VALIDATION OF THE MINIMUM STAFF COMPLEMENT FOR THE NRU REACTOR

Y. Dadashi[1], N. Dadashi[1] and K. Hughes[2]
[1] Candesco Division of Kinectrics, Toronto, Ontario, Canada
[2] Canadian Nuclear Laboratories, Chalk River, Ontario, Canada
yasamin.dadashi@candesco.com, nastaran.dadashi@candesco.com, kathy.hughes@cnl.ca

Abstract

Understanding the optimum number of qualified staff required during normal operations needs identification of the functions, contexts, and technological resources. This estimation is particularly challenging during abnormal conditions where the dynamics of the functions differ, the tasks and their priorities vary, and depending on the type of event, the availability of technological resources may change. This paper describes a series of Human Factors assessments conducted to assess the sufficiency of the minimum staff complement of the NRU Reactor at Chalk River Laboratories (CRL) to meet CNSC's requirements. Various methods were adopted to rationalize and validate the minimum staff complement. A validation exercise was also designed and conducted to validate the minimum staff complement for the most resource intensive scenario. The results of these assessments confirmed that the minimum staff complement is sufficient for safe response to events during all operational conditions at NRU reactor as well as anticipated operational occurrences.

1. Introduction and Background

Ensuring the presence of a sufficient number of qualified workers to carry on the licensed activity safely and in accordance with the Nuclear Safety and Control Act (NSCA, the Act) is a licence requirement for Class I Nuclear Facilities. An assessment of programs and processes at Canadian Nuclear Laboratories (CNL) and their effectiveness identified the following tasks with regards to minimum staff complement at NRU:

- Assess NRU staffing needs for minimum staff complement; and
- Confirm the minimum staff complement via a minimum staff validation exercise.

The objective of this project reported in this paper was to achieve these two goals through to provide a rationale for determination of the minimum staff complement at NRU.

CNSC G-323: Ensuring the Presence of Sufficient Qualified Staff at Class I Nuclear Facilities – Minimum Staff Complement [1] sets out the requirements and expectations for a "systematic analysis" of the minimum staff complement. A review of the regulations and practices in the nuclear and other similar industries also indicate the emphasis on systematic approach to the analysis of minimum staff complement [2].

The other important requirement for establishing and confirming the minimum staff complement is ensuring that the evaluation is performed for the "most resource intensive" operating conditions. An analysis of the activities required to respond to the most resource intensive scenario often reveals that multiple operating and emergency procedures should be considered. This requirement may also introduce a challenge if the existing procedures do not provide a comprehensive set of integrated instructions for effective response to the specific scenario.

The approach developed as part of this project addresses these two challenges by providing a flexible yet structured method to enable a systematic analysis of the most resource intensive operating scenario. In this paper, the approach adopted for selecting the scenario, the framework developed for structuring the information to facilitate the systematic analysis, and the method used for eliciting information from Subject Matter Expert (SMEs) to verify and refine the scenario is described.

2. Methodological Approach

A series of qualitative and quantitative methods were adopted to assess and validate NRU minimum staff complement.

Figure 1 presents an overview of the methodological approach adopted. As a first step, it was important to obtain a preliminary understanding of the context. This was achieved by a review of relevant NRU documents, an initial facility walk-down, and semi-structured interviews with SMEs which included two Senior Reactor Shift Engineers (SRSE) and one Nuclear Operator (NO). The information obtained from these activities led to the selection of a set of scenarios which were then validated through Scenario Walkthroughs (table-top validation) with SMEs.

