UNITED STATES
NUCLEAR REGULATORY COMMISSION
TECHNICAL TRAINING CENTER
OSBORNE OFFICE CENTER
5746 MARLIN ROAD, SUITE 200
CHATTANOOGA, TN 37411-5677

June 13, 2014

MEMORANDUM TO: Miriam L. Cohen
Chief Human Capital Officer

FROM: R. Scott Egli, Chief
Reactor Technology Branch A
Human Resources Training and Development
Office of Chief Human Capital Officer

SUBJECT: PAPER FOR PRESENTATION AT THE ENLARGED HALDEN PROGRAMMED GROUP MEETING, SEPTEMBER 8-12, 2014

Enclosed is the paper "Advanced Reactor Simulator Development at the US NRC" which Janice Griffin and myself plan to present at the Enlarged Halden Programmed Group (EHPG) Meeting being held in Rosos, Norway, September 8-12, 2014.

In accordance with Management Directive 3.9, I ask that you review and approve the publication and presentation of this paper. This paper does not have significant implications with respect to new or unresolved policy issues for the staff.

Approved: * [signature] for Date: 6/25/14
Miriam L. Cohen
Chief Human Capital Officer

Enclosure:
As stated

* approved with revisions as discussed with Scott Egli.

An Update on New Reactor Simulator Development and Usage at the US NRC

Janice Griffin
Office of the Chief Human Captial Officer,
US Nuclear Regulatory Commission
Phone: +1 423 8556516, E-mail: Janice.Griffin@nrc.gov
R. Scott Egli
Office of the Chief Human Captial Officer,
US Nuclear Regulatory Commission
Phone: +1 423 8556511, E-mail: Richard.Egli@nrc.gov

Abstract

The US Nuclear Regulatory Commission (NRC) is responsible for inspecting commercial nuclear power plants and licensing nuclear power plant operators in the U.S. In order to support inspection and operator licensing activities for projected new reactor plants of more advanced designs, the NRC must train its staff on the design and operation of these new plants. This training includes the use of new reactor plant simulators with a scope and fidelity that are sufficient to support the necessary training. This paper provides an update on the development and usage of new reactor plant simulators by the NRC, a project first described at the 2011 EHPG meeting. The final approach used to develop the simulator is described. In addition, this paper describes the development and implementation of training courses for NRC staff on the AP1000 nuclear power plant, and discusses how the results from completed training events have validated the NRC's use of limited-scope new reactor plant simulators in its training programs.

1. Background

1.1 NRC Simulators

Nuclear power plant simulators are used to train NRC staff to achieve the following goals:

- provide students with an integrated perspective of reactor plant operations, system interrelationships, and accident response;
- familiarize students with the operation of representative control room equipment;
- teach students basic control room operator practices, including crew dynamics and individual operator, senior operator, and shift technical advisor roles;
- familiarize students with the conduct of operations in a control room, including procedure usage, response to abnormal conditions, and execution of emergency operating procedures; and
- allow operator license examiner trainees to prepare for their eventual roles by developing and administering operating examinations to operating crews composed of TTC instructors.

The NRC currently owns and operates four full-scope simulators with control room benchboards, and two full-scope reactor simulators utilizing computer-based human-machine interfaces (HMIs), at its Technical Training Center (TTC) in Chattanooga, Tennessee. The four simulators with traditional benchboards represent the four major reactor designs built and operated in the U.S. over the last several decades: General Electric (GE), Westinghouse, Combustion Engineering (CE), and Babcock & Wilcox (B&W). These simulators are integral to the training provided for NRC inspectors and licensed operator examiners (hereafter referred to as examiners). The other two simulators are digital HMI versions of the GE and Westinghouse designs.

As a result of the project on which this paper reports, the NRC now owns and operates a seventh simulator – a limited-scope digital HMI simulator representing the design of the Westinghouse AP1000 nuclear power plant.

1.2 Basis of the Need for New Reactor Simulators

New reactor designs (Generation III and III+) demand simulator training on par with that which has been successfully provided in the past. However, major differences are expected in the HMI for these new reactors. The highly-integrated control rooms proposed for all of the emerging new reactor designs represent fundamental departures from existing control rooms in both the way in which information is displayed and the way in which operators control systems and components. Digital interfaces, in the form of both large-screen information summaries and smaller video display units for both indication and control, are expected to replace the analog meters and controls found in existing control rooms. This approach, combined with the distributed control systems which will form the backbone of the protection, control, and indication schemes, will fundamentally affect the way operators work and the way regulators inspect control room operations. Accordingly, new training simulator options are required to prepare NRC inspectors and examiners for these anticipated control room environments.

