Implementation of CNSC Regulatory Guide G-323 at Pickering Nuclear Generating Station

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Abstract

The Minimum Staff Complement (MSC) is the minimum number of people required to be present on a given shift to ensure safe and reliable operation of the nuclear facility, while maintaining an adequate preparedness level in handling all possible emergency scenarios. In 2009-2010, Ontario Power Generation (OPG) examined its MSC at Pickering using the newly issued regulatory guidelines specified in CNSC Guide G-323 'Ensuring the Presence of Sufficient Qualified Staff at Class I Nuclear Facilities – Minimum Staff Complement'. This was the first project of this nature in the Canadian Nuclear industry to be executed using G-323. The following paper provides an overview of the methodology that was developed to demonstrate Pickering's alignment with G-323 in addition to the successes and challenges of the project.

1. Introduction

The Minimum Staff Complement (MSC) is the minimum number of people required to be present on a given shift to ensure safe and reliable operation of the nuclear facility, while maintaining an adequate preparedness level in handling all possible emergency scenarios. Prior to 2010, the Pickering Nuclear Generating Station (PNGS) A and B MSC was based on the capability to respond safely and effectively to a Loss of Coolant Accident (LOCA) event on either Unit 2 or Unit 5. The LOCA event was considered to be the most resource intensive event because the response requires the coordination of multiple teams within the plant. The MSC was derived using inputs predominantly from Operations.

Ontario Power Generation (OPG) examined its MSC at Pickering using the newly issued regulatory guidelines specified in CNSC Guide G-323 "Ensuring the Presence of Sufficient Qualified Staff at Class I Nuclear Facilities – Minimum Staff Complement" [1] and CNSC Guide G-278 "Human Factors Verification and Validation Plans" [2]. This was the first project of this nature in the Canadian Nuclear industry to be executed using the regulatory guideline G-323.

The objective of the project was to perform and document the systematic analysis to establish the MSC and develop a plan for validation of the MSC to satisfy the regulatory guidelines specified in G-323. The systematic analysis selected a subset of resource-limiting scenarios and then analyzed the scenarios using Human Factors methods to establish the MSC. The project team consisted of multiple stakeholders (Operations, Human Factors, Reactor Safety, Regulatory Affairs, Emergency Preparedness and Training) that resulted in a multi-disciplinary approach to determine the MSC at Pickering.

The methodology was organized into three phases (Figure 1). The first phase of the project determined the subset of resource-limiting scenarios. The focus of the second phase was to analyze the task and resource requirements of the subset of limiting scenarios using Human Factors methods. The Human Factors analysis included the validation of all field tasks associated with the Emergency Operating Procedures for the resource-limiting scenarios. The Human Factors analysis established the most resource-limiting event that would define the basis for the MSC at Pickering NGS A and B. For the third and final phase, the MSC was validated according to the validation objectives outlined in G-323 and the requirements for HF validations specified in G-278.

