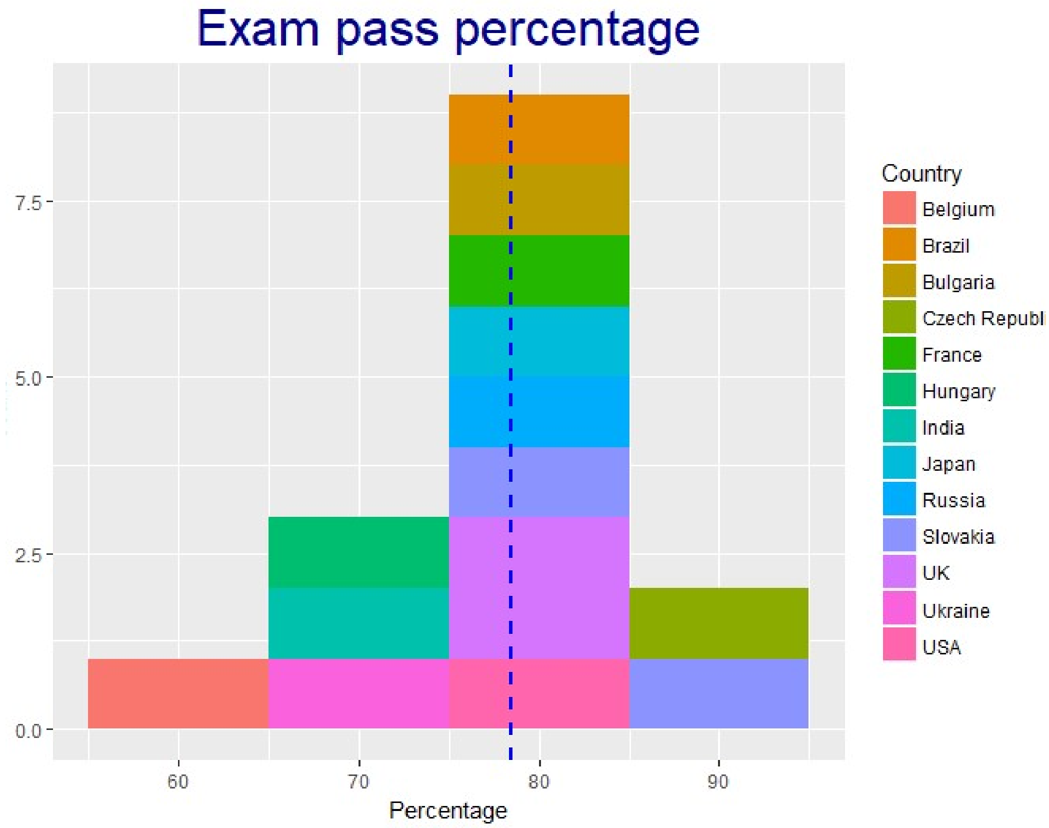

FIG. 27. Different percentage of examination pass requirements in Member states

— The percentage enough to pass the exam varies, between the range 60%-90%;
— The highest score belongs to Slovakia and Czech Republic;
— The lowest score belongs to Belgium;
— The mean score is 78.5% and standard deviation is 8.06%.

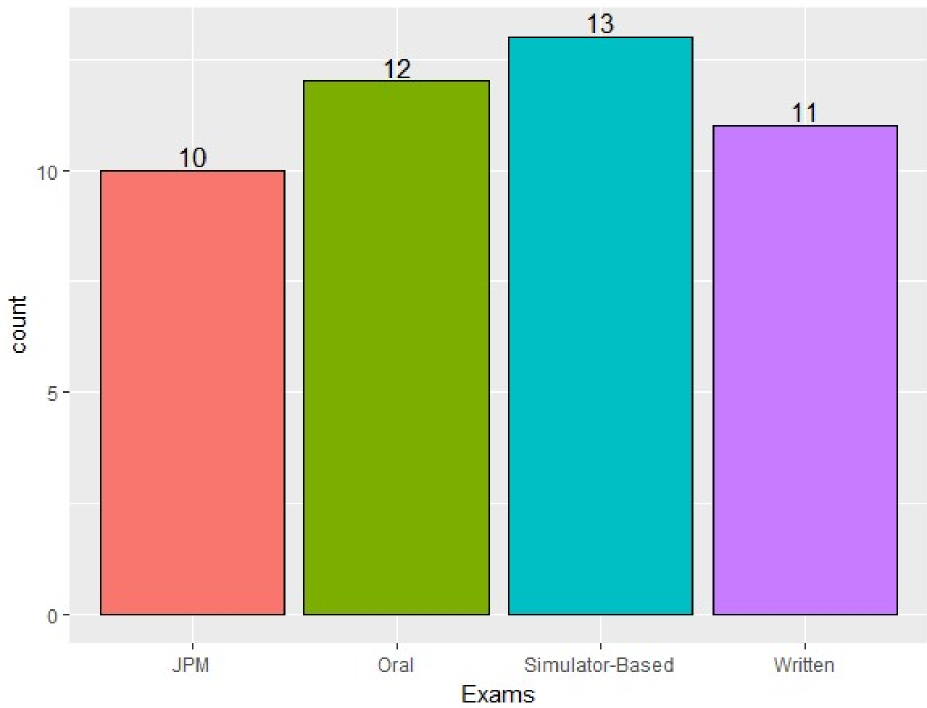

FIG. 28. Different examination types used among Member states

- Generally, all types of the exams are used to the same extent;
- Simulator-based exams are the most widely used;
- Simulator-based exams are not practiced in Belgium and in Slovakia (Slovenske elektrárne);
- JPM exams are less used.