The schedule for developing new reactor plant simulator-based training for the NRC was based on providing the simulator portion of an AP1000 cross-training course to NRC examiners by the fall of 2013[1]. This target date was chosen to ensure that qualified examiners could prepare and administer examinations to operator license applicants in time to meet the most limiting industry demands. The licensing of reactor and senior reactor operators is a necessary prerequisite to loading fuel for any reactor facility licensee. Thus, a failure to develop NRC examiner training on-time could have delayed fuel loading in and operation of new reactor plants by delaying the licensing of adequate numbers of operators.

1.3 Definition of the Needed Fidelity and Scope of New Reactor Simulators

As described in a paper[1] presented at the 2011 EHPG meeting, the NRC commissioned Pacific Northwest National Laboratory (PNNL) to evaluate the training needs of NRC staff being prepared to regulate new reactor plants and the factors that affect simulator physical fidelity requirements to provide a stronger, more specific technical basis for decisions about the fidelity of training simulators. The focus of the PNNL project was on the level of physical fidelity needed to train both newly-hired personnel, who may have no previous experience with any sort of nuclear power plant (NPP) control room, and experienced personnel, who will be assigned to new NPPs.

The following conclusions were developed based on the analyses performed in the PNNL project:

1. Simulator training is imperative for nearly all tasks performed by NRC inspectors and examiners.
2. There is no need for NRC simulators to have a high level of physical fidelity with respect to a reference plant.
3. The full scope of control HMI systems is required because:

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[1] Originally the schedule was also based on providing an Advanced Boiling Water Reactor (ABWR) cross-training course by the fall of 2013 as well. However, the U.S. nuclear industry's interest in the ABWR slowed, and, as a result, the NRC placed that training need on hold.

- Inspectors and examiners have tasks that address emergency operating procedures.
- These tasks require the full scope of control room HMI systems for competent performance.
- These tasks are among the highest importance for training.
- These tasks benefit from simulator training because they require integration of a large amount of conceptual knowledge of different types.

The full details of the PNNL project and its results can be found in [1] and [2].

2. NRC's New Reactor Simulator Development Project

The NRC used the results of the PNNL study to inform its approach to obtaining the new reactor plant simulators that it needs for staff training. Consideration of these results in conjunction with an analysis of various procurement options, available agency resources, and the projected timetable for needed staff training led to the decision to construct two generic digital HMI control room simulators at the TTC, each identical in physical design and capable of accommodating models and HMIs reflecting any of the anticipated new reactor plant designs.

The NRC adopted a two-phase approach for the development of its first new reactor plant simulator.

2.1 Phase 1 – Upgrade of Existing Simulators

To implement its approach, the NRC issued two contracts in 2010 for Phase 1 of the project - upgrades of its Westinghouse and GE Simulators. Each contract provided for rehosting of the software for the affected simulator from obsolete legacy computers running a proprietary operating system, and for upgrades of the reactor core and thermal-hydraulic models. Each contract also provided programming tools for development and maintenance of simulation models using graphical interfaces.

In addition, the contracts provided the hardware for the generic new reactor control rooms and the software for operating the Westinghouse 4-loop and GE BWR/4 simulated plants utilizing advanced HMIs. The design of the digital (computer-based) HMI control rooms was informed by the projected designs of new reactor plant control rooms.

The two contracts were awarded to different vendors.

Phase 1 of the project for the GE Simulator was completed in October, 2011. Phase 1 of the project for the Westinghouse Simulator was completed in December, 2011. Each of the two simulators could then be operated with the standard control room benchboards with simulation models executed on standard computer equipment running the Windows operating system. Each simulator could also be operated from a digital HMI control room based on the designs anticipated to be used in new reactor plants.

2.2 Phase 2 – AP1000 Simulator Development

The bulk of the cost for any simulator is associated with simulation software model development and information handling (as opposed to hardware procurement). Utilizing the results of the PNNL study, it was determined that the high cost of model development might be reduced as a result of the approach taken by the NRC for training.