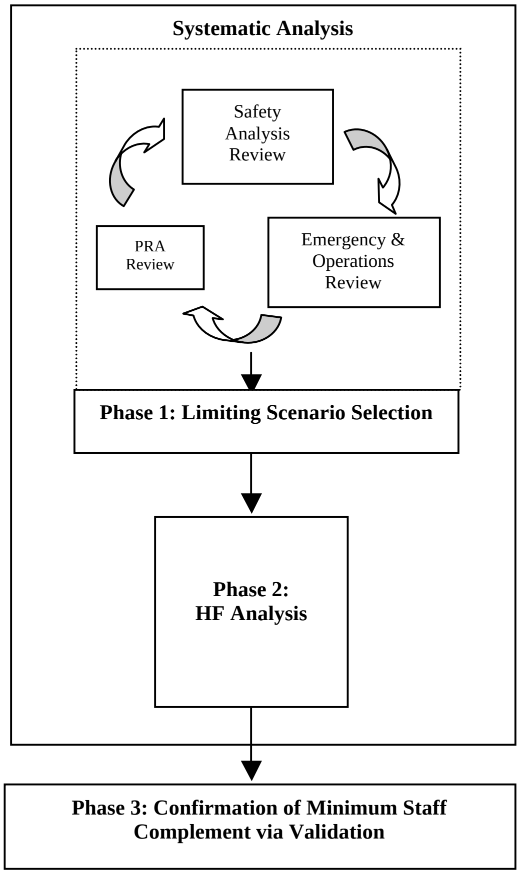

Figure 1 – Phases of Minimum Shift Complement G-323 Implementation

2. Phase 1: Selection of Resource-Limiting Scenarios

As required by G-323, the first phase of the project established and documented the technical basis used for the selection of the limiting event(s) in terms of station personnel resources. It was possible that more than one event would be limiting for each station in terms of a certain resource. For example, one accident scenario may require more control room operators while another scenario may require more field personnel. Thus, the station MSC would be a combination of the limiting number of personnel in each staffing category for all individual event sequences.

A multidisciplinary approach was used to select the subset of resource-limiting scenarios and considered Safety Analysis, Probabilistic Risk Assessment (PRA), Emergency Response and Operational Response. The Safety Analysis and PRA review generated a list of possible events. The list of events was grouped into categories of similar event responses and the Operations procedural staffing requirements were estimated for each event category. Emergency Response actions for the MSC in addition to the staffing required to respond to the Emergency Operating Procedures (EOPs) were also reviewed. This information was used to determine the subset of resource-limiting scenarios. Each review element contained in Phase 1 is discussed in detail in the sections that follow.

2.1 Safety Analysis Review

The objective of the safety analysis review was to identify the initial set of event sequences for consideration as potentially limiting events including the required mitigating actions. A thorough review of the safety analysis basis for Pickering ensured that events and event sequences had not been overlooked when selecting a limiting scenario.

The following assumptions were applied to the identification of events to be considered:

1. All Design Basis Accidents (DBAs) identified for Pickering A and B were included. Currently, Anticipated Operational Occurrences (AOOs) are captured by the corresponding DBAs that bound them.

2. Only event combinations of initiating events/equipment failures occurring within 8 hours were considered since it was assumed that the plant condition will be stabilized by then and/or additional resources will have been brought in to stabilize the plant.

3. The only relevant operator actions considered for this analysis were those occurring within 8 hours of the initiating event.

For Pickering A and Pickering B, the list of events and event combinations and the list of required operator actions was taken from the Safety Report and supporting design basis analyses. The review also considered events, within the design basis, that would result in consequential events happening on other units. For example, a Main Steam Line Break (MSLB) that causes losses of power on other units. Common mode or external events, that are part of the design basis but that are not documented in the Safety Report, were also addressed. This included a Loss of Bulk Electrical System (LOBES) event, a seismic event, major fires, and intake channel related events.

The list of event sequences and required operator actions was transferred to the Operations and Procedure Review and was cross-referenced to the Abnormal Incident Manual (AIM) procedures, which in turn identified the preliminary staff requirements for operator response to the event.

2.2 Probabilistic Risk Assessment Review

The Probabilistic Risk Assessment (PRA) models for Pickering A and Pickering B were used to ensure that a complete set of initiating events, dominant failures and modeled important operator actions were considered in determining the resource-limiting scenarios. The PRA review provided a list of initiating events, risk significant cutsets and post-accident human interactions, along with their Fussell-Vesely importance to both severe core damage (SCD) frequency and limited core damage (LCD) frequency. The Fussell-Vesely importance measure represents the percentage contributions of the cutsets that contain a specific event. A cutset is a combination of failures that cause the event of interest, severe core damage for example. The Fussell-Vesely importance measures were included with the list of modeled events to ensure that analysts performing the systematic review of station operations and procedures were aware of the risk importance of the various events and considered this importance in the selection of the limiting scenarios. The PRA information was used to ensure the list of events considered was complete and added some context with respect to initiating events, human interactions and failures significant to core damage.

