



CAE Inc.

1135 Innovation Drive
Ottawa, Ont., K2K 3G7 Canada
Tel: 613-247-0342
Fax: 613-271-0963

**MINIMUM STAFF COMPLEMENT:
A REVIEW OF REGULATORY REQUIREMENTS, INDUSTRY
PRACTICES, SCIENTIFIC LITERATURE AND EXPERIENCE OF
STAKEHOLDERS**

FOR

CANADIAN NUCLEAR SAFETY COMMISSION

PO Box 1046, Station B, 280 Slater St, Ottawa, ON, K1P 5S9

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Primary Author

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Name Shelley Kelsey
Position Human Factors Consultant

28 Sept 2015
Date

Reviewer

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Name Tab Lamoureux
Position Senior Human Factors
Consultant

28 Sept 2015
Date

Approval

FOR:

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5745-001 5745-001 5745-001 5745-001 5745-001 5745-001 5745-001

Name Chris Brown
Position Manager Advanced Solutions

28 Sept 2015
Date

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EXECUTIVE SUMMARY

As a precursor to the review and update of the Canadian Nuclear Safety Commission (CNSC) regulatory guidance document G-323 entitled 'Ensuring the Presence of Sufficient Qualified Staff at Class I Nuclear Facilities – Minimum Staff Complement', the CNSC initiated a research activity with the following objectives:

- review regulatory requirements, industry practices and scientific literature related to minimum staffing, including practices in relation to Beyond Design Basis Accidents (BDBA) from a range of related industries; and,
- solicit feedback from stakeholders regarding their experience with the current CNSC approach to the Minimum Staff Complement (MSC), as defined in G-323, and their expectations for the evolution of G-323 in the future.

The completion of a review of domestic and international nuclear regulators, related industries and other related literature revealed three noteworthy findings. First, the review of regulatory requirements suggests that nuclear regulatory agencies reviewed all take slightly different approaches to how they incorporate the International Atomic Energy Agency (IAEA) recommendations regarding minimum staff complement. However, a distinction can be drawn between the CNSC and other agencies in that the CNSC takes a comprehensive approach to providing licensees and applicants with guidance that includes periodic reviews and changes to MSC as well as the explicit inclusion of non-licensed workers as part of the MSC.

Second, the review of related domestic and international industry practices suggests that although they are varied in terms of their minimum staff practices, specifically when MSC is determined (during the design phase or post build) and the tools they rely on, there are considerable similarities as well. Similarities are most evident within the systematic approach to determining and validating the number of staff with most industries relying on human factors principles.

Third, a review of nuclear and related industries' practices regarding the approach to BDBAs and the sufficient number of qualified staff suggest that published regulatory requirements related to staffing levels have not yet changed post-Fukushima: BDBA are not explicitly taken into account when determining staffing levels. A variety of lessons were drawn from BDBA practices in related industries and are presented in this report, including the advantages of having additional expert staff available and integrating them effectively within the 'core' staff, the value of staff having strong mental models of the system rather than following highly routinized procedures, and the importance of clear lines of accountability. In the review of tools used by related industries, the use of simulation, especially elements of constructive and virtual simulation, holds great promise for the nuclear industry as part of a systematic approach to setting staffing levels and validating them for both accidents within the design-basis and BDBAs.

High level recommendations regarding the implementation of G-323 were based on feedback gathered from interviews. Information drawn from stakeholders including those from the CNSC,

licensees and contractors indicated that G-323 offers a formalized process which benefits all parties, affording the opportunity to create and support a more rigorous, scientific-based approach to determining and managing MSC. A positive outcome in using G-323 to determine the MSC is the rare opportunity to engage a multidisciplinary team that spans numerous departments to consider factors to a greater depth, revealing potential areas for improvement in human performance, processes and equipment. The following five high-level recommendations are suggested when revising G-323:

1. move G-323 from a guideline to a regulatory document and distinguish between requirements ('shall' and 'must') and guidance ('should' and 'may');
2. provide more detailed direction concerning expectations for the level of fidelity, selection of scenarios, and the specific metrics required to assure the regulators that the determined MSC is valid;
3. review the content and applicability of infrequently used sections of G-323 and consider combining them or distributing their requirements amongst more frequently used sections;
4. include guidance specific to the decommissioning phase, and
5. integrate BDBA consideration into the next revision of G-323.

Over 50 best practices and recommendations are provided resulting from the literature review and interview data.

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1 INTRODUCTION

CAE – Canada (hereafter referred to as CAE) was contracted by the Canadian Nuclear Safety Commission (CNSC) to support a project entitled “R584.1 Minimum Staff Complement: A Review of Regulatory Requirements, Industry Practices, Scientific Literature and Experience of Stakeholders” through Solicitation #87055-14-0261.

Regulatory bodies of high reliability industries such as nuclear, oil and gas, air traffic control, and mining must ensure the presence of a sufficient number of qualified workers with specific qualifications during all operating conditions, known as the Minimum Staff Complement (MSC). The importance of evaluating the staffing levels for high reliability sites is crucial, particularly when steps are taken to reduce staffing levels on operating teams. In common with most, if not all high reliability industries, is a push toward lowered levels of manning for cost savings by way of automation or other means (e.g. reallocating tasks to others). However, staff reductions could have a severe impact on the ability of a site to control abnormal and emergency events. Further, staffing level reduction can negatively affect human performance through its impact on workload, fatigue, and team communication (Brabazon & Conlin, 2001).

The CNSC’s regulatory framework includes laws passed by Parliament that govern the nuclear industry in Canada, regulations, licenses and documents – all tools used by the CNSC to regulate the industry. Regulatory documents provide requirements and guidance. Guidance provides licensees and applicants with direction on how to meet the requirements¹.

The Regulatory Guide, G-323, entitled “Ensuring the presence of sufficient qualified staff at Class I Nuclear Facilities – Minimum Staff Complement” provides the key factors that the CNSC staff take into account when assessing a licensee’s or applicant’s minimum staff complement. G-323 focuses on the licensee’s or applicant’s forethought for ensuring the presence of a sufficient number of qualified staff to successfully respond to all credible events, including the most resource-intensive conditions for a facility. Licensees and license applicants are directed by G-323 to conduct analyses to determine the minimum staff complement requirements and to consider such things as: actions and associated timings during the most resource-intensive initiating events and credible failures; the facilities’ operating strategies that define how personnel respond to events; staffing demands; and staffing strategies. G-323 was published in 2007 and is due to be analyzed and revised if deemed necessary.

1.1 Background

Canadian Class 1 nuclear facility operators are required to ensure 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 regulations made under the NSCA, and the licence. One aspect of ensuring the presence of a sufficient number of qualified workers is defining a MSC, which is the minimum number of qualified workers who must be present at all times to ensure the safe operation of the nuclear facility. The number and qualifications of workers in

¹ <http://www.cnscc.gc.ca/eng/acts-and-regulations/regulatory-framework/index.cfm>

the minimum staff complement must be adequate to successfully respond to all credible events, including the most resource-intensive conditions for a facility.

The CNSC's Regulatory Guide G-323 sets out the key factors that the CNSC staff should take into account when assessing whether a licensee or licence applicant has made adequate provision for ensuring the presence of a sufficient number of qualified staff. The guide addresses staffing levels required to respond to the most resource-intensive conditions under all operating states.

G-323 was published in 2007 and is due to be analyzed and revised, if deemed necessary. As part of the process of reviewing this Regulatory Guide on MSC, the CAE human factors team met the following objectives:

1. Reviewed regulatory requirements, industry practices and scientific literature related to minimum staffing from a range of high reliability industries; and,
2. Collected and synthesized feedback from a range of stakeholders representing the CNSC, licensed facilities, and contractor organizations to gain insight about their experience implementing G-323.