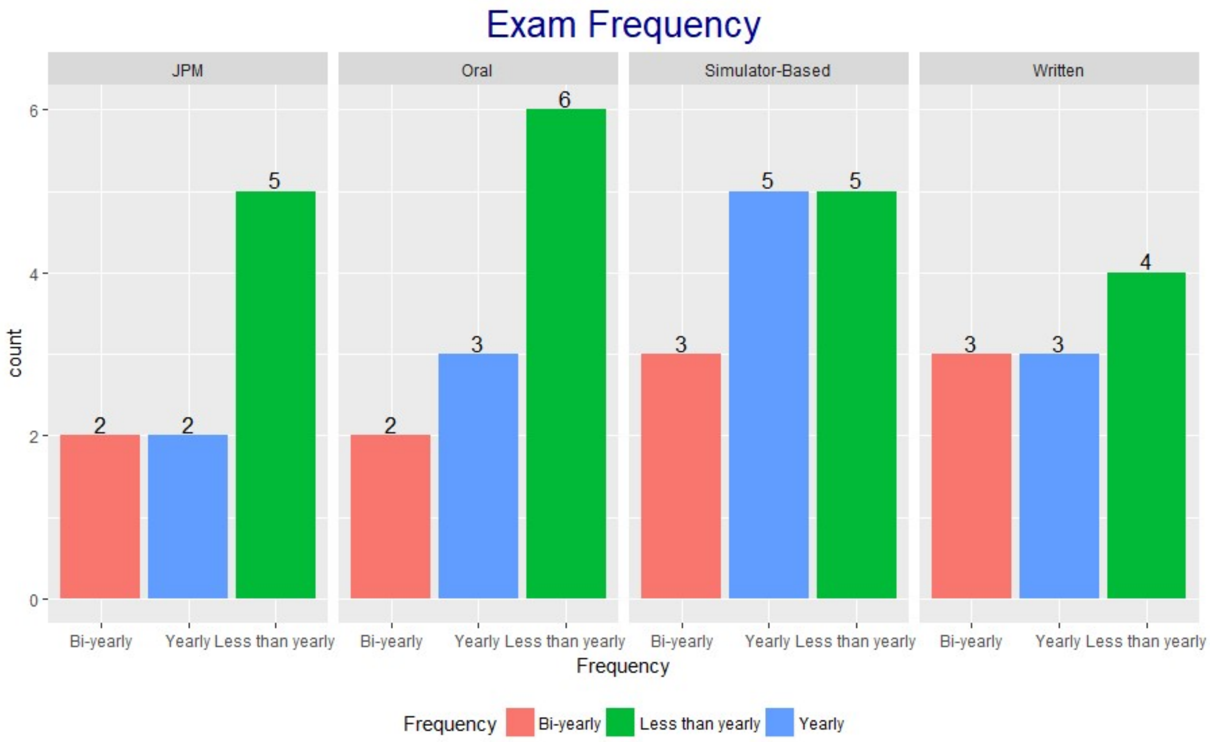

FIG. 29. Exam Frequency.

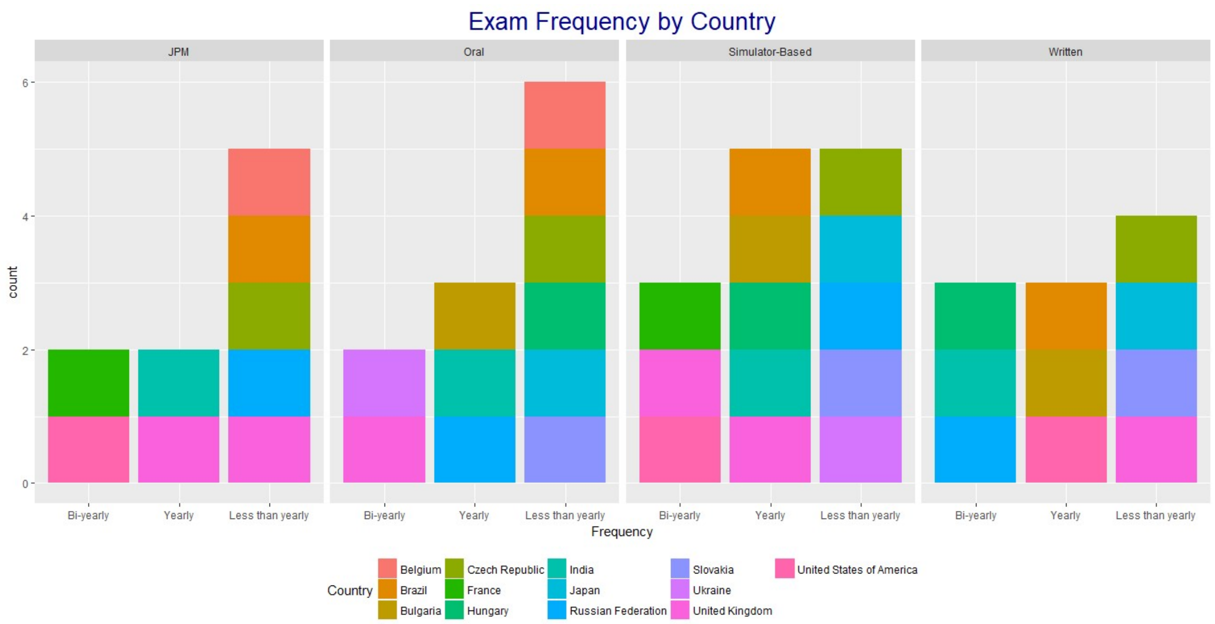

FIG. 30. Showing the frequency of examination and different examination types in different Member states.