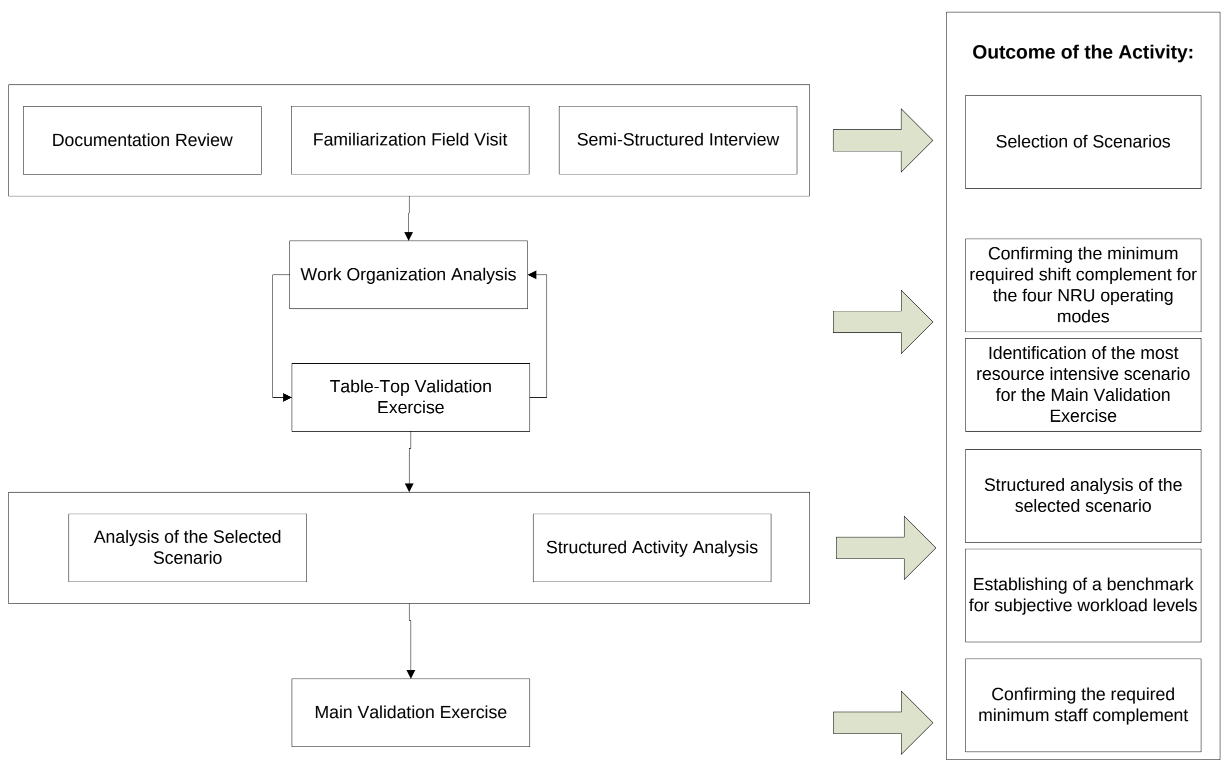

Figure 1 - Methodological Approach

In the next stage, and in order to ensure that a systematic and traceable analysis approach is adopted, a work organization analysis was performed. Results of these analyses were documented in Contextual Activity Matrices that provided a structured framework for contextualizing the tasks within their work settings.

The Table-Top Validation Study was facilitated through a set of Scenario Walkthroughs. A representative from each of the roles required as part of the minimum staff complement participated in the Scenario Walkthrough. Data gathering during these sessions was facilitated through the use of Contextual Activity Matrices to elicit and confirm sufficiency of staff complement for each scenario. Additionally, the results of this analysis provided information on constraints where task sequences, points of interface, and task locations were not reasonably aligned.

This exercise resulted in an understanding of operational procedures and operators' roles and responsibilities as well as operators' subjective workload. Additionally, participants' comments during the Scenario Walkthroughs together with the results of the overall perceived workload led to the selection of the most resource intensive scenario which was validated in a Validation Exercise.

The next three sections provide detailed information on the main elements of the methodological framework described above.

2.1 Scenario Selection

In accordance with the requirements identified in Section 5.1.2.1 of CNSC G-323 [1], the validation scenarios were selected to ensure that they include the most resource intensive credible events, including those that involve coincident operational occurrences, design basis accidents, and emergencies. In order to ensure that the most resource intensive credible events are selected, the following criteria were considered:

- Amount of information needed to perform the task;
- Amount of communication required;
- Safety significance of the tasks;
- Number of systems and subsystems involved, i.e., complexity of the task; and
- Time requirements for performing (one or more of) the tasks.

The scenarios were selected based on a review of NRU documents and interviews with three Senior SRSEs and one NO. A set of questions were also defined to address the criteria identified above which were used during interviews with the SMEs.

Results of the interviews with the SMEs were analyzed to map the identified scenarios on the established criteria and to ensure that the scenarios cover all aspects that determine resource intensiveness of a task.

2.2 Work Organization Analysis

Work organization analysis was used to associate tasks required to achieve objectives of each scenario with the situation in which the work will take place. Results of the SME interviews and document reviews to identify suitable scenarios were documented in a series of Contextual Activity Matrices to facilitate this analysis.