To meet the two objectives stated above the following tasks were completed:

1. Applied a systematic method to obtain and review regulatory requirements, industry practices, and scientific literature from a range of high reliability industries in Canada and internationally (e.g. nuclear, oil and gas, military, chemical, coastguards) related to minimum staff complements;
2. Provided recommendations that are supported by the synthesis of information obtained from the review of regulatory requirements, industry practices and scientific literature related to minimum staff complements;
3. Developed a set of interview questions and conducted interviews with a range of stakeholders from the CNSC, licensed facilities, and contractor organizations related to the minimum staff complement and their experience implementing G-323;
4. Analyzed interview data to identify common themes; and
5. Provided recommendations that were based on the analysis of interview data and literature review results.

1.2 Contents of this Document

This document includes the following chapters:

Chapter 1: Introduction: providing the background to this contract and its relationship to the larger programme objectives of the CNSC;

Chapter 2: Literature Review Method and Results: providing the approach adopted to sift and select literature for review, the industries considered, and the specific findings of relevance to MSC and the planned evolution of G-323;

Chapter 3: Stakeholder Interview Method and Results: describing the demographic composition of the stakeholders interviewed, the questions they were asked, and the answers provided, both from consensus and individual perspectives;

Chapter 4: Best Practices and Recommendations: presents a succinct description in tabular format of the best practices and recommendations to improve and update G-323 identified during the literature review and stakeholder interviews;

Chapter 5: Conclusions: discusses the findings of the literature review and the interviews within the context of determining, reviewing, and ensuring MSC, and updating G-323 in the future to address the current industry best practice;

Chapter 6: List of Acronyms: a comprehensive list of acronyms used in this report; and

Chapter 7: References: a list of references used in the development of this report.

2 LITERATURE REVIEW METHOD AND RESULTS

2.1 Method

The purpose of the current literature review was to obtain and synthesize regulatory requirements, domestic and international industry practices, and scientific literature related to MSC from a range of high reliability industries in Canada and internationally. The review was used to provide recommendations that are supported by the synthesis of information obtained from the literature. The literature review relating to MSC was performed to gather information concerning MSC best practices, validation approaches, tools, and emerging technologies. CAE searched scientific, academic, government and internet-based databases. The following search strategies (i.e., keywords, databases, exclusion criteria) were developed in conjunction with the Technical Authority (TA):

1. Keywords (various combinations of terms were used):

- Accidents;
- Nuclear;
- Normal operations;
- Emergency(ies);
- Response;
- Design basis accidents;
- Beyond design basis;
- Operations;
- Accidents;
- Guidelines;
- Regulations;
- G-323;
- Human factors;
- Staff;
- Worker;
- Manning;
- Crew;
- Personnel;
- Shift;
- Complement;
- Management;
- Minimum crew;
- Compliance;
- Method;
- Approach;
- Assess;
- Comprehension;
- Implementation;
- Optimize;
- Violation;
- Validation;
- Simulation;
- Virtual Reality;
- Modeling;
- Agent-based;
- Model-based;
- Chemical;
- Oil;
- Gas;
- Navy;
- Ship;
- Air;
- Defense;
- Flight crew;
- Air traffic control;
- Healthcare;
- Mining;
- Fire;
- Coastguard;
- HRO (High reliability organizations); and
- Energy.

2. The following databases/search engines were used:
 - a) Google Scholar;
 - b) general internet search;
 - c) <https://inis.iaea.org>;
 - d) Carleton University's online databases (including PsychInfo, Medline, PubMed, Web of Science, IngentaConnect, SpringerLink, and American Medical Association). Carleton's databases include journal access to the following relevant journals; Human Factors, Ergonomics, Applied Ergonomics, Journal of Cognitive Engineering & Decision Making, Cognition, Technology & Work, and the International Journal of Industrial Ergonomics;
 - e) Human Factors and Ergonomics Society (HFES) which includes Ergonomics in Design, HFES Proceedings, Ergonomics Abstracts and HFES reviews;
 - f) nuclear societies' conference proceedings (e.g. The American Nuclear Society, Canadian Nuclear Society etc.), and
 - g) literature provided by the CNSC.
3. The literature to be reviewed was identified and then analyzed. To identify the relevant literature the keywords listed above and Boolean search logic were used to search across all databases. A focused search to find key articles regarding minimum crew was used which afforded CAE with the best approach to ascertain the state of knowledge on the topic of minimum crewing within each domain. The literature search was continuously updated and was agreed upon through collaboration with the TA at the CNSC and included a combination of scientific papers (from internet knowledge bases and more generally from peer-reviewed journal articles), concept papers (book chapters, special journal issues on the topic of interest), and foundational and groundwork material (theses, edited books and regulatory documents on the topic of interest). The titles and abstracts were read and articles that appeared most relevant were added to the review. Reference lists from relevant articles were reviewed for further relevant references.

2.2 Literature Review Results

There is a consistent drive to “optimize” crews particularly in the domains reviewed. Crew reduction has been a recent significant focus for the Military, specifically within the Maritime domain. Recent innovation in automated systems, driven by technological advances, reduces the need for humans to control these systems. However, there are well documented problems when removing the human from the system due the change in their role from an active participant to a passive one (Senior, 2014). The implementation of increased automation makes it necessary to assess staffing requirements before new systems are built and existing systems implement automated systems.

The Canadian Navy were interested in how crewing levels may be reduced without jeopardizing the ship's ability to complete its mission in a safe and effective manner. In 2005 Defense Research and Development Canada (DRDC) initiated a project entitled "Damage Control and Crew Optimization". This project evaluated approaches to reduce crewing and evaluated the outcomes of several configurations, including automation, by way of modeling and simulation (Hiltz, 2005). Additionally the Canadian Navy has completed significant work regarding crew complement validation and technologies to assist the assessment of crew size (Chow, 2014; Wang, 2011). Similarly, over the last decade the chemical industry has been facing increasing financial pressure which has caused continuous staff efficiency measures to take place (Zwetsloot, Gort, Steijger, & Moonen, 2007) and plans to further reduce the levels are under scrutiny by the regulators (Senior, 2014).

As reactor designs advance and additional digital and automated systems are introduced into the processes and procedures, nuclear power plants will be faced with changing roles, responsibilities, composition, and size of crews to control normal and abnormal plant operations. A review of related high reliability domains resulted in a comprehensive understanding of the leading research in industries facing similar complex staffing issues. The literature review results are presented in four sub-chapters;

1. a review of current guidelines published by similar nuclear regulatory bodies (not including BDBAs);
2. a review of current best practices and recommendations for MSC in BDBAs;
3. a review of current guidelines and research from other related industries; and
4. a review of tools and technologies used in high reliability domains to validate (internally by licensee) and assess (externally by regulatory body) MSC.

The analysis of this collated information, in addition to the results of the interviews, was used to develop best practices and recommendations regarding how G-323 may be improved or altered in future revisions (as described in Chapter 4).

2.2.1 Nuclear Regulatory MSC Guidelines – A Review of Current Best Practices

This section presents a brief overview of National and International nuclear regulatory practices. Included in this review are the CNSC, the U.S. Nuclear Regulatory Commission (NRC) and the U.K. Office for Nuclear Regulation (ONR) of the Health and Safety Executive (HSE). France and Sweden were also reviewed but in less detail due to a lack of public documentation and language barriers. It is important to note that this section only includes information related to MSC within normal operations, anticipated operational occurrences, design-basis accidents and emergencies. MSC results related to BDBAs are discussed in sub-section 2.2.3.

The International Atomic Energy Agency (IAEA) is the world's centre for cooperation in the nuclear field. The IAEA's statute authorizes the Agency to establish safety standards to protect health and minimize danger to life and property. These standards are followed by the IAEA in its own operations; however, any State can also apply these standards by means of its nuclear

regulatory body (International Atomic Energy Agency Safety Fundamentals No. SF-1, 2006). Through its principles and guidelines the IAEA recognizes the importance of human factors and more specifically they have expectations related to minimum staffing levels at power plants and research reactors. Under the umbrella of the IAEA, all nuclear regulators and operators recognize staff as one of the barriers incorporated as part of a 'defence in depth' approach to safety, but their respective approaches to MSC differ and have been reviewed to identify best practices and recommendations. Relevant IAEA safety guides include;

1. IAEA Safety Guide 'The Operating Organization for Nuclear Power Plants', NS-G-2.4, IAEA, 2008. (International Atomic Energy Agency NS-G-2.4, 2001);
2. IAEA Safety Guide 'Conduct of Operations at Nuclear Power Plants', NS-G-2.14, IAEA, 2008. (International Atomic Energy Agency Safety Guide No. NS-G-2.14, 2008); and,
3. IAEA-TECDOC-1052 NPP Organization and staffing for improved performance – lessons learned, IAEA, 1998. (International Atomic Energy Agency TEC-DOC-1052, 1998).