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ANNEX I.
EXAMPLE OF TRAINING PROGRAMME FOR INITIAL SPECIALIZED TRAINING OF FSS INSTRUCTORS

This is an example of a training programme for initial specialized training on Full Scope Simulator instructors

<table>
<tr><td colspan="2">PROGRAMME</td><td colspan="3"></td></tr>
<tr><td colspan="2">COURSE NAME</td><td colspan="3"></td></tr>
<tr><td colspan="2">COURSE NUMBER</td><td colspan="3"></td></tr>
<tr><td colspan="2">TOTAL TIME</td><td colspan="3"></td></tr>
<tr><td colspan="5"></td></tr>
<tr><td></td><td colspan="3">Position, Name, signature</td><td>Date</td></tr>
<tr><td>Developed by</td><td colspan="3"></td><td></td></tr>
<tr><td>Approved by</td><td colspan="3"></td><td></td></tr>
<tr><td>Coordinated by</td><td colspan="3"></td><td></td></tr>
<tr><td colspan="5"></td></tr>
<tr><td colspan="5" align="center">GUIDE REQUIREMENTS</td></tr>
<tr><td>Instructional Aim</td><td colspan="4"></td></tr>
<tr><td>Learning Objectives</td><td colspan="4"></td></tr>
<tr><td>Prerequisites</td><td colspan="4"></td></tr>
<tr><td>Training Resources</td><td colspan="4"></td></tr>
<tr><td rowspan="2">References</td><td>Local</td><td colspan="3"></td></tr>
<tr><td>Generic</td><td colspan="3"></td></tr>
<tr><td>Commitments</td><td colspan="4"></td></tr>
<tr><td>Evaluation Method</td><td colspan="4"></td></tr>
<tr><td>Operating Experience</td><td colspan="4"></td></tr>
<tr><td>Nuclear Professionalism</td><td colspan="4"></td></tr>
<tr><td>Historical Record</td><td colspan="4"></td></tr>
<tr><td>Plant Status</td><td colspan="4"></td></tr>
</table>

	Position	Name	Signature	Date
Developed by				
Approved by				
Coordinated by				

1 GENERAL

This training programme defines the training courses, training settings, types of the knowledge check, criteria for passing an examination and the duration of the initial specialized training for the position of FSS WWER-1000 instructor.

The content and duration of the courses correspond to the conducted analysis of the functions connected with the position assigned and characteristics of the certain working place.

2 PRELIMINARY REQUIREMENTS FOR QUALIFICATION

2.1 Education – Higher:

- Degree - Master
- Higher Education field - Technical studies
- Professional field - Power Engineering

2.2 Experience

- To take the position the individual must have valid license and min 3 years of experience as a licensed Unit Shift Supervisor or a licensed Plant Shift Supervisor at the relevant unit type.

3 TRAINING TASKS RESULTING FROM THE FUNCTION ANALYSIS

3.1 Training needs analysis

- Needs and Position analysis conduct - data interpretation
- Analyses modification/revision
- Task analysis conduct - data interpretation
- Analyses modification/revision
- Training requests evaluation
- Development of questionnaires for the identification of the trainees and management's needs

3.2 Conduct of the training

3.3 Design of the training

— Development of a work plan for training programme
— Training programmes coordination
— Development of training objectives
— Choosing training methods
— Choosing the training environment and the necessary technical means and materials to conduct the training

3.4 Training development

— Development of the structure, content and activities of a training course
— Development of guidelines for trainees
— Development of a simulator training
— Development of exam questions to show compliance between the performed actions and the rules and procedures
— Development of procedures for examination conduct
— Development of a training matrix
— Development of lesson plans for classroom sessions
— Development of OJT guides
— Development of a computer-based training

3.5 Training evaluation

— Review of the examination results together with the trainees
— Analysis of the training results
— Analysis of the feedback from the trainees received upon completion of the programme
— Analysis of the feedback from the instructors received upon completion of the programme
— Effectiveness evaluation of the training materials
— Effectiveness evaluation of the teaching methods
— Evaluation of a training conducted by external organizations
— Evaluation of a training course and programme

3.6 Maintaining instructor mastery and licence

3.7 Work with the simulator

— Development of team-oriented training objectives
— Choosing simulator training scenarios from an existing list of scenarios
— Pre-simulation training session
— Conduct of a demonstration simulator session
— Collecting data for a post-simulation analysis
— Evaluation of the individual performance of members of the trained team
— Scenarios effectiveness evaluation

3.8 Technical training means management

3.9 Administrative tasks performance

3.10 Consulting

3.11 Understanding the organizational relations

4 LIST OF THE TRAINING COURSES FOR INITIAL SPECIALISED TRAINING

4.1 The initial specialized training consists of:

- Theoretical training (lectures and/or seminar)
- Simulator training (OJT)
- Practical training (on-the-job/site-training)

4.2 Duration of the initial specialized training

- 320 class hours training in courses i.e. 46 working days (one working day has 7 class hours)
- The duration of the different types of training and courses is shown in Table 4.1.

4.3 The specialised training courses and topics as well as the assessments of knowledge and skills gained follow in a logical succession reflected in the individual training programme

4.4 List of the training courses

4.4.1 The full list of training courses and their duration for FSS instructor are presented in Section 5

Table 4.1 DURATION OF THE DIFFERENT TYPES OF TRAINING IN THE COURSE

Course title		TT	ST	OJT	PT	Type of check
Human Factor		25	0	0	0	D
Training of Nuclear Power Unit Simulator Instructors		135	0	91	21	T/D/PE
Personnel Training and Qualification		6	0	0	0	D/T
Systematic Approach to Training		14	0	0	0	D/T
Classroom Training Fundamentals		11	0	0	3	D/T
Work with MS Office		14	0	0	0	D
Total		205	0	91	24	320

Tables legend:

- TT theoretical training
- ST simulator training
- OJT practical on-the-job training
- PT Practical training to use workshops, laboratories, mock-ups, computers, radiometry, dosimetry and spectrometry instrumentation and other technical devices
- D discussion
- T test
- PE practical examination