Because the principles of plant operation for new reactor plant designs are very similar to those for existing NPPs, it was thought it might be possible to marry HMIs similar to those employed in new reactor plants to existing NRC-owned models and to modify NRC-owned models to create simulations that are of sufficient fidelity for regulatory personnel. This approach could help reduce the costs of model development. This was the original plan for Phase 2 – modify the rehosted and upgraded Westinghouse 4-Loop simulation and the associated digital HMI as necessary to produce a generic AP1000 simulator.

However, as Phase 1 progressed and the preparation work for Phase 2 began, it was determined that this concept for Phase 2 was not ideal and would probably not be successful. As more specific information on the design, operation, and control of an AP1000 nuclear power plant was obtained, it was determined that significant and/or extensive changes would have to be made to the Westinghouse 4-Loop models to achieve an effective AP1000 simulation. The changes in many cases would be so massive that it would be more efficient to create new models from scratch.

In addition, it was concluded that in order to meet the training objectives, it was necessary to have reactor core and thermal-hydraulic models that were based specifically on the AP1000 reactor and reactor coolant system design. The passive core cooling design of the emergency systems results in a significant change in the dynamic response of the thermal-hydraulic models. This could not be achieved by merely modifying the Westinghouse 4-Loop simulation.

Consequently, it was decided late in 2011 to modify one of the Phase 1 contracts to include development of the reactor core, thermal-hydraulic, and passive core cooling system models for the AP1000 simulator.

The cost of developing the rest of the AP1000 simulation models was reduced by limiting the scope of simulation, i.e., how much of the new plant design is simulated. The scope of simulation was defined with the assistance of the TTC's training instructors and incorporated the results of the PNNL study. In addition, this input from the instructors was used to set model development priorities, which also helped define the scope of the initial new reactor plant simulator. While some new plant features may not have been captured under this approach, ongoing training development indicated that significant systems which were not simulated could be adequately taught in a classroom environment. Precedent for this approach exists within the existing training framework. Differences in reactor protection systems of different CE vintages, the existence of isolation condensers (passive components) in BWR/2 designs, and various approaches to containment design at both PWRs and BWRs all represent examples of concepts presented in a classroom environment that are not reflected in NRC simulator design. This approach was supported by the data gleaned in the PNNL study.

Development of these AP1000 simulation models was divided between contractor and NRC personnel. The contractor personnel developed the dynamic models, and the NRC simulator engineers developed the control and logic models. This division of labor was based on the accessibility of plant design information. Much of the design information for the control systems was identified as proprietary by the AP1000 vendor and was therefore not publicly available. NRC staff had access to this information, but was not permitted to provide it to its simulator contractor. As a result, NRC simulator engineers developed the models that required use of the proprietary information. All of the models were developed utilizing the programming tools provided under Phase 1 of the project.

The NRC simulator engineers also developed the HMI controls and interfaced them with the models. The HMI was based on design information available at the time of development. Most of the controls and plant information presentations on the HMI screens were developed by the NRC engineers.

Based on a conceptual design provided by the NRC, the contractor also developed the database-driven alarm system. This alarm system is representative of what is expected in a new reactor plant control room. It incorporates system- and function-related tiles, alarm lists, and some alarm suppression capabilities. Alarm response procedures are also accessible through the operator interface.

Since its use constitutes a major change in the conduct of operations in the control room, a computerized procedure system (CPS) was developed by NRC simulator engineers and integrated with the AP1000 simulator. The CPS provides an interactive, dynamic presentation of emergency and abnormal operating procedures. Each task/step within the active procedure has a logical statement that the system evaluates using real-time information about the plant conditions gathered from the simulated instrumentation. From this evaluation, the CPS determines the next procedure step that should be performed. The operator always has the ability to perform any step deemed appropriate, as the CPS is only an advisory tool.

Model development for the NRC's AP1000 simulator began in October, 2011. TTC instructors began testing the simulator in June, 2013. After a dry run of the training course, with TTC instructors as students, the NRC's AP1000 simulator was declared ready for training in the middle of September, 2013.