2.2.1.1 Canada: G-323

G-323 is a guideline that outlines the key elements the CNSC considers when assessing whether a licensee or applicant has ensured that there is a sufficient number of qualified staff on site at all times. G-323 addresses staffing levels required to respond to the most resource-intensive conditions under all operating states. Key areas addressed in this guide include expectations regarding determining MSC, implementation of MSC, compliance with MSC, reviews required, and future changes to MSC. G-323 focuses on these 5 sections which are discussed next (Berntson & Budau, 2009; Canadian Nuclear Safety Commission Regulatory Guide G-323, 2007; Dolecki & McRobbie, 2011; Shoukas, Vieira, & Phyland, 2011).

Section 5.1, Determining the MSC: The CNSC has expectations when licensees are determining their MSC (referred to as the 'basis'). The licensee is required to conduct a systematic analysis to determine MSC. The Safety Analysis and Probabilistic Safety Assessment should be used to determine the most resource-intensive events. Once this is determined the regulator expects that the systematic analysis will consider the tasks and staffing required to conduct the most resource-intensive events selected. Examples include possible concurrent use of procedures, safety-critical tasks, control room and field operations, unplanned events and location restrictions placed on staff that may affect their ability to complete tasks. It is also expected that staff required to complete all tasks, beyond the operators, are included in the analysis; for example fuel handling, stores and lab technicians. The MSC must then be validated to assure the CNSC that the proposed complement can respond to the most resource intensive events. The licensee is expected to consider the most resource intensive credible events and events that may affect more than one unit, if applicable.

Section 5.2, Implementation of MSC: It is expected that the analysis is documented and contains information regarding the methods and results used to determine and validate the basis for MSC. Additionally the process for scheduling should be formalized in a procedure and include the MSC requirements regarding the number of staff, the positions being filled, the required qualifications and any limits on the location of staff in the facility. Staffing requirements

for each design basis accident procedure should also be documented with clearly stated numbers and locations of staff required to complete the procedure.

Section 5.3, Compliance with MSC: It is expected that licensees and applicants should also have a process that accounts for shift scheduling to ensure the MSC is filled at all times including shift turnover and planned and unplanned circumstances. Documentation should be in place that provides confirmation that each person that is considered part of the MSC is fit physically and mentally for work.

Section 5.4, Review of MSC: It is expected that the MSC is reviewed periodically by way of exercises and drills, incorporating lessons learned from internal and external operating experiences and standards and guidelines from international sources.

Section 5.5, Changes to MSC: If changes to the MSC are proposed, it is expected that the implementation plan is documented and includes a staffing analysis for the modified staffing levels, potential negative effects, how the effects have been mitigated and how the transition will be managed.

2.2.1.2 United States: Nuclear Regulatory Commission

The U.S. NRC reviews the Human Factors Engineering (HFE) programs of licensees and applicants for nuclear power plant construction permits, operating licenses, standard design, certifications and combined operating licenses (O'Hara, Higgins, & Flegler, 2012). Similar to the CNSC the safety reviews conducted by the NRC help to ensure that personnel performance and reliability are appropriately supported. The NRC does not currently have a separate regulatory document or guideline comparable to G-323 that assists regulators to assess MSC. Instead NRC relies on an amalgamation of the following four documents to determine and inspect MSC: (1) the U.S. Code of Federal Regulations 10CFR50.54(m), (2) the U.S. Nuclear Regulatory Commission Regulation (NUREG)/IA-0137, (3) NUREG-0711 and (4) NUREG-1791.

The U.S. Code of Federal Regulations 10CFR50.54(m) provides the U.S. NRC's basis for operator staffing requirements within the Main Control Room (MCR). This regulation provides the licensee and applicants with the number of licensed operators required based on the number of nuclear power units operating and the number of control rooms (U.S. Nuclear Regulatory Commission, 2015). Background information regarding staffing levels is captured in the U.S. NRC Regulation (NUREG)/IA-0137 and includes the method and results of a study of operator and plant performance in simulator-based settings (Hallbert, Sebok, & Morriseau, 2000).

NUREG-0711 "Human Factors Engineering Program Review Model" (O'Hara, Higgins, Perensky, Lewis, & Bongarra, 1994; O'Hara et al., 2012) is used by the NRC staff to review HFE programs of applicants and licensees to verify that the applicant's program incorporates HFE best practices and guidelines accepted by the staff as described within crucial elements of an HFE program. These items include functional requirements analysis and allocation, task analysis, staffing and qualifications. More specifically, Section 6 "Staffing and Qualifications" provides a general overview of staffing and qualification reviews that need to be considered as part of the design process. The review criteria states that the staffing and qualifications

assessment should address applicable requirements found in NUREG -0800 Section 13.1, which includes the Conduct of Operations for Management and Technical Support and Operating Organization (U.S. Nuclear Regulatory Commission NUREG-0800, 2014). Note that these documents do not provide guidance on staffing levels for field operations.

Once a plant is in operation, the US NRC is responsible for reviewing any exemption or change requests and must determine whether the proposals for a change in staff complement, post design, provide adequate assertion that safety will be maintained. If there is a request for exemption from the requirements stated in 10 CFR 50.54 (m), then validation of the modified staffing plans will be required as per NUREG-0711 or NUREG-1791 titled “Guidance for Assessing Exemption Requests from the Nuclear Power Plant Licensed Operator Staffing Requirements Specified in 10 CFR 50.54(m)” (Persensky, Szabo, Plott, Engh, & Barnes, 2004). This document focuses on “change requests” to staffing and may be considered the most similar to G-323 and as such will be described in more detail next (Persensky et al., 2004). Within NUREG-1791 a series of review steps are provided and include a high level review of the exemption request, the concept of operations, the operational conditions, any reviews of operating experience that have been analyzed, a functional requirements analysis, function allocation, task analysis, job definitions, staffing plans, and any additional data and analyses used to support the proposal for change (Persensky et al., 2004). A comprehensive glossary of terms used and a list of references are also provided. Of more interest is the associated series of checklists for each review step. These checklists may enable efficiency, transparency and consistency between and within the regulatory body and the licensees (Persensky et al., 2004; Reniers, 2010b). Within each checklist (organized by step) there is an indication box to check off whether the licensee has complied with the review criteria and whether there is supporting data/information. A summary of the item being reviewed and comments associated with the item is also provided. Figure 2-1 provides an example of a checklist associated with “step 5: Functional Requirements Analysis and Function Allocation”. It is important to note that although NUREG-1791 addresses MSC in the MCR, it does not take into consideration non-licensed staff that carry out field operations.

STEP 5. REVIEW FUNCTIONAL REQUIREMENTS ANALYSIS AND FUNCTION ALLOCATION				
Purpose: The first purpose of this step of the review is to ensure that the applicant has defined and evaluated the impact of the exemption request on the plant/system functions that must be performed to satisfy plant safety objectives. The second purpose is to ensure that the allocation of functions to humans and systems has resulted in a role for control personnel that uses human strengths, avoids human limitation, and can be performed under the operational conditions evaluated in the exemption request.				
Applicability: This section is applicable in all cases for which an exemption from 10 CFR 50.54(m) is requested.				
Instructions: Verify that the request includes the following information. If the information is not provided or deemed not applicable, please indicate the reason in the comments field.				
Y	N	N/A	Data and information contain:	Comments
			The set of functions identified as being relevant to the exemption request.	
			The sequence of performance of the functions, triggering events for their initiation, and conditions for their completion or suspension.	
			Minimum function performance requirements in terms of time, timing, and accuracy.	
			Identification of functions that include risk-important human actions and the consequences (e.g., error rates or estimates of error rates) of not performing those actions, performing them incompletely, or not performing them within the time required.	
			A description of the allocation of functions to control personnel, automated systems, or a combination of the two.	
			A description of how the allocation of functions supports integrated control staff roles across functions and systems.	