5 DESCRIPTION OF THE TRAINING COURSES CONTENT AND DURATION OF THE TOPICS

5.1 The list of the topics and their duration are presented Tables 5.1-5.5.

Table 5.1 NUCLEAR POWER UNIT SIMULATOR INSTRUCTORS TRAINING

Short description of the training course content	Duration			
	TT	ST	OJT	PT
Scope of FSS-1000	21	0	0	0
Capabilities of FSS-1000 instructor station Capabilities of FSS-1000 mobile instructor station	14	0	0	0
Roles performed by the instructor and the trainees - requirements	14	0	0	0
Application of the Systematic Approach to Training to the simulator training	7	0	0	0
Terminal and enabling objectives in the simulator training	7	0	0	0
Evaluation methods and techniques in the simulator training. Feedback.	14	0	0	0
Training materials for simulator training	14	0	0	0
Development, validation and performance of scenarios for: — Normal operation mode — Emergency operation mode	0	0	70	14
Simulator training conduct methodology	21	0	0	0
Procedure and methodology used in the event analysis	2	0	0	0
Administrative requirements to the simulator training conduct and methodology	7	0	0	0
Roles of the instructor when using and maintaining the conformance between the simulator and the reference unit Roles of the instructor during conduct of simulator engineering and validation tests	14	0	0	0
Development of terms of reference for simulator upgrade in compliance with projects for modifications of its reference unit	0	0	7	0
Development of procedures for testing the simulator after its upgrade and/or modernization	0	0	7	0
Simulator acceptance tests	0	0	7	0
Performance of tests on procedures for acceptance of the simulator for training	0	0	0	7
Total	135	0	91	21

Table 5.2 PERSONNEL TRAINING AND QUALIFICATION

Short description of the training course content	Duration			
	TT	ST	OJT	PT
Regulation on the terms and procedure for obtaining of vocational qualification and on the procedure for issuing of licences for specialised training and of individual licences for use of nuclear power;	2	0	0	0
Conduct of examinations	4	0	0	0
Total	6	0	0	0

Table 5.3 HUMAN FACTOR

Short description of the training course content	Duration			
	TT	ST	OJT	PT
Human Error	4	0	0	0
The impact of behaviour on the performance	3	0	0	0
Decision making	2	0	0	0
Leadership	4	0	0	0
Teamwork	2	0	0	0
Groups management	1	0	0	0
Communication	2	0	0	0
Conflicts and conflict management	3	0	0	0
Stress management	4	0	0	0
Total	25	0	0	0

Table 5.4 SYSTEMATIC APPROACH TO TRAINING

Short description of the training course content	Duration			
	TT	ST	OJT	PT
Introduction	1	0	0	0
Analysis Phase	3	0	0	0
Design Phase	4	0	0	0
Development Phase	2	0	0	0

Table 5.4 SYSTEMATIC APPROACH TO TRAINING

Short description of the training course content	Duration			
	TT	ST	OJT	PT
Implementation Phase	1	0	0	0
Evaluation Phase	2	0	0	0
Summary	1	0	0	0
Total	14	0	0	0

Table 5.5 CLASSROOM TRAINING FUNDAMENTALS

Short description of the training course content	Duration			
	TT	ST	OJT	PT
Role of the instructor	1	0	0	0
The process of studying	1	0	0	0
Training objectives	2	0	0	0
Introductions	1	0	0	0
The adult trainee Training control	1	0	0	0
Asking questions Strategy for achieving the training objectives	1	0	0	0
Teaching methods	1	0	0	0
Training aids	1	0	0	0
Training evaluation	1	0	0	0
Lesson planning	1	0	0	0
Delivery of a lesson - demonstration by the trainees	0	0	0	3
Total	11	0	0	3

6 CRITERIA FOR PASSING EXAMINATION OF THIS PROGRAMME

6.1 Introduction

— Upon completion of the initial specialised training, the trainee is checked for compliance of the acquired knowledge and skills with the ones established in this programme
— Test, discussion or a practical examination are the types of knowledge check upon completion of a course
— A test or a discussion is conducted upon completion of a theoretical training. A practical examination is conducted after ST, OJT or PT

- The requirement for passing a test is to have at least 80% correct answers of the answers to all the test questions
- The examination is considered successful if the mark of each examiner is ‘passed’ for all questions

ANNEX II.
EXAMPLE OF OUTLINE FOR INITIAL TRAINING PROGRAMME PLAN

The example shows an outline for initial training programme plan:

— Introduction References Definitions;
— Pre-requisites for Assignment;
— Programme Sequence, Schedule and Cycles;
— Trainee Attendance;
— Exemptions from Training/Equivalent qualification;
— Training Settings/Course Loading;
— Task or Competency to Training Matrix;
— Programme Evaluation;
— Trainee Evaluations and Examinations;
— Instructor Qualifications;
— Programme Content/Course Descriptions:

  - Theory and Fundamentals;
  - Systems and Components;
  - Simulator training;

— On-Shift Participation: OJT.

ANNEX III.
EXAMPLE OF SIMULATOR EXERCISE GUIDE (SEG)

SEGs are used as the lessons plans by the instructor for all simulator training. On conclusion of the training scenario the SEGs are used to support debrief and evaluation/assessment of individuals as well as team performance.

<table>
<tr><td colspan="2">SEG TITLE</td><td colspan="3"></td></tr>
<tr><td colspan="2">PROGRAMME</td><td colspan="3"></td></tr>
<tr><td colspan="2">COURSE NAME</td><td colspan="3"></td></tr>
<tr><td colspan="2">COURSE NUMBER</td><td colspan="3"></td></tr>
<tr><td colspan="2">TOTAL TIME</td><td colspan="3"></td></tr>
<tr><td colspan="5"></td></tr>
<tr><td>Developed by</td><td>Instructor</td><td></td><td>Date</td><td></td></tr>
<tr><td>Reviewed by</td><td>Review Instructor</td><td></td><td>Date</td><td></td></tr>
<tr><td>Approved by</td><td>Training Group Head</td><td></td><td>Date</td><td></td></tr>
<tr><td colspan="5"></td></tr>
<tr><td colspan="5">GUIDE REQUIREMENTS</td></tr>
<tr><td>Instructional Aim</td><td colspan="4"></td></tr>
<tr><td>Learning Objectives</td><td colspan="4"></td></tr>
<tr><td>Prerequisites</td><td colspan="4"></td></tr>
<tr><td>Training Resources</td><td colspan="4"></td></tr>
<tr><td rowspan="2">References</td><td>Local</td><td colspan="3"></td></tr>
<tr><td>Generic</td><td colspan="3"></td></tr>
<tr><td>Commitments</td><td colspan="4"></td></tr>
<tr><td>Evaluation Method</td><td colspan="4">Adequate performance will be demonstrated during the dynamic simulator evaluation by satisfactory completion of the session objectives, critical & significant tasks.</td></tr>
<tr><td>Operating Experience</td><td colspan="4">Review of local and international Opex including SERs/ SOERs</td></tr>
<tr><td>Nuclear Professionalism</td><td colspan="4"></td></tr>
<tr><td>Historical Record</td><td colspan="4"></td></tr>
<tr><td>Plant Status</td><td colspan="4"></td></tr>
</table>

Scenario overview

Initial conditions.