3. NRC's AP1000 Training Development Project

3.1 Phase 1 – AP1000 Initial Classroom Training Course Development

The need for developing training courses for the Westinghouse AP1000 nuclear power plant was identified in late 2006 and assigned to a small group of the training instructors located at the TTC. The TTC personnel recognized the need for two courses, each targeted at particular groups of NRC staff. It was decided that the training courses to be developed would follow the same model as that for the existing courses for Westinghouse, CE, and B&W commercial nuclear power plants currently in operation.

The target audience for the initial course to be developed was NRC Headquarters staff involved in the review of submitted material from Westinghouse to support the AP1000 Design Certification Document (DCD) certification and involved in the review of material from U.S. utilities in support of Combined Operating License (COL) applications. For this audience the TTC staff would develop a basic introductory AP1000 course. This course could also be taken by any interested NRC staff.

The team began work on the basic introductory course for the AP1000 plant, concentrating on the major differences in design between it and the existing Westinghouse operating fleet, in January, 2007. This course ended up being 2 days in length. The first offering of the course was completed on April 4, 2007. This course has since been taught a total of 34 times, including once in China and twice in Canada to the nuclear regulatory staffs of those countries.

During the initial development phase, members of the NRC training staff acquired the requisite knowledge of the AP1000 design from several sources. First, the submitted AP1000 DCD was available to the staff. Second, several TTC training staff members attended one-week Westinghouse AP1000 introductory courses offered to U.S. nuclear utility personnel. Third, several of those same individuals attended digital protection and control systems courses offered by Westinghouse. Lastly, searches of publicly available reports, presentations, papers, and other such documents yielded a wealth of additional information to assist in the course development.

After completion of the NRC AP1000 introductory course, a contract was awarded for a 2-week advanced design course, to be conducted by Westinghouse design and training staff, which would be targeted at NRC personnel conducting reviews for certification of the AP1000 design and reviews of COL applications from U.S. utilities. The NRC training staff members who had completed and implemented the 2-day introductory course performed all the technical reviews of the training material submitted by Westinghouse along with exam question development. After the Westinghouse course material was approved by NRC staff, the first course was completed on March 7, 2008. Since this was a contracted course, the NRC now owned the course materials, and the NRC training staff used this material to enhance the existing NRC-developed course for AP1000.

Completion of the last 2-week Westinghouse-contracted AP1000 design course on October 2, 2009, ended Phase 1 of the AP1000 course-development project, for which the primary audience had been NRC Headquarters staff and the construction inspection staff located in Region II.

3.2 Phase 2 – AP1000 Simulator Course Development for Examiners/Inspectors

Phase 2 involved the development of training for examiners and operating-reactor inspectors to support licensing of utility operations staff. Phase 2 also included the integration of the usage of the digital HMI simulator into the training program.

The scope of the second AP1000 course is in concert with the existing qualification training for region-based NRC personnel. NRC license examiners and inspectors are required to complete a 7-week series of courses for qualification to conduct license exams or to perform inspections at operating Westinghouse nuclear power plants. The series consists of a 3-week systems course, a 2-week advanced course, and a 2-week simulator course. Prior to taking this series of courses, NRC personnel can also take a 1-week basic Westinghouse systems course to prepare them for taking the series. After completion of the 7-week series, NRC inspectors who are assigned to a CE or B&W nuclear facility are required to take a 3-week design-differences course (classroom and simulator) which concentrates on major differences from the Westinghouse design. These additional CE and B&W technology courses are known as cross-training courses. Hence, the second AP1000 technology course would be 3-week cross-training course, based on the existing CE/B&W course model, targeted at the NRC region-based license examiner and inspection staff. The completion of the 3-week differences course would be timed to support training of examiners involved with plant operator license exams for AP1000 units currently under construction in the U.S. Development of an "AP1000-like" simulator would be required to support full administration of the 3-week course.

In order for the NRC training staff and simulator engineers to acquire the necessary knowledge and skills to develop the second training course utilizing a simulator, the TTC awarded another contract to Westinghouse for a Westinghouse-conducted 3-week classroom and simulator AP1000 course at its Cranberry, PA headquarters complex. This training was completed by all involved TTC instructors and two simulator engineers on September 2, 2011.

The training material from the contracted Westinghouse course became the basis of the 3-week cross-training course developed by the TTC staff, which included incorporation of a digital HMI simulator closely approximating the design of the AP1000. TTC instructors developed the classroom portion of the course, including manual chapters, illustrations, associated presentations, and related reference documents, between September, 2011 and May, 2012.