2.3 Emergency Response Review

OPG's Consolidated Nuclear Emergency Plan (CNEP) [3], a regulatory requirement, is the basis for the plant-specific Emergency Response structure. The CNEP describes the various organizations involved, and provides roles, responsibilities and number of positions by role required to address a nuclear emergency response at the OPG Nuclear Generating Stations. The Emergency Response Organization (ERO), as described in the CNEP, is responsible for executing the emergency plan. The ERO is made up of three primary components. The first two comprise the on-site response organization. This includes shift ‘duty’ staff and augmentation staff who are called in to fill the Site ERO. Management, technical, operations, and support staff of the Site Management Center (SMC) are also assembled to fulfill their responsibilities and duties in response to an emergency. The third component is the Corporate Emergency Operations Facility (CEOF), an off-site facility common to all OPG nuclear sites, whose staff is responsible for coordinating and managing the overall response to a nuclear emergency. The focus of this work was the emergency response organization that is currently identified as being part of the MSC.

The applicable emergency response procedures and governing documents were reviewed to ascertain if there are functions required to be performed by station staff that are not already encompassed by the Operations and Procedure Review. The required actions, timeframes, numbers and types of staff involved were reviewed to determine if they could be completed by staff that are already part of the MSC. The main outcome from the Emergency Response review was the determination that the ERO is made up of a distinct group of individuals, who are qualified in addition to their regular job functions to carry out their emergency response procedures. The ERO response is event independent.

The only MSC positions which had a role in the ERO and event response were the Shift Manager (SM), the Control Room Shift Supervisor (CRSS), the Field Shift Operating Supervisor (FSOS) and the Shift Advisor Technical (SAT). The other ERO minimum complement positions were assigned predominantly to maintenance personnel. These positions included the Shift Resource Coordinators, In Plant Coordinator, Out of Plant Coordinator, On-Site Radiation Emergency Response Group, Off-Site Survey Group and the Emergency Response Group. The analysis did not assess the adequacy of the ERO as this is reviewed on an ongoing basis by station drills. The analysis assumed that these individuals were occupied with their ERO responsibilities for the duration of the time-line analyzed.

2.4 Operations and Procedure Review

Using the list of events generated from the Safety Analysis and PRA Reviews, the applicable emergency operating procedures were reviewed to understand the event-specific procedures, the general nature of the required response and how this differs for different types of incidents. Particular attention was given to identifying events that are atypical in terms of response staffing. For example, some design basis events may require that more than one emergency procedure be used by the duty crew to address consequential failures - sequentially to address consequential failures on a single unit, or concurrently to address consequential failures on different units (e.g., initial accident, such as Main Steam Line Break, followed by assumed consequential loss of Class IV power).

The events in this list were rationalized into groups of similar events according to the defined Operator Response. The groups included, but were not limited to, the following categories: a single unit event involving the use of a common system, a single unit event resulting in consequential failures on other units, multi-unit events requiring common mode response. The most restrictive in each group (as determined by the review of staffing requirements used for initial classification) was then used for an analysis of the minimum staffing requirements for each of the groups. This activity is represented by the schematic in Figure 2.

For the representative event from each group, the next step was to define the staffing requirements to establish short-term and long-term heat sinks, address losses of PHT inventory, ensure appropriate containment response/isolations and control of emissions. High-level Main Control Room (MCR) actions, Unit Emergency Control Centre (UECC) actions, and field actions, in addition to equipment accessibility during an event were all considered.

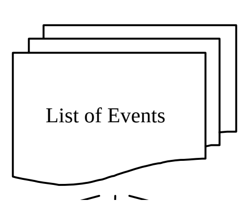

Figure 2 – Overview of Operations and Procedure Review

Following the review of the staffing requirements for each event, the most limiting scenarios in terms of staffing requirements and timing of actions was selected for further Human Factors analysis. The resource-limiting scenarios selected for Human Factors Analysis were those which presented the greatest challenge to the station staff, and which would provide an opportunity to resolve any uncertainties about role assignments during the event. The following resource-limiting events were chosen:

- Seismic event (Common Mode event),
- Pickering A LOCA + LOBES,
- Pickering B LOCA + LOBES,
- Pickering B MSLB Event

3. Phase 2: Analysis of Resource-Limiting Events Using Human Factors Methods

The HF analysis consisted of task analysis, time-line analysis, workload analysis and interim validation exercises. The HF analysis was performed for each of the selected resource-limiting scenarios.