— This Evaluation may be run from the following assessment Scenario Standard (Specific) IC (Initial Condition) sets:

- IC-* (IC-*), (IC Conditions Summary);

— The following equipment is Out of Service (OOS):

- Briefs – Communicate the following:
  - Safety message and state of plant;
  - Nature of the training (assessment led, coached session, tutor intervention);
  - Expectations of and focus areas for training exercise;
  - Trainee questions prior to start;
  - Expected start time.

Exercise Brief	
Operator Brief	
Role Player Brief	
Tutor Brief	
SCENARIO OVERVIEW	
SEQUENCE OF EVENTS	
Event 1	
Event 2	

SEQ	Sequence of Events/Instructor Notes	Simulator Operations/Notes	Expected Student Responses
	Complete Shift Handover: — "UNIT AEO Handover LOG" (should be provided with the scenario IC) — The "Daily at Power Risk Assessment" (should be updated daily) — The "LCO Log" (should be updated daily) — Verify MCR Team performs walk down of control boards and the reviews Handover checklists		
	Use Performance Measures Data – Critical Task Scoring		Students meet critical/significant objectives
	When the conditions are stabilised or at discretion of lead instructor/evaluator		☐With the MCR Team
	End the scenario by placing the simulator in freeze		☐With the MCR Team
	Conduct end of scenario critique and debrief		☐With the MCR Team
NOTE: Modify this table as needed to include all scenario time-line items, expected responses, critical steps, manual plant manipulation simulator codes and any other instructions or information that may prove useful whilst delivering the scenario.			

Debrief

— Trainee(s) self-critique;
— Review of exercise objectives;
— Review of trainee(s) technical performance;
— Review of trainee(s) behaviour (including Management Expectations and application of HU error prevention tools);
— Summary of trainee performance with opportunities for improvement identified.

By the end of debrief the instructor should ensure that:

— The aims and objectives of the session are understood by all crew participants;
— Any technical knowledge issues raised during the scenario are addressed;
— Any safety significant or nuclear safety significant issues raised during the scenario are discussed accordingly;
— Any key HU and plant performance issues identified during the scenario are discussed accordingly;

— Any individual and/or crew performance issues, self-identified and line manager identified, are discussed accordingly;
— Any procedural shortfalls or suggested improvements raised during the scenario are actioned by a member of the crew;
— Adequate OpEx has been discussed.

MCR Team	SCE
— Participate in scenario debrief — Assess performance in meeting Human Performance Expectations	— Participate in scenario critique — Facilitate scenario debrief with the MCR Team.

Simulator set-up checklist

Relative Order	System or Panel Drawing	Type	Code	Severity or Value	Event Trigger	Timing	Description

Attach the following site-specific information as necessary:

— Simulator Set-up Checklist (before and after training);
— Pre-evaluation Brief Guide (for evaluations only);
— Post-evaluation Critique (for evaluations only);
— Handover Log;
— Historical Record (Optional).

Performance Measures Data – Critical Task Scoring

Shift		Date	
Shift Manager (SM)		Lead Assessor	
Control Room Supervisor (CRS)		CRS Assessor	
Reactor Desk Engineer (RDE)/RO		RDE/RO Assessor	
Other		Other	

Scenario Part No.	Task/Obj			Details/Performance Measure (Competency check sheet correlation) SCENARIO TITLE	SM	CRS	RDE
	C	S	O				
	No each perf. objective. E.g.			*Identify action or observation to be taken by team or individual to meet the critical or significant performance measure.*	Grey out perf. Objs not appropriate. E.g.		
1	C1						
	C2						
		S1					
	C3						
		S2					
			O1				
	C4						
	C5						
2	C6						

C *Simulator Critical Action*: A significant operator or team action which must be completed correctly during the simulator training scenario. Unsatisfactory completion of critical tasks will result in automatic failure during simulator assessments or significant remediation actions during non-assessed scenarios.

S *Safety Significant Action*: A significant operator or team action which must be completed correctly during the simulator training scenario. Unsatisfactory completion of safety significant tasks will require a follow up Shift Manager Action plan to prevent recurrence.

O *Operator Performance Actions*: An operator action which if performed incorrectly or missed represents a degradation of individual or team performance. Failure to perform such actions during dynamic simulator assessment may lead to exam failure. During non-assessed scenarios the relevant Shift Manager must manage any operator performance actions which are below standard.

ANNEX IV.
EXAMPLE OF TYPICAL SCENARIOS TO BE USED DURING SIMULATOR TRAINING

List of typical plant normal, abnormal and emergency operating evolutions performed on a simulator by the individual during training shown in this annex. This kind of typical task list is used worldwide for NPPs.

Plant or reactor manoeuvres to include a range that reactivity feedback from nuclear heat addition is noticeable and heat up rate is established.