Figure 2-1: An Example of a Checklist Provided for Each Review Step Required in NUREG-1791 (Persensky et al., 2004, p. 76)

To summarize, the NRC does not rely on one comprehensive regulatory document or guideline that is comparable to G-323. Instead the NRC relies on an amalgamation of documentation to determine and inspect a licensee’s MSC and validates this information through discussions with licensees. In general, although the NRC provides prescriptive requirements for licensed operators (senior reactor and reactor operators) based on the number of nuclear power units operating and the number of control rooms at the nuclear facility they do not explicitly consider non-licensed operators. The next section describes the process and documentation relied upon in the United Kingdom.

2.2.1.3 United Kingdom: Office of the Nuclear Regulator

Similar to the CNSC, the ONR of the HSE has the responsibility for regulating the safety of nuclear installations in the United Kingdom. The ONR provides their inspectors with two types of guidance documents, Safety Assessment Principles (SAPs) and Technical Assessment Guides (TAGs). SAPs provide the framework to guide regulatory decision-making in the nuclear licensing process and the TAGs further aid the decision-making process for specific areas of investigation. Specifically, the “*Staffing levels and task organisation*” TAG (Senior, 2014) was written for use by ONR human factors specialist inspectors. It provides detailed guidance to support the assessment of the approaches and methods used by applicants and licensees to derive, validate and monitor staffing arrangements, and to specify task organization. Essentially the TAG provides guidance for ONR inspectors to evaluate staffing complements as well as any proposed changes which may have an impact on nuclear safety.

The ONR defines ‘staffing’ as the “number of Suitably Qualified and Experienced Persons (SQEPs) in place to remain in control of activities that could impact nuclear safety under all foreseeable circumstances throughout the life cycle of the facility” (Senior, 2014). ‘Task organization’ is defined as “the way tasks are organized to ensure compatibility with human cognitive and physiological characteristics, and in a way which ensures that nuclear safety is maintained at all times...and includes considerations such as the design of shift work systems, workload and team design” (2014, p. 2). The “*Staffing levels and task organisation*” TAG provides guidance for the review of staffing and task organization for new facilities and proposed changes triggered by events, design changes, or lessons learned at existing facilities. It contains 7 main sections:

1. General principles;
2. Staffing arrangements;
3. Formal methods to establish staffing (Task/workload analysis and validation);
4. Team design;
5. Design of shiftwork systems;
6. Specific considerations for new facilities or new technology being introduced; and
7. Proposed changes to staffing.

The general principles’ section provides information regarding best practices for integrating continuous improvement by learning from past internal and external experiences relating to staffing and best practices. Licensees are expected to demonstrate that they have considered the use of operating experience feedback, lessons learned, and identified problem areas that may require additional validation analyses. It is also expected that licensees’ event reports and analyses consider staffing and task organization issues such as work patterns, communication and coordination problems, and inadequacies in the number of workers with the required competencies. The staffing models chosen should be auditable as inspectors may request a comprehensive description of the staffing model and justification for its selection. Similar to G-323, licensees are expected to demonstrate that there are adequate resources, by way of quantitative and qualitative justification, for the most resource-intensive conditions feasible in each operational mode and/or state. In addition, and similar to G-323, Section 5.2.2, it is expected that evidence is available regarding effective management of staffing levels above the required minimum, for example rapid call-out due to unexpected absences.

The methods used for all analyses should be consistent with standards and best practices outlined in the “*Staffing levels and task organisation*” TAG. Methods used to analyze and validate staffing arrangements include task analysis, workload analysis and staffing validation. The licensee is expected to have completed an analysis of tasks associated to those that are important to safety in order to determine a basis for staffing levels, and demands on staff’s perception, decision making, action and workload. Licensees are also expected to validate the MSC, that is “to demonstrate that a sufficient number of qualified workers are present at all times to ensure the safe operation of the nuclear facility and to ensure adequate emergency

response capability” (2014, p. 11). The methods proposed include data from operating experience programs and results from emergency exercises, table top exercises, simulator modelling and human performance modelling (for example Task Network Modelling [TNM]). Interestingly, in a section titled “Formal Methods to Establish or Substantiate Staffing Arrangements” under a sub-section titled “Task Analysis” a reference to G-323 is provided for additional guidance on the assessment of minimum staff complement (Senior, 2014).

2.2.1.4 Other International Regulators

Information from other International regulators including France and Sweden were reviewed but in less detail compared to Canada, U.S. and U.K. This section provides a brief overview of their current requirements and practices.

France: The Nuclear Safety Authority (ASN) is an independent administrative authority set up by law that concerns itself with nuclear transparency as well as workers’, patients’, the public and environmental safety². The French Atomic Energy Commission (CEA) is a public body that leads the development and innovation of nuclear research in energy, information and health technologies, and defense and national security³. The CEA stipulates that for the construction of a Basis Nuclear Installation (BNI) the authorization must take into account technical and financial capacities of the operator. In addition “the human and technical resources and the organization implemented for performance of an activity concerned by quality must be appropriate to this activity and enable the defined requirements to be met. In particular, only persons with the required competence may be assigned to an activity concerned by quality; the assessment of competence of these persons is based in particular on their training and their experience.”

The organization of staffing, regarding normal and accident situations, is established with CEA. The regulatory requirements regarding adequate staffing levels are defined in general with the main requirement being that the licensee has to demonstrate the adequacy of its organization from design, construction and operation perspective (Official Journal of the French Republic, 2012). Within this order, article 7.3 states that the “licensee set up a permanent organisation in its installation, including designated persons capable of assessing the seriousness of a situation and having the power to trigger the on-site emergency plan...and to rapidly initiate the appropriate actions. Qualified and trained personnel must be available at all times in sufficient numbers to implement these actions.”

Sweden: The Swedish Radiation Safety Authority (SSM) is the Swedish nuclear regulator and reports to the Ministry of the Environment. The SSM’s has a mandate from the Swedish Government within the areas of nuclear safety, radiation protection and nuclear non-proliferation. The SSM works proactively and preventively in order to protect people and the environment from the undesirable effects of radiation, now and in the future⁴. Although there is a

² <http://www.french-nuclear-safety.fr/>

³ <http://www.world-nuclear.org/info/Country-Profiles/Countries-A-F/France/>

⁴ Taken from <http://www.stralsakerhetsmyndigheten.se/In-English/Facts-about-us/>

regulatory document concerning the competence of operations personnel, it is unclear if there is a document associated with determining the minimum staffing complement.

In sum, it can be determined that the majority of international regulators reviewed in this document have in place some implicit requirements on MSC, but do not appear to have a regulatory requirement to set, validate, and maintain MSC to the same degree as the CNSC.

2.2.2 Best Practices from Related Domains

High-reliability organizations (HROs) have been defined as organizations that work with hazardous systems that function in a “nearly error-free fashion” (La Porte and Consolini, 1998: p.848). Typical HROs include air traffic control, nuclear power stations and nuclear aircraft carrier operations. In order to understand with more breadth how other organizations manage MSC, domains that are not traditionally classified as HROs were included. Therefore this document will refer to these domains as “related domains or industries” and not HROs to reduce confusion.

This section provides the reader with an overview of the guidelines and research that can be found in related domains which included, defense (Army/Joint, Navy/Marines, and Air Force,), civil transportation (maritime, aviation), chemical, and Coast Guard/Petroleum. Below is a brief overview of the findings; however, more detail within each domain reviewed can be found in ANNEX A.

2.2.2.1 Defence

A review of military standards and practices for determining minimum staff complement was carried out which comprised of five military domains; Army, Navy, Air Force, Marines, and Joint. Each of these domains is discussed below regarding MSC and includes a brief summary of each military domain. Note that militaries the world over tend to be organized in similar ways with Western militaries having the most fully developed processes and procedures. Therefore most documents referenced here represent the US or Canada but should be considered equally applicable to militaries from other countries.