The task and time-line analysis determined the basis of what needs to be done, by whom and by when. The interim validation exercises were completed to gather detailed timing information and workload data for critical tasks. A schematic of the HF methodology is included in Figure 3 and a description of each step is included in the sections that follow.

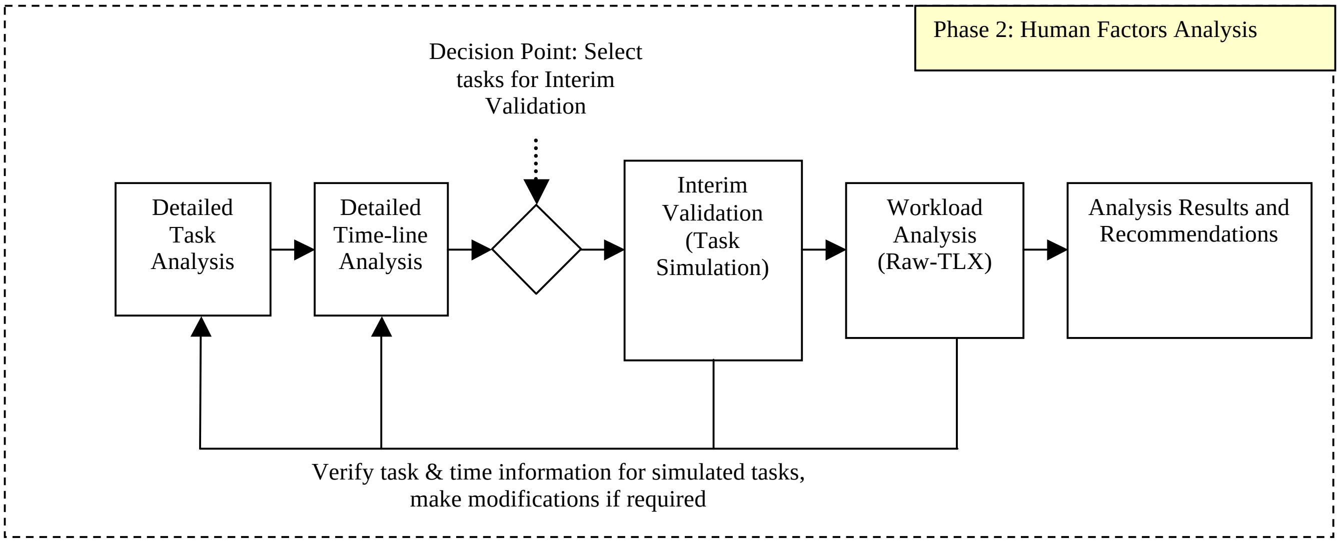

Figure 3 – Human Factors Methodology

3.1 Task Analysis

The task analysis was carried out to break down the high-level tasks of the resource-limiting events which were identified in the Safety Analysis and Operations review. A task analysis was completed for each role and identified the following information:

- Specific task steps to be performed;
- Task frequency and sequence (whether tasks can be carried out in parallel);
- Task category (Diagnosis/Troubleshooting, Action, Monitoring, Verification);
- Task location (MCR, field etc);
- Required interactions with other personnel for the purpose of diagnosing, planning, communicating, coordinating and controlling the scenario; and
- Critical decision points, operational strategies, competing priorities, wait times and required team updates. Station experts will be asked to provide this information since it is not necessarily explicitly included in the procedures.

Inputs to the task analysis were extracted from the reviews carried out in Phase 1. Structured interviews with Subject Matter Experts (SMEs) were conducted to supplement the information required for the task analysis. At least one SME from each work group or role was interviewed.

The level of task breakdown that was considered for this analysis included the following components and was used as a guideline when completing the task analysis:

- Collection of necessary equipment;
- Time to put on protective clothing if necessary;

- Communication requirements (pre-job briefing, supervision, interaction with others etc.);
- Travel to task location;
- Equipment/control manipulation;
- Process monitoring and feedback; and
- Checks and verification.

3.2 Time-line Analysis

The completed task analysis was used to prepare a time-line representation of the activities carried out for each role within each resource-limiting event for the duration of the event (8-hours). The time-line showed high-level tasks, sub-tasks, task duration, frequency and sequence.