Contextual Activity Matrix is one of the components of Cognitive Work Analysis (CWA) [3]. Once the matrices were developed for each scenario, they were used during Scenario Walkthroughs to provide a structured framework for analysing activities that needed to be performed to achieve the objective of the scenario. The matrices also facilitated thorough and structured data gathering during the Scenario Walkthroughs. Specifically, the matrices provided information on the following aspects of each scenario:

- Task sequences from initiation of the scenario to the point when SRSEs confirmed that the situation is considered to be under control and no other immediate actions are required;
- Responsibilities of different roles during the scenario identified using a colour coded system (coloured circles in Table 1 denote the different roles; e.g., SRSE is denoted by brown circles and Alarm Desk Operator is identified by blue circles);
- Communication links between different roles denoted by arrows in the matrix to show the direction of the communication;
- Different locations throughout NRU where operators needed to be present to perform their different tasks; and
- Any procedures that operators may need to refer to for performing their tasks.

Structuring this information in a tabular format provided the HF specialists with a comprehensive overview of the performance of the team during the scenario and helped identify whether:

- There are any conflicting responsibilities for a single role; and/or
- Any single role is overloaded during the scenario (based on SME comments).

An example of the matrix developed for the main validation scenario is illustrated in Table 1 below.

Table 1 – Scenario 1: Contextual Activity Matrix

Locations / Task Steps	Main Control Room		Room 1	Room 2	Panel 1	Panel 2	Room 3	All other locations within the main Bldg.	All other locations outside the main Bldg.
	Alarm Desk	SRSE's Control Panels							
Fire alarm goes off.									
Inform SRSE of the location of fire.									
Report as fire liaison officer									
SRSE informs crew that the reactor will be tripped.									
SRSE refers to Fire Response Procedure									
Stop the loop operation and return to safe state.									
SRSE trips the reactor.									
Alarm Unit 39 is received.									
SRSE instructs the Electrician to open the dump valve breakers.									
Electrician opens the dump valve breakers.									

2.3 Activity Analysis and Subjective Workload Analysis

Another important aspect of validating the adequacy of the minimum staff complement was assessing mental workload levels of the operators. During scenario walkthroughs, it was identified that the SRSE and Alarm Desk Operator have the highest level of workload during the scenario. A preliminary review of the scenario-specific procedures for tasks performed by SRSE and Alarm Desk Operators during the scenario was conducted. This review provided a high level understanding of activities performed by these roles and helped identify the key activities for each role. These high level activities were grouped under the following categories:

- Monitoring the main panel;
- Monitoring alarms;
- Communications;
- Paperwork; and
- Idle Time.

This information was used for a structured Activity Analysis which was conducted to establish the benchmark workload levels of the SRSE and Alarm Desk Operator. In order to structure the observational data to be collected during the Activity Analysis, a time stamped Excel™ Spreadsheet was developed and used by the two Human Factors Specialists who were shadowing the SRSE and Alarm Desk Operator. The facilitators shadowing each operator documented time spent by operators on each of the task categories identified above.

The start and end time of each activity as well as the duration of the activity (in minutes) was recorded automatically in the Spreadsheet. Notes and comments by HF specialists were also recorded. Time-related information was complemented by comments from the operators about their activities to assist the HF specialists in understanding the task and the context better.

This information was complemented by subjective workload assessments which was done using NASA Task Load Index (TLX). NASA-TLX is a multi-dimensional rating scale which provides information about the magnitude and sources of six workload-related factors to estimate the workload. Three of the dimensions reflect the demands the task puts on the operators (mental, physical, and temporal) and the other three stress the interaction of operator with the task (performance, effort, and frustration).

3. Results

Adequacy of the existing Minimum Staff Complement at NRU is supported by more than 50 years of operation. A review of the internal OPEX of design basis and emergency events in the past 10 years reveals that minimum staff complement has never been identified to be the main or contributing cause for any of the events. The main objective of this project was to rationalize the basis for determining the minimum staff complement and validate the adequacy of the operating staff for response to the most likely resource intensive scenarios. The results of the analyses performed validates the adequacy of the minimum staff complement for effective and safe operation of the NRU Reactor.

In order to demonstrate that the two challenging requirements of performing a "systematic analysis" for "the most resource intensive operating conditions" have been met, the criteria identified in section 5.1.1 of CNSC G-323 [1] was mapped against the methodological approach reported here. Table 2 summarizes the results of this mapping for the criteria that were addressed through the methods described above[1].