2.2.2.1.1 Army/Joint

Army and Joint Forces determine their manpower requirements on an organizational basis. The Army is a hierarchically arranged organization where each level of the hierarchy consists of defined numbers of its subordinate levels. This organizational definition of manning requirements does not take account of the specific numbers of personnel required to complete its mission, instead applying coarse organizational units of measure and mapping these against an estimate of the geographical ‘spread’ of the manpower. This approach is defined in a nation’s military doctrine. Nevertheless, the US Army has published guidance on manpower requirements (Department of the Army Regulation 570-4, 2006) and has a US Army Manpower Analysis Agency which engages in specific Research and Development (R&D) on manpower issues concerning specific contexts and missions. These studies represent R&D and are not used as a basis for certification of that context or mission.

The exception to this approach is US Army Aviation. US Army Regulation 95-1 (Department of the Army, 2014) stipulates that the minimum crew of an aircraft will be in accordance with the operator's manual, which is certified by either the Federal Aviation Authority (FAA) (in the case of commercially-derived aircraft) or the military airworthiness authority (in the case of military aircraft). The approach to certification of military aircraft is described in this document, Section 2.2.2.1.3. The approach to certifying civilian and commercially-derived aircraft is described in this document, Section 2.2.2.2.2. In general, Armies and their equipment are not certified for staffing arrangement therefore making it difficult to compare the Army's method of calculating manpower requirements and that of licensed nuclear operations.

In common with the Army, Joint organisations are staffed according to organizational needs rather than based on an analysis of workload, roles and responsibilities. The requirements for manpower calculations for US Joint operations are outlined in Joint Publication 1-0: Joint Personnel Support (2011). While concerned with manning, there is very little that could be added to G-323 from Joint Publication 1-0; the approach to manning is fundamentally different. In general, military standards and handbooks are relied upon across all military domains to conduct HFE work, including manning studies and determination of crew.

2.2.2.1.2 Navy

Navies of the world have employed the philosophy that you must be able to battle while engaging in damage control, expressed in the term 'Float-Move-Fight' and the manning required reflects this philosophy (Directorate of Maritime Strategy, 2001). This reflects a historical view where a damaged ship had no option but to save itself while continuing in battle or risk losing the ship and the crew, since there was little hope of escaping the enemy and being subsequently rescued. More recent experience has seen a shift toward ceasing operations until damage is contained. The need to only pursue one objective has reduced the manning requirement in the Navy but at some cost.

Recent direction in Canada concerning the design of a new class of Navy ship has included a blanket statement that traditional manning levels should be maintained (i.e. in the region of 200 – 250 personnel for a ship of approximately 5000 tonnes). However, there are efforts by the Directorate of Naval Personnel and Training to consider the systems on the ship with respect to optimizing manning and crew configurations while still achieving mission success (Lawrynczyk & Lamoureux, 2015). These efforts are currently being scoped but include studies and validation via constructive simulation. In the future, this work may include live and virtual simulation to validate the evidence from the studies and constructive simulation (refer to section 2.3.2 for more information on simulation to validate MSC).

The US Navy currently has a Manpower Analysis Centre (NAVMAC), which was created to develop and document manpower requirements for all fleet activities within the Navy (Department of the Navy Bupersinst 5450.49C, 2007). The NAVMAC has the responsibility to conduct the technical work to support the Office of the Chief of Naval Operations Instruction (Department of the Navy Opnavinst 1000.16J CH-1, 2002), which lays out the process by which crew size, roles and responsibilities should be defined for the US Navy. In general, this process involves three steps; analyze and validate manpower, validate and monitor revisions, and ensure manpower supports each mission and acquisition. It should be noted that the

acquisition process continues until the ship is released to service. OPNAVINST 1000-16J also outlines the elements to be considered in manpower studies and can be found in ANNEX A. Each of the elements described in OPNAVINST 1000-16J are relevant to the calculation of MSC in the nuclear domain, with obvious changes in terminology. However, as a guidance or regulatory document, G-323 goes further than OPNAVINST 1000-16J and there is little that can be added to G-323 based on OPNAVINST 1000-16J. Although not prescriptive in the tools and techniques to be applied, the instructions specify that evidence of an analysis and validation must be provided. Based on the worst-case scenario (typically a battle damage scenario involving fire and hull breach, while continuing to engage in defensive actions), the number of work hours is calculated. These calculations are then used to determine the crew size required for the ship. It should be noted that the manpower for ships is calculated prior to and during the design and procurement phase, congruent to what an applicant may be faced with when applying for a nuclear license to operate. However once the ship is procured, there is no prescription or guidelines followed for manning safety even if significant changes to the ship have been made. If the ship went through significant modifications that changed its size, plant, or control systems a review of manning might be undertaken as part of the design process, but typically these types of fundamental changes are not made through the life of a ship.

2.2.2.1.3 Air Force

The air force in Canada and its allies determines manpower requirements based on the number of people required to maintain and operate the aircraft fleets. However, when an aircraft is not flying, it is in a stable state and therefore the number of staff for maintenance operations is not subject to minimum staffing requirements. When airborne, however, aircraft can represent a hazard to others in the area and minimum flight crew is regulated and certified before being released to normal service.

Flight crew requirements for the air force represent a design objective by the aircraft manufacturer. As such, the aircraft systems, functionality, controls and displays are all developed after the number of crew and the roles and responsibilities of each crew member are defined. As with the organizational method of determining staffing requirements, using the number of flight crew as a design objective represents a different approach to that adopted by the nuclear industry. In spite of the differences, the process adopted by the aircraft manufacturers to prove that the stated flight crew number assumptions is relevant to the nuclear industry and mirrors that of the civilian aviation authorities. Specifically, they consider whether the crew are able to recover the aircraft to safety (i.e. land the aircraft) from all flight regimes (including all failure conditions).

The US Air Force Air Force Policy Directive (2010) lays out a process that involves the development of a tailored set of airworthiness certification criteria specific for developing aircraft. This process is elaborated by flight standards defined in MIL-HDBK-516B (2008). In brief, this process involves a collaborative effort by the aircraft manufacturer and the airworthiness authority to determine the basis of certification. Once this is agreed upon, it is up to the manufacturer to provide evidence supporting the basis of certification, which the airworthiness authority will review for compliance. This evidence will usually include data from simulations, including crew workload ratings, using an identified and validated workload rating tool. After this evidence is accepted, flight trials are undertaken from which evidence is also collected in

support of the basis of certification. In Canada the Department of National Defence Military Airworthiness Authority is the Department of Technical Airworthiness (DTAES). DTAES' Technical Airworthiness Manual and Airworthiness Design Standards Manual describe a very similar process to that of the European Defence Agency. European and U.K Airworthiness processes were found to be similar in nature and details can be found in ANNEX A. DTAES primarily relies on workload data to certify new aircraft or design changes from the HFE perspective.

The key advantage the aviation industry has in certifying a design is that 'worst-case' conditions can be tested in a simulator and measured using validated measurement instruments. The use of simulation in aviation has a long and successful history.

2.2.2.1.4 Defense Related Processes

2.2.2.1.4.1 MANPRINT/HSI

The Manpower and Personnel Integration (MANPRINT) programme is concerned with the integration of the human into the system being developed. MANPRINT is typically referred to as Human-Systems Integration (HSI). MANPRINT/HSI is a process guideline rather than a design guideline and applies to all branches of the military. MANPRINT in the US consists of seven domains:

- Manpower: the number of personnel required to operate, maintain, sustain and provide training for systems;
- Personnel: the cognitive and physical capabilities required of personnel;
- Training: the instruction or education that must be provided to personnel;
- HFE: the integration of human characteristics into system design;
- Health Hazard Assessment: short or long-term hazards to health that result from normal operation of the system;
- System Safety: safety risks that arise when the system is used in an abnormal manner; and
- Survivability: characteristics of the system that can reduce threats to system integrity, human health, or cognitive and physical performance.