An estimate was made of the time required to complete each task, based upon discussions with minimum complement staff and actual time measurements recorded during previously simulated tasks, where possible. A representative sample of staff was interviewed to elicit task times. At least one member from each role group identified in the time-line analysis participated. In addition, attempts were made to ensure that the sample of SMEs contained individuals with a range of experience (i.e. recently certified operators and more experienced operators). Where the task times obtained during the interviews varied for a specific task, the more conservative estimate was used to construct the time-lines.

The time limits (time available for task completion) were obtained from the safety analysis operator credits and any other timing information provided in the procedures. Alternatively, the analysis determined where and how these tasks (without specific time credits) fit into the overall event based on:

- The window of time for task completion (earliest-latest);
- Whether there were other time-specific tasks that depended on the task and the time requirements for those tasks; and
- Equipment/process constraints (e.g. an Operator will need to wait until power is available before energizing a bus).

3.3 Workload Analysis

The information yielded by the task analysis and time-lines for the limiting scenarios was used as a basis for the workload analysis as it defines the task steps to be carried out by the personnel that comprise the MSC, in addition to information about the time to complete these tasks. The aim of the workload analysis was to establish whether the station personnel would be able to adequately carry out all their required tasks within the required time frame as per the procedural requirements of the resource-limiting scenarios selected.

Workload is often defined as the physiological and mental demands that occur while performing a task. Workload emerges from the interaction between the requirements of a task, the circumstances under which it is performed, and the skills, behaviors, and perceptions of the worker. Workload measurement is a controversial subject.

Subjective rating scales are the most widely used workload assessment tools. These questionnaires or rating scales are filled out by the worker and target the worker's personal estimation of workload. Subjective workload measures are useful in characterizing the perceived demands of the task, which are an important aspect of any system and influence the operator's acceptance of the system. The advantages of subjective workload assessments are ease of implementation, low cost, and limited intrusion on task performance. The disadvantage is the variability that may exist between subjective estimates. A frequently used subjective rating tool is the NASA Task Load Index (TLX). The NASA-TLX incorporates six subscales: mental demand, physical demand, temporal demand, performance, effort level, and frustration level. The rating scales and their descriptions are included in Table 1.

Table 1: NASA-TLX Rating Scale Definitions

Subscale	Endpoints	Description
Mental Demand	Low/High	How much mental and perceptual activity was required (e.g. thinking, deciding, calculating, remembering, looking, searching, etc.)? Was the task easy or demanding, simple or complex, exacting or forgiving?
Physical Demand	Low/High	How much physical activity was required (e.g. pushing, pulling, turning, controlling, activating, etc.)? Was the task easy or demanding, slow or brisk, slack or strenuous, restful or laborious?
Temporal Demand	Low/High	How much time pressure did you feel due to the rate or pace at which the tasks or task elements occurred? Was the pace slow and leisurely or rapid and frantic?
Effort	Low/High	How hard did you have to work (mentally and physically) to accomplish your level of performance?
Performance	Good/Poor	How successful do you think you were in accomplishing the goals of the task set by the experimenter (or yourself)? How satisfied were you with your performance in accomplishing these goals?
Frustration Level	Low/High	How insecure, discouraged, irritated, stressed and annoyed versus secure, gratified, content, relaxed and complacent did you feel during the task?

Operators provide estimates of workload on a graduated scale (from 0% to 100%) while they are performing a task or immediately afterwards. NASA-TLX is a two-part evaluation procedure consisting of both weights and ratings. The first requirement is for each operator to evaluate the contribution of each factor (its weight) to the workload of a specific task. The second requirement is to obtain numerical ratings for each sub-scale that reflects the magnitude of that factor in a given task. The most common modification made to NASA-TLX has been to eliminate the weighting process. This has been referred to as Raw-TLX (RTLX) and it is typically used because it is straightforward to apply. This simplification has been found to be equally sensitive to the complete TLX methodology [4][5]. Another common variation is to analyze subscale ratings instead of generating a single overall workload score. This approach emphasizes the diagnostic value of the subscales. The individual subscale ratings can help to pinpoint the source of a workload or performance problem. The Raw-TLX was selected as the most suitable technique for the context of the MSC analysis. Also the brevity of the Raw-TLX method was a benefit, since the workload questionnaires were being administered in the plant environment and time with SMEs was often limited.