Scenarios Performed on a Simulator (for PWR or BWR):

- Plant shutdown;
- Manual control of steam generators or feedwater or both during start up and shutdown;
- Boration or dilution during power operation;
- Significant (more than10%) power changes in manual rod control or recirculation flow;
- Reactor power change of 10% or greater;
- Loss of coolant, including:
    - Significant PWR steam generator leaks;
    - Inside and outside primary containment;
    - Large and small, including leak-rate determination;
    - Saturated reactor coolant response (PWR);
- Loss of instrument air (if simulated, plant specific);
- Loss of electrical power (or degraded power sources);
- Loss of core coolant flow/natural circulation;
- Loss of feedwater (normal and emergency);
- Loss of service water, if required for safety;
- Loss of decay heat removal cooling;
- Loss of component cooling system or cooling to an individual component;
- Loss of normal feedwater or normal feedwater system failure;
- Loss of condenser vacuum;
- Loss of protective system channel;
- Miss-positioned control rod or rods (or rod drop);
- Inability to drive control rods;
- Conditions requiring use of emergency boration or standby liquid control system;
- Fuel cladding failure, causing high activity in reactor coolant or off gas;
- Turbine or generator trip;
- Malfunction of an automatic control system that affects reactivity;
- Malfunction of reactor coolant pressure/volume control system;
- Reactor trip;
- Main steam line break (inside or outside containment);
- Instrument failures (e.g. nuclear instrumentation);
- Anticipated Transient with Failure to Scram (ATWS).

Multiple safety system failures are:

- Annunciator failures during both normal and emergency evolutions;

- DCS failure / use of back-up panels.

  Station black-out:

- External events (earthquake, flooding, Tsunami, loss of heat-sink, whatever applicable);
- Security events.

ANNEX V.
EXAMPLE OF COURSE OBSERVATION CHECK-LIST

This is an example of a checklist used for course observation.

Course observer			NPP		
Course observation on			Instructor		
☐	Refresher training		☐	Initial training course	
☐	Other courses				
Summary					
Recommendations					
Measures agreed upon					
Date			Course observer		
Date			Instructor		

	Observation contents	OK	Recommendations	Not observable	Comment #
1.	Explanatory notes on initial conditions after changing the plant status	☐	☐	☐	
2.	Interventions, assistance, influences on the course participants	☐	☐	☐	
3.	Human performance tools and MARKER	☐	☐	☐	
4.	Feedback discussion after completion of each exercise sequence	☐	☐	☐	
5.	Involvement, activation and motivation of all course participants	☐	☐	☐	
6.	Training objectives control on technical subjects and behavioural aspects	☐	☐	☐	

Comments: (Equipped with the comment # according to the right column)

1 Explanatory notes on initial conditions after changing the plant status

1.1 After each change of the initial conditions the instructor hands over by giving information about the plant status.

2 Interventions, assistance, influences on the course participants

2.1 In the refresher training the instructor as far as possible keeps himself in the background and will only act in the exercise sequence if training objectives are endangered.

2.2 Preferably in the initial training the instructor may ask the course participants to perform relevant switching operations repeatedly.

2.3 Preferably in the initial training the instructor stops the simulation, explains and scrutinises as well as he aids in the problem-solving process.

2.4 In the initial training the instructor asks the course participants to explain the intended activity before performing relevant actions.

3 Human performance tools and MARKER

3.1 During the feedback discussions in the control room the instructor has actively mentioned the aspects of the MARKERs and human performance tools, which have been relevant for the exercise sequences. He has communicated his observations to the course participants and reflected these against the required behaviour.

3.2 In telephone calls the instructor plays the role of the different contact persons in the plant.

4 Feedback discussion after completion of each exercise sequence

4.1 As part of the program flow the instructor gives a small feedback at the end of an exercise sequence.

4.2 Besides the technical process the instructor also speaks about the relevant MARKERs as well as about the elements of the human performance tools in such a way, that a positive behaviour is reinforced or a course correction for the next exercise section is achieved.

5 Involvement, activation and motivation of all course participants

5.1 The instructor finds a motivating approach to the seminar subject and keeps the motivation of the course participants throughout the course.

5.2 The instructor uses different didactic methods (use of media) and provides possibilities for initiatives of the course participants.

5.3 The instructor encourages the course participants to ask and give suggestions to the content and the future design of the course.

5.4 The instructor asks the course participants for feedback concerning performance and organization of the course.

6 Training objectives control on technical subjects and behavioural aspects

6.1 The instructor regularly controls the achievement of the training objectives orally or in writing.

6.2 The instructor addresses and scrutinises recognised deficiencies concerning technical and behavioural aspects.

ANNEX VI.
EXAMPLE OF PERSONAL EVALUATION FOR FSS

This is an example of a Personal Assessment Form for on-going evaluation of operator fundamentals during simulator training.

Personal Assessment Form	
SIMULATOR SCENARIO TITLE	

TYPE OF TRAINING	☐	Initial	TYPE OF SCENARIO	☐	Demonstration
	☐	Continuous		☐	Training
	☐	Extra		☐	Examination
				☐	Other

TRAINEES				
First Name/Family Name		Job Position/MCR No		
		Job position	MCR 5	MCR 6
DURATION [h]	Briefing	Scenario	Debriefing	

LEAD INSTRUCTOR			Shift ID		Week
INSTRUCTOR					
Date					
Time					

SCENARIO TITLE							Page 2/2
Job Position	Fundamental / Name	Controlling of plant conditions	Applying conservative approach	Using and following procedures	Having a solid knowledge of plant design and systems	Team working	Team attitude/ Training attitude
PSS		excellent ☐ good ☐ need improvement ☐	excellent ☐ good ☐ need improvement ☐	excellent ☐ good ☐ need improvement ☐	excellent ☐ good ☐ need improvement ☐	excellent ☐ good ☐ need improvement ☐	excellent ☐ good ☐ need improvement ☐
USS		excellent ☐ good ☐ need improvement ☐	excellent ☐ good ☐ need improvement ☐	excellent ☐ good ☐ need improvement ☐	excellent ☐ good ☐ need improvement ☐	excellent ☐ good ☐ need improvement ☐	excellent ☐ good ☐ need improvement ☐
SRO		excellent ☐ good ☐ need improvement ☐	excellent ☐ good ☐ need improvement ☐	excellent ☐ good ☐ need improvement ☐	excellent ☐ good ☐ need improvement ☐	excellent ☐ good ☐ need improvement ☐	excellent ☐ good ☐ need improvement ☐
TO		excellent ☐ good ☐ need improvement ☐	excellent ☐ good ☐ need improvement ☐	excellent ☐ good ☐ need improvement ☐	excellent ☐ good ☐ need improvement ☐	excellent ☐ good ☐ need improvement ☐	excellent ☐ good ☐ need improvement ☐
TO		excellent ☐ good ☐ need improvement ☐	excellent ☐ good ☐ need improvement ☐	excellent ☐ good ☐ need improvement ☐	excellent ☐ good ☐ need improvement ☐	excellent ☐ good ☐ need improvement ☐	excellent ☐ good ☐ need improvement ☐
RF		excellent ☐ good ☐ need improvement ☐	excellent ☐ good ☐ need improvement ☐	excellent ☐ good ☐ need improvement ☐	excellent ☐ good ☐ need improvement ☐	excellent ☐ good ☐ need improvement ☐	excellent ☐ good ☐ need improvement ☐