MANPRINT is not necessarily a method to specify the MSC for a system. Rather, a variety of domains may contribute data in an effort to set the MSC. Therein lies the real value of a MANPRINT programme: the leveraging of outputs from one domain for the mutual benefit of other domains.

MANPRINT is the subject of Army Regulation 602-2 (27 February 2015): "Human Systems Integration in the System Acquisition Process" and Navy OPNAVINST 5310.23 (10 November 2009): "Naval Personnel Human Systems Integration (NAVPRINT)". These documents are brief

and outline the responsibilities of staff officers responsible for acquiring new systems. Although similar in nature, there is little in these documents to add to the guidance contained in G-323.

2.2.2.1.4.2 DODAF

The Department of Defense Architecture Framework (DODAF) is a visualisation infrastructure to represent the perspectives of different stakeholders in system development. There can be many different views displaying subtly different perspectives. Many of these views will ‘interact’ to result in different, or summative, views. DODAF has equivalents in Canada (Department of National Defence Architecture Framework: DNDAF), the UK (Ministry of Defence Architecture Framework: MODAF) and commercially (The Open Group Architecture Framework: TOGAF).

DODAF has not been used for HFE purposes, and none of the views deal explicitly with the humans in the system. However, some of the operational views could specify a human as a resource, at which point a summative view could be produced to specify how many personnel are required. The nature of DODAF, however, is that it focuses on the system to be designed, rather than the process to be controlled or influenced by the system. DODAF is a tool for communicating system architectures using a common language, in particular when changes are being made to the system or compatible systems must be constructed separately at multiple sites. DODAF is unlikely to be effective at modelling systems or processes that are beyond design basis.

Compared to HFE processes and tools, DODAF can be considered a form of system-level task analysis. DODAF is extensive, however, and many of its views are unlikely to be germane to the MSC process. It is possible; however, that DODAF could be applied to the setting of MSC as part of the systematic analysis. While DODAF should not be explicitly recommended in G-323, CNSC personnel should be open to proposals to incorporate DODAF views as part of the submission in support of setting the MSC for a nuclear facility.

2.2.2.2 Civil Transportation

Each nation has a transportation standards organization responsible for safety and standards for conveyances within their jurisdiction. This section focuses on the certification of ships and Aircraft by different authorities around the world.

2.2.2.2.1 Maritime

The International Maritime Organization (IMO) defines safe manning as “a function of the number of qualified and experienced seafarers necessary to ensure the safety of the ship, crew, passengers, cargo and property for the protection of the marine environment” (International Maritime Organization Resolution A.890(21), 2000). In addition the ability of seafarers to maintain observance of the requirements is dependent upon conditions relating to training, hours of work and rest, occupational safety, health and hygiene and the proper provision of food (International Maritime Organization Resolution A.890(21), 2000). The IMO released a principles of safe manning document in 2000 (International Maritime Organization, 2000) that outlines issues that should be observed in determining the minimum safe manning of a ship. At a high level, the minimum safe manning level of a ship should be established based on 9 factors

such as the ship size and type, cargo, and applicable work hour limits as examples. Proposals for minimum safe manning levels are submitted to the IMO who then evaluates the levels to ensure that the complement is adequate for the safe operation and protection of the ship and its emergency procedures. A template is provided that includes all of the information that IMO will require to adequately assess the MSC and can be found in ANNEX B (International Maritime Organization, 2000, p. 15).

In Canada minimum crew size of small commercial vessels is based on two factors (Transport Publication TP14070 E, Chapter 4 (2010); the size of the ship and the crew required to carry out safety-related tasks. The regulations also specify that crewing must be maintained continuously during operations. Crewmembers must also have appropriate qualifications for the safety-related tasks to which they are assigned. In practice, most crew have as their second and/or third duties the safety-related tasks, meaning most crew are cross-trained (the exception is the operator and engineer, who must be separate individuals on vessels greater than 20 metres length). This allows marine operators to sail with reduced crews.

Transport Canada is authorized to test crew competency by asking questions related to safety, emergency, and survival procedures at any time. Transport Canada inspectors may also require a test voyage during which the crew will prove their competence in all aspects of safe operation of their vessel. There is no published document specifying whether this test voyage may occur more than once and, if so, how frequently it may occur. Further, Transport Canada requires certificates of competency and/or operators' cards which are awarded following completion of a specific syllabus of qualifications, which may include a practical test or a period of practical experience.

2.2.2.2.2 Aviation

As noted under the Air Force Section 2.2.2.1.3 the crew size is a design objective when developing a new aircraft. However, aviation authorities have developed standards for cabin crew that are independent of the design of the aircraft; these are based on research concerning aircraft evacuation and the role of cabin crew during abnormal events. Only by conducting an evacuation trial of a new aircraft, and demonstrating that passengers can evacuate an aircraft within prescribed time limits, can exceptions to the national minimum numbers of cabin crew be certified (JAR-OPS 1.990;ACJ OPS 1.990).

The FAA is a worldwide leader in the certification of new aircraft, owing in part to the number of aircraft developed in the United States. Europe and the European Aviation Safety Association (EASA), follow closely due to their development of aircraft and, in practice, the two organisations share much of their approaches. Part of the certification for new aircraft includes establishing that it is possible for the posited crew to operate the aircraft in all flight regimes. In particular, this concerns recovering the aircraft safely from emergency situations. The design objectives regarding crewing are subject to extensive testing following a defined process. The FAA's AC23-1523 (2005) process guidance specifies steps that must be followed (e.g. submit an evaluation test plan, collect data and analyze, etc.).

The FAA's standard provides guidance, references, methods, and forms required for submission. This is subject to review by qualified airworthiness authorities at every stage to

ensure that manning is sufficient. The FAA also provides general guidance concerning workload which states that “the minimum flight crew must be established so that it is sufficient for safe operations”.

Canadian Aviation Regulations (CARs) govern the minimum crew requirements when certifying aircraft in Canada. The CARs include various types of aircraft and various human factors must be considered including workload of individual crew members as well as the accessibility and ease of operation. Note that the criteria required by the CARs are identical to those of the FAA. There is no guidance on how any of the data that would be submitted would be deemed acceptable. However, it does seem clear that sufficient evidence would need to include a task analysis and sufficient data aggregated to form overall conclusions regarding acceptable numbers for the flight crew.

The EASA guidance is contained within their Airworthiness of Type Design document (European Aviation Safety Agency, 2012) This document describes how EASA discharges its technical process responsibilities for certification activities of new aircraft. EASA may also choose to accept the certification of National Aviation Authorities (e.g. the Civil Aviation Authority in the UK) but such an acceptance will generally have followed a process that is acceptable to EASA.

The aviation regulations followed by different countries effectively impose the same requirements on aircraft manufacturers and aircraft operators as G-323 does on nuclear operators: sufficient numbers of qualified staff must be present to manage emergency situations if and when they arise. The perspective adopted by the aviation industry is different, however, because crew complement is a design objective whereas crew complement is set to meet the demand of the system in the nuclear industry (i.e. safe execution of the nuclear process is the design objective). The requirements of aviation regulators for evidence and demonstrations of the adequacy of aircraft manning is an example that could usefully be added to G-323. While not explicitly required by JAR, CAR, and other regulations, these approaches have emerged as de facto best practice in the aviation industry. G-323 seeks to provide much more guidance than aviation regulatory documents.

2.2.2.3 Chemical

As production increases in the chemical and allied industries employment has been decreasing (Alaptite & Kozine, 2012; Reniers, 2010a). Most modern chemical plants have undergone extensive pressure to be as lean as possible resulting in reduced staffing levels. A lack of qualified operational personnel in unusual conditions and the resulting lack of process control can trigger a series of internal or external accidents, eventually leading to a major accident (Reniers, Dullaert, Ale, Verschueren, & Soudan, 2007). Though this seems to be of concern to the research community (typically human factors and safety), literature on this subject is limited. According to Reniers (2007) accident reports and research to date within this domain tend to omit any investigation into the relationship between incidents and staffing levels.