The threshold for unacceptable workload on the NASA-TLX scales has not been formally defined. For this study, the acceptability criterion that was applied was that any scores below 80 (on any of the scales) were acceptable but any scores equal to or above 80 required further investigation. These tasks were examined to provide greater detail about the context and to determine whether the task can be modified in any way to decrease the workload.

Although the NASA-TLX method assesses the workloads of individuals, the time-line analysis was used to assess the overall workload imposed on the staff (in terms of task distribution and allocation) at different times in the event. The time-lines were analyzed to identify high workload situations resulting from the functional and temporal requirements of a task. Functional requirements include task factors such as task complexity, personnel interactions and location. Temporal requirements include items such as task timing, sequencing and process delays.

3.4 Interim Validation Exercises

The task analysis and initial time-lines were reviewed to determine candidates for task walkthroughs and simulations and workload analysis in order to obtain more accurate time measurements and task information. Since MCR tasks are frequently practised in the simulator, the emphasis was on validating the time to complete the tasks that were carried out in the field. The information that was collected included task timing, task observations and Raw-TLX scores (as described in Section 3.3). The information from the interim validation exercises was used to refine the task and time-line analysis and was also used for the workload analysis.

The acceptance criteria for the interim validation exercise were:

1. The time taken to complete the task as compared to timing specified in the Safety Report (if the action is a credited action), and

2. Workload, such that any workload scores equal to or above 80 required further discussion with participants.

For each interim validation exercise, the operator was asked to simulate the task as it would be performed. This included obtaining personal protective equipment and other equipment required. The operators were not required to manipulate equipment (ie. open valves) but were asked to provide an estimate of time and workload based on their experience. The HF analyst timed the task and took notes. A workload questionnaire (Raw-TLX) was administered after each exercise and the results were discussed with participants in a de-briefing that followed the exercise.

The main result from the HF analysis was a resource distribution for each resource-limiting event based on a time-line constructed using both estimated and measured values. These results were used to improve operator safety related action times. Changes were made to the plant configuration and to the sequencing of tasks within procedures to implement identified improvements, they were field validated and incorporated into the integrated validation exercise. The Human Factors analysis for each limiting scenario was completed and documented. The seismic event was found to be the most resource-limiting scenario of the four analyzed requiring 78 staff to respond to the event, which is below the current MSC of 82 for Pickering A and B.

4. Phase 3: Validation of Most Resource-Limiting Scenario

As the analysis covered multiple scenarios the emphasis of the final phase was to validate that the most resource-limiting scenario identified during the HF analysis could be completed within the prescribed limits and meets the validation acceptability criteria. The scenario that placed the greatest demand on the MSC, i.e. the most-resource limiting scenario, was selected for the final MSC validation exercise. This was identified to be the seismic event impacting both Pickering A and Pickering B.

To meet the expectations of G-323 [1], the integrated validation exercise was required to demonstrate that the following could be achieved by the minimum staff complement for the validation scenario:

1. The relevant procedures can be effectively implemented in a timely manner;

2. There is an effective and timely response to anticipated operational occurrences, design basis accidents, and emergencies;

3. The facility can be effectively monitored, controlled and stabilized (control, cool, contain);

4. There is effective communication and coordination of required actions;

5. Workers are able to maintain awareness of facility conditions;

6. The physical and mental workload of the minimum staff complement is acceptable; and

7. All safety-critical human actions are achievable, based on the personnel resources available, and the time available for the action to be completed by.

The exercise was based on the Validation Plan that was prepared in accordance with CNSC Regulatory Guide G-278 "Human Factors Verification and Validation Plans" [2]. The validation was carried out in two parts. The first part was conducted in the Main Control Room (MCR) simulators of the Pickering Learning Centre (PLC) and focused on the MCR response. The second part was conducted in the plant and focused on the field response as well as the communication and coordination between the MCR and the field. The time-line and critical safety parameter data from the first part of the validation exercise was used to drive the MCR response in the second part of the exercise. The event provided some interesting challenges in that the Pickering A MCR is seismically qualified so the PA staff remained in the control room; whereas, the Pickering B MCR is not seismically qualified so the PB staff evacuated to their secondary control areas.