Table 2 – Criteria for Systematic Analysis to Determine the Minimum Staff Complement Requirements

Criteria for Systematic Analysis	Method
The actions required in the facility and their timing for the full range of the most resource-intensive conditions under all operating states, including normal operations, anticipated operational occurrences, design basis accidents, and/or emergencies.	Through the use of the Work Organization Analysis, it was possible to break the identified scenarios into actions required to be performed throughout the facility. The timing of the actions was recorded during Scenario Walkthroughs and with feedback from SMEs.
The most resource-intensive initiating events and credible failures considered in the Safety Analysis Report and the Probabilistic Safety Assessment.	The scenarios were selected based on a review of NRU documents and interviews with SMEs. A set of questions were also defined to address the criteria identified in Section 5.1.2.1 of CNSC G-323.
The operating strategies that define how the nuclear facility personnel respond to anticipated operational occurrences, design basis accidents, and emergencies.	Work organization analysis was used to associate tasks required to achieve functional objectives of the system with the situation in which the work will take place. Results of these analyses were documented in contextual activity matrices that provided a structured framework for contextualizing the tasks within their work settings. Visualizing task analysis information using the contextual activity matrices facilitated a discussion of various operating strategies during the Scenario Walkthroughs.
The required interactions among facility personnel for the purpose of diagnosing, planning, communicating, coordinating and controlling anticipated operational occurrences, design basis accidents, and emergencies.	Interactions among facility personnel, communication and coordination were assessed through the validation exercise.
The staffing demands required for the possible concurrent use of procedures related to anticipated operational occurrences, design basis accidents, and emergencies.	This criterion was addressed through selection of scenarios that combined system failures with an emergency situation to assess performance of the staff when having to deal with various procedures to respond to different aspects of the event. Additionally, staffing demands were evaluated by using the NASA Task Load Index (TLX) to assess workload throughout the scenario.
The staffing demands required to monitor indicators, displays and alarms and to promptly and effectively	In order to ensure that this criterion is taken into account as part of the systematic analysis of the

[1] The last three criteria identified in CNSC G323 are addressed through NRU procedures.

operate the facility's equipment controls using procedures related to anticipated operational occurrences, design basis accidents, and emergencies.	scenario, the interfaces and panels with which operators had to interact with during the scenarios were identified and documented in the contextual activity matrices. This approach helped to ensure that the information presented to operators on indicators, displays, and alarms effectively supports them in performing their tasks.
The staffing demands required to perform tasks in field locations using procedures related to anticipated operational occurrences, design basis accidents, and emergencies.	The identified scenarios included tasks throughout different locations in NRU to validate the staffing demands required to perform tasks in field. Time requirements for tasks performed in the field were also assessed to ensure that staff are able to complete all procedures that require tasks to be performed in different locations throughout the facility.
The staffing demands required for the successful completion of any safety-critical human actions using procedures related to anticipated operational occurrences, design basis accidents, and emergencies.	There are very few events where operator action is credited in the safety analysis in NRU. In general, no operator action is credited until 15 minutes after clear indication that an initiating event has occurred. Operator actions (after the 15 minute period) identified for the scenarios were discussed with SMEs during the table-top and main validation studies to evaluate the staffing demands for successful completion of these tasks.
The additional staffing demands when independent verification of task completion is specified in procedures related to anticipated operational occurrences, design basis accidents, and emergencies.	This criterion was addressed by selection of scenarios that required verification of the status of various elements in the field to assess additional staffing demands placed on operators.

4. Conclusions

The methodological framework reported in this paper can be adopted in the nuclear industry (and also in other risk critical domains) to meet the objectives of a "systematic analysis" for validating the minimum staff complement in response to the "most resource intensive" operating conditions. The combination of qualitative and quantitative methods developed to meet these objectives facilitated a comprehensive and structured evaluation of the identified scenario.

Contextual understanding is not a novel approach and has been applied in various domains. The movement from bottom-top understanding towards holistic perspective of complex control settings was recognised by Bainbridge (1997) [4]. She recommends that in order to develop a thorough and informative understanding of complex dynamic tasks, a mixed approach is required where the context is analyzed and the sequence of practices and procedures are incorporated within this well-defined and structured understanding of the context

One of the challenges of responding to resource intensive operating conditions (e.g., a design basis event) is the need for distributed communication and work prioritisations amongst operators responding to the incident. Weil and Apostolakis (2001) [5] state that the prioritisation of work is the most important feature of operation; lack of which can lead to costly consequences. Contextual understanding of operators' strategies and tactics whilst dealing with such scenarios can therefore shed light on existing work prioritisation mechanisms and can provide information about effective guidelines for better and more efficient incident management techniques and emergency response programs.

Therefore, an approach such as the one reported in this paper, which facilitates a structured understanding of the context while providing complementing subjective information about operators' strategies and their level of workload can be used for applications beyond validation of minimum staff complement to define and establish comprehensive emergency response procedures.

5. References

[1] CNSC G-323 – Ensuring the Presence of Sufficient Qualified Staff at Class I Nuclear Facilities – Minimum Staff Complement, Canadian Nuclear Safety Commission, 2007.

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