The Energy Institute, the professional body for the energy industry in the UK provide a “Human Factors – Staffing Arrangements” webpage where they provide high level best practices for implementing safe staffing arrangements. The webpage was developed to provide those in the

oil and gas and other high-reliability industries with the resources required to determine staffing arrangements in control rooms and other locations. The webpage provides general best practice guidance, research, case studies and useful links. In addition they refer to the document titled “Safe Staffing Arrangements – User Guide for CRR348/2001 Methodology: Practical application of Entec/HSE process operations staffing assessment methodology and its extension to automated plant and/or equipment” (Energy Institute, 2004).

As of 2010, the HSE document written by Brabazon and Conlin (2001) is cited as the most important work on the topic within the chemical and allied industries. Brabazon and Conlin (2001) introduced a method for assessing the manning levels in the control room at chemical plants. The method provides a staffing assessment to ensure that the plant can prevent and respond to hazardous events based on the worst-case scenarios, comparable to the nuclear industry. The methodology addresses a wide range of human factors issues associated with operating process plants. It should be noted that the intention of this document is not to determine MSC, but to flag where staffing arrangements may not be sufficient enough to respond to worst-case scenarios, therefore post build. For a detailed review of this method please refer to ANNEX A. Feedback from users of this proposed methodology resulted in a need for a guiding document that provided a best practice approach to following the method. Therefore, HSE produced a user guide (Energy Institute, 2004) that accompanies the method. A high-level overview of the method and user guide can be found in a bulletin released by The Energy Institute (The Energy Institute Safety Bulletin no 3, 2005).

This method also provides some high level guidance regarding continuous improvement, peer review, and changes to staffing levels. As suggested by the authors, the best practice for continuous improvement would be to actively seek ways to improve staffing arrangements and strive to surpass current best practices. They also suggest that a peer review is conducted that may help to highlight any biases or omissions in the assessment. Any change to the plant that alters the original physical and ladder assessments should be re-evaluated prior to implementation and changes to staffing levels. The document provides an overview of the type of changes and how they may impact the original staffing assessment. Other areas of interest to the CNSC, such as implementation and procedures are “embedded” in the physical and ladder assessment statements.

An emerging theme through this literature review is the lack of inclusion of field operations in the determination and assessment of the MSC. This conclusion is mostly founded within the chemical industry as it is the most similar in terms of a contained facility that requires field operators. As stated in section 2.2.1.2 it is not uncommon to focus on the licensed operators within the MCR. Similarly the assessment tool developed by Brabazon and Conlin (2001) fails to evaluate tasks related to field operations and does not instruct users to include a range of safety critical scenarios and tasks, as noted by Reniers et al (2007). Reniers also states that there have been no directives on safety critical staffing levels within the Chemical plant domain nor have any best practices been established to determine the quantity and quality of minimum staff required being onsite to ensure plant safety and therefore the responsibility still lies within each individual company.

A paper written by Reniers (2010b) suggests a practical method to evaluate safety critical staffing levels required to meet safety critical activities, such as loss of containment (LOC). The

intent is that this method can provide inspectors with evidence that the plant offers staffing levels that can support safety critical operations such as a 4-day hostage crisis, terrorist threat, and a BDBA. The activities designed to ensure safe operations at chemical installations can be divided in terms of the different situations in which they must be executed and include standard safety activities (pre-accident warnings, or 'high alarms'), safety critical activities (may lead to final line of defense, or 'high high alarms') and finally emergency activities (situations resulting from a LOC). Staffing levels are typically based on production and safety requirements. Reniers (2010a) describes 5 possible manning levels that support the industry needs and are described in descending order.

1. Full staffing: number of personnel to guarantee production (composed of field and control room operators as well as support staff).
2. Standard Safety Staffing: minimum number of personnel required to guarantee that the production team will fulfil all necessary activities (safety critical tasks and standard tasks – not emergency tasks).
3. Safety Critical Staffing: minimum number of personnel required in a production team to fulfill production and all safety critical tasks including emergency tasks.
4. Minimum Staffing: minimum number of personnel required in a production team determined from the safety viewpoint, i.e. safety is guaranteed but production is not.
5. Emergency Staffing: The minimum number of personnel required in a production team to take care of all emergency tasks.

Comparable to G-323, Reniers (2010a) suggests that the methods used to reduce staffing levels should be based on worst-case scenarios and that optimization be based on tasks required to fulfill functions related to these events. Also comparable to G-323, Reniers (2010) suggests that the sequence of tasks is considered and numbers are lowered based on the ability to serially conduct the tasks or raised if parallel tasks are required to be executed by the same operators. Reniers provides an evaluation tool, in the form of a checklist, to consider safety critical tasks in the control room as well as in the field (Reniers et al., 2007, p. 72). Whether operators are able to move from one point to another within certain time limits, the consequences resulting when operators are not able to be in a particular place within a given time are identified and the reliability of the supporting equipment and the supporting documentation is questioned. The information obtained while using the checklist can vary significantly between and within facilities. Therefore, the checklist provides best practice guidance for collecting accurate information to support the evaluation of the current staffing levels in a consistent and traceable format. In summary, the evaluation verifies whether safety critical staffing levels in an industrial area affect the reliability and timeliness of detecting safety critical problems, diagnosing them, and recovering to a safe state.

2.2.2.4 Coast Guard and Petroleum

In 1995 the USCG recognized that effective implementation of international conventions and enforcement of domestic laws relies upon the development of a comprehensive legal and

organizational infrastructure. Therefore they developed a Model Code which is used as a reference document for maritime states as they are developing or changing their governmental infrastructure. The Model Code “suggests a method for establishing a Maritime Force. The proposed legislation in the Model Code enhances the security and safety of the maritime state, protects the mariner and the marine environment, and allows the maritime state to exercise its rights and meet its obligations under international law”⁵. The Model Code is organized in chapters, with Chapter 14 speaking specifically to issues of personnel. Chapter 14 provides the requirements necessary to grant a Maritime Force the authority to ensure the safety of merchant vessel personnel (seafarers) and the safe and efficient operation of vessels on which they work. Vessels may be operated safely and efficiently when they are manned by certified seafarers in sufficient number⁶. More relevant to the current review, Subpart 14(A), entitled "Manning of Vessels", establishes the framework for the development of guidelines for the creation of a Minimum Safe Manning Document which details the number of each type of certified seafarer required to adequately man a vessel. Example items include principles of safe watch-keeping (navigational, engineering, and cargo operation), operation of all firefighting and life-saving equipment, and work hour limitations and rest period requirements as well as factors that contribute to crew fatigue

Regardless of the Model Code, there is a great deal of attention to staffing in the offshore oil production industry⁷ since 2010. According to Alaptite and Kozine (2012) the staffing levels have dwindled down slowly over the years and they believe safety is compromised. One such example is the explosion of the Deepwater Horizon oil rig in the Gulf of Mexico. As companies are allowed to treat rigs as “ships” they have flexibility in terms of what type of vessel they register them as, as well as their location. Unfortunately the location is often within impoverished nations with very minimal standards of inspection (Hamburger & Geiger, 2010). According to Hamburger and Geiger (2010) experts and survivors of the explosion that led to the massive spill say foreign registration allowed for understaffing which may have contributed to the disaster. The crux of the issue seems to be that different types of rigs are classified differently, and the Marshall Islands assigned the Deepwater Horizon to a category that permitted lower staffing levels (Alaptite & Kozine, 2012).

Recently there has been a drive by the USCG to begin looking into inspection and staffing issues of offshore supply vessels (OSVs) and mobile offshore drilling units (MODUs). The coastguard has focused on expanding its maritime safety training requirements to cover all persons other than crew. According to the new proposed rules (U.S. Coast Guard Federal Register, 2014) these new rules are necessary to enhance the ability to respond to emergencies such as fire, personal injury, and abandon ship situations in hazardous environments (2014, p. 1). As MODUs become increasingly large and navigated farther from shore, the USCG is particularly concerned with whether there are an adequate number of engineers and mates assigned to these vessels that are able and qualified to respond to emergency situations.