Note: Each fundamental is associated with requirements, which should be covered by operators. Those requirements are described in separate attachment. Evaluation criteria are as follow:

Excellent	100% coverage
Good	≥80% coverage
Need improvement	<80% coverage

ANNEX VII.
EXAMPLE OF SIMULATOR NON-REGRESSION TESTS BWR

Within the acceptance procedure the following Non-Regression-Tests have been performed and compared with test results recorded before the modifications provided in the <project name> were implemented.

Test scenario	Reference simulator load	Status	Comment
NON-REGRESSION-TESTS FOR ALL BWR SIMULATORS			
Reactor trip with containment isolation 100 % rated output MOC			
Manual reactor trip 100 % rated output BOC			
Manual turbine trip 100 % rated output EOC			
Loss of all main coolant pumps BOC			
Loss of a main feedwater pump 100 % rated output BOC and EOC			
Loss of all main condensate pumps 100 % rated output BOC and EOC			
Loss of a LP feedwater heater 100 % rated output BOC and EOC			
Loss of a HP feedwater heater 100 % rated output BOC and EOC			
Main steam line rupture inside containment 100 % rated output BOC			
Main steam line rupture outside containment 100 % rated output			
BOC			
Feedwater line rupture downstream of HP feedwater heater 100 % rated output EOC			
Load rejection to auxiliary power from 100 % rated output BOC			

<table>
<tr><th>Test scenario</th><th>Reference simulator load</th><th>Status</th><th>Comment</th></tr>
<tr><td>Feed-out accident
100 % rated output
EOC</td><td></td><td></td><td></td></tr>
<tr><td colspan="4">SIMULATOR SPECIFIC NON-REGRESSION-TESTS</td></tr>
<tr><td><additional specific test scenarios></td><td></td><td></td><td></td></tr>
<tr><td></td><td></td><td></td><td></td></tr>
<tr><td></td><td></td><td></td><td></td></tr>
<tr><td></td><td></td><td></td><td></td></tr>
<tr><td></td><td></td><td></td><td></td></tr>
<tr><td colspan="4">CONCLUSION</td></tr>
<tr><td colspan="4"><Evaluation of the test results with regard to the implemented modifications. The conclusion should give information whether the overall test result allows the simulator load to be used in simulator training.></td></tr>
<tr><td>TEST MANAGER NAME</td><td colspan="3"></td></tr>
<tr><td>SIGNATURE</td><td colspan="3"></td></tr>
<tr><td>DATE</td><td colspan="3"></td></tr>
</table>

ANNEX VIII.
EXAMPLE OF SIMULATOR NON-REGRESSION TESTS PWR

Within the acceptance procedure the following Non-Regression-Tests have been performed and compared with test results recorded before the modifications provided in the <project name> were implemented.

Test scenario	Reference simulator load	Status	Comment
NON-REGRESSION-TESTS FOR ALL PWR SIMULATORS			
Manual reactor trip 100 % rated output BOC			
Manual turbine trip 100 % rated output EOC			
Failure of a reactor coolant pump 100 % rated output BOC und EOC			
Failure of a main feedwater pump 100 % rated output EOC			
Failure of a main steam bypass station 100 % rated output BOC and EOC			
Load rejection to auxiliary power from 100 % rated output BOC			
ATWS with emergency power supply 100 % rated output BOC			
SG tube rupture 100 % rated output BOC and MOC			
Failure of a pressurizer safety valve 100 % rated output BOC			
Rupture of a main steam line at the header 100 % rated output BOC			
Medium hot leg leakage 100 % rated output BOC			
Rod drop event 100 % rated output BOC and EOC			

Test scenario	Reference simulator load	Status	Comment
SIMULATOR SPECIFIC NON-REGRESSION-TESTS			
<additional specific test scenarios>			
CONCLUSION			
<Evaluation of the test results with regard to the implemented modifications. The conclusion should give information whether the overall test result allows the simulator load to be used in simulator training.>			
TEST MANAGER NAME			
SIGNATURE			
DATE			

GLOSSARY

critiquing – in the simulator world this is the reviewing of actions, behaviours, performance etc. a debriefing/coaching technique termed self-critiquing is a technique where the instructor encourages the students/trainees to self-identify their own strengths and areas for improvement.

engineering simulator – a type of control room simulator designed to study plant behaviour in detail. Previously termed an Analytical Simulator, at some locations, when utilised by fault study and/or engineering groups. *See Other-Than-Full-Scope Control Room Simulator.*

generic (basic principles) simulator – A simulator that illustrates general/fundamental concepts, demonstrating and displaying the fundamental physical processes of a plant. This type of simulator can provide an overview of plant behaviours or a basic understanding of the main operating modes. The simulation scope focuses on the main systems; auxiliary or support systems are often not simulated or are simulated to a very limited capacity. Basic Principles simulators is to train individuals on basic physical processes, interactions and operation of complex systems related to the operation of the plant.