Additionally, members of the NRC training staff observed AP1000 simulator demonstrations by qualified Westinghouse staff at Cranberry, and later by plant operators at the Vogtle and V.C. Summer nuclear sites once their simulators were delivered. Their observations enhanced the development of the NRC's AP1000 simulator. Qualified members of the NRC training instruction staff also participated in the factory and site acceptance tests for the NRC digital HMI simulator platforms, which further enhanced their skills in operating a nuclear power plant using a digital HMI.

TTC instructors first conducted the two-week classroom portion of the 3-week course in May, 2012, and it was conducted five more times between June, 2012 and May, 2013 for NRC examiners to support their development of the written portions of operator license exams for the Vogtle and V.C. Summer AP1000 units. The original scheduled dates for these written exams were in July of 2013, but those dates were delayed around the time the classroom portion of the training started. Currently, the first written and operating license exams for Vogtle and V.C. Summer are scheduled for May of 2015.

After delivery of the first set of AP1000 simulation models from the contractor and NRC simulator engineers, qualified TTC instructors worked closely with the simulator engineers to troubleshoot problems and to enhance the performance of the simulator. During this time the instructors also reviewed emergency, abnormal, and normal operating procedures obtained from Vogtle and revised them as necessary, so that they could be implemented during simulator operation. Work to ensure simulator functionality started in January of 2013 and ended September 13, 2013, when TTC personnel successfully completed a "dry run" of the simulator portion of the 3-week course.

4. Results of Training Using NRC's AP1000 Simulator

The one-week simulator portion of the cross-training course was provided mainly to NRC examiners, who had previously completed the classroom portion, in several sessions between November, 2013 and March, 2014. Also attending the training were senior reactor operators from Vogtle, who provided the TTC team with feedback on the simulator functionality and course content. Based on the course evaluations and feedback received from course attendees, the TTC instructional staff considers the NRC AP1000 simulator project to be a resounding success. Course evaluations have averaged 4.6 out of a possible 5 (highest rating) from 31 members of the NRC staff who attended. Some of the written comments concerning the NRC's AP1000 simulator training were:

- "This was probably the most useful training I have had to date."
- "The use of the automated procedures system during use of the EOPs was particularly instructive and fascinating."
- "The hands-on simulator time was extremely valuable in understanding the response the plant will have to different events."
- "Instructors were very knowledgeable and the new AP-1000 simulator performed better than the Westinghouse simulator in Cranberry PA."
- "Best training course I have attended at the TTC."

- "I found the simulator to be an excellent learning tool, and have a sincere appreciation of the effort that went into course development and presentation."
- "I learned a great deal from the week in the simulator and left feeling more confident in my abilities to perform AP1000 job related activities."
- "Instructors were very knowledgeable and provided interesting simulator scenarios to demonstrate integrated plant operations."
- "My hat is off to the TTC staff, I think they have done a fabulous job in developing this simulator and developing and delivering this training."
- "The TTC instructor and simulator staff has put together a very impressive product that I feel will be well received by all attendees."
- "Developers of this course and the simulator should get significant kudos. Very impressive accomplishment."

In addition to NRC staff comments, the Vogtle representatives provided positive feedback. They were all largely impressed with how well the NRC's simulator models AP1000 plant response and with the software-based plant control applications (soft controls, interactive computerized procedures, alarm presentation). They were also impressed with the effectiveness of the training. All of the Vogtle staff observers noted that the NRC's AP1000 simulator was more capable in certain respects than Vogtle's current limited-scope simulator.

The NRC's limited scope AP1000 simulator is shown in Figures 1 and 2.

5. References

[1] J. Griffin, "New Reactor Simulator Development at the US NRC", Proceedings of the Enlarged Halden Programme Group Meeting on Man-Technology-Organisation, Sandefjord, 2011.

[2] BS Minks, MR Mitchell, et al, "Technical Basis for Physical Fidelity of NRC Control Room Training Simulators for Advanced Reactors", PNNL-18865, October, 2009.

Figure 1. NRC's Limited-Scope AP1000 Simulator – View 1

Figure 2. NRC's Limited-Scope AP1000 Simulator – View 2