For the second part of the exercise, all field handouts were dispatched to be simulated, and communication and coordination between the field, the MCR and/or the secondary control areas (UECCs) were required. Process delays were built into the response. For example, a field operator would estimate the time required for a piece of equipment to change state and this time would be added to the response time before the operator would be available to carry out any other tasks. HF Analysts, trained volunteers and validation observers were staged at various locations throughout the plant to collect task observation, timing and workload data.

The seismic event validation exercises involved many participants, observers and analysts distributed throughout the plant. The validation of the seismic event had not been practiced to such an integrated extent by the validation participants. The results of the validation exercise were that there were enough resources to execute all of the tasks required to respond adequately to this event. Pickering A had a peak resource requirement of 20 operations staff at 1 hour into the exercise. This corresponded to the minimum complement at Pickering A. Pickering B also had a peak resource of 19 operations staff close to 2 hours into the exercise. This was below the minimum complement of 24. In addition, the critical timing requirements for credited operator actions were met. The subjective workload results were acceptable. Some instances of high workload were identified and recommendations were provided to address the ratings. The roles experiencing high workload were identified to be the Shift Manager (SM), the Authorized Nuclear Operators (ANOs), the Control Room Shift Supervisor (CRSS) and the Field Shift Operating Supervisor (FSOS). There were some high workload ratings attributed to how the validation exercise was executed; this feedback can be used to improve such drills in the future.

The main challenges associated with the response to the event were the use of the emergency communications system and providing unit oversight for a multi-unit event with staff at different locations. This can be improved with the provision of additional training on the use of the emergency communications system and training on event management from the Unit Emergency Control Centres (UECCs).

5. Lessons Learned

Some of the lessons learned from the project are included below:

- The interim validation exercises added value to the project in solidifying task times and obtaining operator input to improve the quality of the procedures; however, they were time intensive and it was not always possible to repeat each exercise more than once.

- The project required involvement from all project stakeholders from the beginning of the project. Frequent team meetings were held and all stakeholders were aware of project concerns and developments.

- Training and simulator staff should have been involved from the project onset. They are valuable resources and can assist with planning the final validation in the simulator.

- It was important to maintain regular communication with the regulator so that regulator was able to stay informed and provide timely feedback.

6. Positive Outcomes Realized by OPG during G-323 Implementation

The project successfully developed the basis for the MSC for Pickering and as a result the action notices on Pickering will be closed. This will result in a satisfactory rating in the CNSC Annual Industry Report. Some additional benefits derived through the project were as follows:

- The limiting event was previously a LOCA event. The project determined that a seismic event is more onerous to manage from a resource perspective. This resulted in the first drill of its kind where operations staff were required to go to the UECC's and simulate the operation of the units using the UECCs under an accident scenario. During the analytical phase, all handouts were walked down by field staff. Positive feedback was received from the field staff during this process as it provided them an opportunity to walk the procedure down, identify improvements and have the improvements implemented. The key finding here is that an integrated approach to training the operations staff would provide the authorized staff and the field staff an opportunity to evaluate all aspects of the event. This includes both the control room simulator response and the ability to execute field procedures, both effectively and with the available resources.

- The field walkdowns were key to assuring OPG could achieve Safety Report credited operator response times. The field walkdowns helped to determine the actual time required to complete the task and identified areas to improve task execution.

- This thorough understanding of the basis for the MSC has led to further refinements of the complement that will further benefit the plant.

7. Conclusion

The Pickering MSC project was the first project of this nature in the Canadian Nuclear industry to be completed using the newly issued CNSC Guide G-323. The success of the project demonstrated the safe and reliable operation of the nuclear facility, while maintaining an adequate level of preparedness in handling all possible emergency scenarios. The valuable lessons learned at Pickering have been shared with Darlington NGS and the Darlington MSC project is currently on track for completion in 2011.

8. Acknowledgements

We would like to acknowledge the dedication of the Pickering NGS staff and the AMEC NSS staff that contributed to the successful execution of this project.

9. References

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