emulation **–** Implementation of a reference plant system or subsystem typically by migration of the plant system software to run in the simulator operating environment. The performance and physical fidelity of the emulated system is identical to the reference plant system or subsystem

full-scope simulator – Full Scope Simulator is to train in a replica control room and includes detailed modelling of the referenced plant systems, interface and environment.

functional simulator – A type of control room simulator. *See Other-Than-Full-Scope Control Room Simulator.*

graphical simulator – a type of control room simulator. *See Other-Than-Full-Scope Control Room Simulator.*

hands-on – incorporating the theory learnt in the classroom with practical use and application/ manipulation of the simulator controls. Activities using equipment, real or simulated, rather than theoretical study alone.

instructional method – method of providing instruction, such as discussion, role play, instructional strategy, lecture, simulation or tutorial.

mock-ups – Physical replications of plant items or equipment, used for hands-on training or pre-job briefings. *See Brief, Hands-on and Simulation.*

multi-functional simulator – A type of control room simulator. *See Other-Than-Full-Scope Control Room Simulator.*

negative training - Training that causes a person to make an error or an inappropriate response when completing a task (poorly designed, implemented training that does not produce the desired response from the student).

other-than-full-scope control room simulator – A simulator that does provide the same identical interface as the reference plant. Normally, these simulators provide the human-machine interfaces through systems such as touch screens or other computer-based systems. The role of these is to provide trainees with an understanding of plant thermo-hydraulic, and neurotics characteristics. Example of these simulators include: Engineering Simulators, Functional Simulators, Generic Simulators, Graphic Simulators and Multifunctional Simulators.

part-task simulator – A simulator that incorporates the reference plant in a limited manner to enable individuals to be trained on specific, relevant tasks.

plant-referenced simulator – A simulator that represents a specific nuclear power plant in its design and fidelity, including the control room physical layout and control board hardware and software modelling. Generally, for a Plant-Referenced Simulator, standards are defined for the required fidelity between the NPP plant and the simulator manufacturer. *See Simulation.*

pre-exercise brief – A brief in preparation, to all those participating in an exercise. e.g. on a simulator assessment or training, a rehearsal of emergency procedures or enacting an emergency plan demonstration involving onsite and off-site services and may be witnessed by the regulator.

reactor simulator – A device that simulates the kinetics and operation of a nuclear reactor, used for training and for studying reactor dynamics. Reactor Simulators are of different complexities depending on their purpose. *See Simulation.*

simulation – The imitation of real systems and situations to allow activities to be practiced and trained upon in a plant scenario where it would be too awkward, complex, un-realistic or dangerous to put the actual plant or personnel in that position. *See also Reactor Simulator and Training Strategy.*

simulator standard – A standard that defines the requirements for a simulator to meet the needs of an organization for a specified purpose. *See Simulation.*

soft panel simulator – A simulator that replaces the actual panels with touchscreens, where the actual controls are graphically represented. The simulator can consist of multiple panels, imitating the panels in the main control room (or a part of them). It could be a plant referenced simulator, used in addition to a full scope simulator but also a Part-Task-Simulator or a Generic Simulator.

stimulation - Implementation of a reference plant system or subsystem using the actual hardware and software installed in the reference plant. Stimulated systems should either have built in support for simulator operational modes such as Freeze, Run, Backtrack, etc., or these capabilities should be added by a software control layer as part of the implementation.

virtual reality simulator – A simulator model connected to a Virtual reality environment. In a sense, all simulators are virtual but here the virtual simulator can make the physical control room replica redundant. Also, any plant environment or situation can easily be reproduced for training purposes, not only the main control room, this enables simulator training possibilities for job categories and fields of operation and maintenance.

LIST OF ABBREVIATIONS

AFI	areas for improvement
AGR	advanced gas-cooled reactor
APP	application for mobile phones or tablet PCs
AR	augmented reality
ATP	acceptance test procedure
A/V	audio/video
BDBA	beyond design basis accident
BOP	balance of plant
BPS	basic principles simulator
BWR	boiling water reactor
CAC	candidate action checklist
CANDU	CANada Deuterium Uranium (reactor)
CCR	Central Control Room
CDM	conservative decision making
CPO	crew performance observation
CR	condition report
CRM	crew resource management
CRS	Control Room Supervisor
DBA	design basis accident
DCS	digital or distributed control system
DORT	daily operational readiness test
EP	emergency preparedness
EPRI	Electric Power Research Institute
ERO	Emergency Response Organization
FSS	Full Scope Simulator (also called an Operator Training Simulator (OTS) by some Member States)
GUI	graphical user interface
HMI	human-machine interface
HU	human performance
IC	initial condition
I&C	instrumentation & controls
INPO	Institute of Nuclear Power Operations
I/O	input/output
IP	intellectual property
IPTE	infrequently performed tests & evolutions
JIT	just in time (training)
JPM	job performance measure

KPI	key performance indicator
LOA	local operator action or remote function
LOCA	loss of coolant accident
MAAP	modular accident analysis program
MCR	Main Control Room
MMI	man-machine interface
MR	mixed reality
NEI	Nuclear Energy Institute
NNB	nuclear new build
NPP	nuclear power plant
NSSS	nuclear steam supply system
ODM	operational decision making
OEM	original equipment manufacturer
OTS	Operator Training Simulator (also called Full Scope Simulator (FSS) by some Member States)
PSCC	plant status configuration control
PPC	plant process computer
PRA	probabilistic risk assessment
PRS	plant referenced simulator
PSA	probabilistic safety analysis or assessment
PWR	pressurised water reactor
RFT	ready for training
SA	severe accident
SAC	severe accident codes
SAMG	severe accident mitigation guidelines
SAS	severe accident simulation
SAT	site acceptance testing or systematic approach to training
SBT	scenario based training
SEG	simulator exercise guide
SGTR	steam generator tube rupture
SM	Shift Manager
SME	subject matter expert
SQEP	suitably qualified and experienced personnel
VR	virtual reality
V&V	verification & validation
WANO	World Association of Nuclear Operators

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