⁵ <http://www.uscg.mil/international/affairs/Publications/MMSCode/english/preface.htm>

⁶ <http://www.uscg.mil/international/affairs/Publications/MMSCode/english/Chap14.htm>

⁷ ‘Drilling’ refers to an exploratory process. Drilling units do not remain at a location for long periods of time, instead moving from drill site to drill site. Production units remain at a single location for long periods of time until the resources are exhausted.

While not directly applicable to nuclear installations, the complexities of regulation, inspection, and enforcement in national boundary or international areas underlines the importance of maintaining an active and consistent regulatory regime, including regular contact and inspection of operators. G-323 makes provision for personnel from the CNSC to verify the MSC at any time. This should be maintained in future versions of G-323.

2.2.3 Beyond Design Basis Accidents

BDBA is a term used to describe a significant event in which a system, structure or component of a system was not designed to operate within, which could possibly result in a major failure. This term is used as a technical way to discuss accident sequences that are possible but were not fully considered in the design process because they were judged to be too unlikely⁸. This includes accidents that contain sequences of events that are possible, but not designed as part of the system as they were either not considered, or extremely unlikely to occur and therefore beyond the scope of an accident that a nuclear facility is required to be designed to withstand (NRC, 2015). Examples of beyond BDBAs include natural disasters such as tornadoes and earthquakes, for instance the earthquake and tsunami that led to the Fukushima Daiichi nuclear disaster (Atomic Energy Society of Japan, 2014) and man-made disasters such as those attributed to human error or aircraft incursion accidents (U.S. Nuclear Regulatory Commission Draft Regulatory Guide CG-1176, 2009). Best practices and guidelines associated with the potential effects of BDBAs on MSC are not included in the current G-323. In this section findings associated with nuclear regulators and related domains offer some guidance.

It is worth noting that the term BDBA is primarily used by, and associated with, the nuclear industry. Although the concept would be understood, other industries do not seem to have an equivalent term.

2.2.3.1 BDBA Practices in Nuclear Domain

Following the Fukushima event, numerous “lessons learned” documents have been published. Canada (CNSC) and the U.S. (NRC) each stood up task forces following the Fukushima Daiichi nuclear accident. This section provides an overview of how Canada and the U.S. regulate MSC in relation to these types of events.

The CNSC prepared an integrated action plan (Canadian Nuclear Safety Commission, 2013) following lessons learned from the Fukushima event. Although the CNSC Fukushima Task Force concluded that Canadian plants were safe and currently rely on layers of defences in depth⁹, the CNSC was committed to addressing recommendations provided by the Task Force. The plan included actions that will strengthen reactor defence-in-depth and emergency response. In relation to MSC, it was recommended that the CNSC staff examine Human and

⁸ <http://www.nrc.gov/reading-rm/basic-ref/glossary/beyond-design-basis-accidents.html>

⁹ Defense in depth includes the use of multiple barriers to prevent the release of radioactive materials and uses a variety of programs to ensure the integrity of barriers and related systems (IAEA, 1998). These programs include conservative design, quality assurance, administrative controls, and human factors. Human factors plays a significant role in supporting plant safety and providing defense in depth (O’Hara et al., 2012).

Organizational Performance (HOP) related to beyond-design basis scenarios and accident management (Canadian Nuclear Safety Commission, 2013, p. 15). These include HOP activities related to various aspects of potential beyond design-basis scenarios.

The CNSC Task Force also identified areas of further improvement relating to enhancing emergency response. Enhancements were recommended to be achieved through streamlining emergency preparedness between onsite and offsite authorities while considering HOP (Canadian Nuclear Safety Commission, 2013, p. 17). Of particular relevancy to this literature review is that an action (4.1) was recommended to advise licensees to evaluate their emergency plans, deliberately considering multi-unit accidents and severe external events in relation to an assessment of the MSC, by way of drills or exercises in order to ensure their Emergency Response Organization (ERO) is capable of responding.

The U.S. Near-Term Task Force (NTTF) provided various recommendations that will potentially support plants to deal with issues related to BDBAs. In general, the NTTF advised that licensees rely more on probabilistic risk analysis to consider a broader range of risks, and also the use of “defenses in depth” to deal with contingencies beyond the design-basis event. In 2012, the Nuclear Energy Institute (NEI) published a guideline titled “Guideline for Assessing Beyond Design Basis Accident Response Staffing and Communications Capabilities” (Young, 2012). This technical report was created in response to lessons learned from the Fukushima event (Dietrich, 2012). This report provides recommendations to assist licensees in preparation for future recruitment and training of licensed operators and non-licensed workers and communication assessments that will determine the required staff necessary for responding to a beyond design basis external event that could affect multiple units at a site, in similar vein to the Canadian recommendations as stated above.

Following the lessons learned from Fukushima, the NRC recommended assessing current staffing levels and determining the appropriate staff to fill all necessary positions for responding to a multi-unit event during a beyond design basis external event. This included a two phase approach for multi-unit plants. Phase 1 included a staffing assessment that required licensees to “complete a detailed analysis demonstrating that on-shift personnel assigned emergency plan implementation functions are not assigned responsibilities that would prevent the timely performance of their assigned functions as specified in the emergency plan” (Young, 2012, p. 11).

Phase 2 included a staffing assessment of the requested functions related to Fukushima NTTF, Recommendation 4.2, which states that licensees should “provide reasonable protection for equipment currently provided pursuant to 10 CFR 50.54(hh)(2) from the effects of design-basis external events and to add equipment as needed to address multi-unit events while other requirements are being revised and implemented” (Young, 2012, p. 11). The order issued in relation to this recommendation required a three-phase approach for mitigating beyond design-basis external events including:

1. the use of equipment and resources required to maintain or restore core cooling, containment and spent fuel pool cooling;

2. providing sufficient, portable, onsite equipment and consumables to maintain or restore functions until they can be accomplished by off-site resources; and
3. obtain offsite resources to sustain the functions indefinitely (Young, 2012, p. 11).

Once the site-specific actions associated with the new response strategies, functions and tasks were defined, the staffing needed to perform these tasks could then be assessed.

Numerous assumptions were provided for the assessments such as:

1. the scale of the event (e.g. all on-site units affected, extended loss of AC power);
2. the event impedes site access at various times and at various levels;
3. a staffing assessment may utilize a “no site access” end time of less than 6 hours if supported by a documented basis including resources and capabilities with documented arrangements with all appropriate service providers; and
4. baseline staffing for the event is with MSC.

In addition, the NRC provides extensive conditions that the assessment needs to adhere to relating to various phases of the response, operating procedures, mitigation equipment, fuel status and emergency response staffing.

2.2.3.2 BDBA Practices in Related Domains

As noted above, BDBA is primarily a term used in the nuclear industry. Thus, instead of searching for BDBA in other industries, some well-known examples that fit the definition were chosen as case studies.

2.2.3.2.1 United Airlines Flight 232 Sioux City, Iowa Crash Landing

This flight suffered a failure of a fan blade in the tail-mounted engine. The shrapnel from this failure severed all three independent hydraulic systems onboard the aircraft. All flight controls on this aircraft were actuated through these hydraulic systems, and the presence of three independent systems was meant to provide sufficient redundancy for all anticipated events. The flight deck crew consisted of a Captain and First Officer who were responsible for flying the aircraft, and a Flight Engineer who was responsible for monitoring and managing aircraft systems. After the failure, the crew were left only with thrust control on the two remaining engines. Although cued to the failure by a jolt, it wasn't until the aircraft suffered un-commanded pitch and roll that they realised how grave and improbable the problem was. After noticing the crew's difficulty in controlling the aircraft, an off-duty flight instructor joined the flight deck crew.

The four worked together to manage all the tasks required to both control the aircraft and work through potential solutions to the problem. This involved significant communication, shared mental models, common objectives, and clear divisions of responsibilities. The aircraft eventually crash-landed at Sioux City, Iowa with the loss of 111 lives, but 185 survivors. That the flight crew were able to recover the situation, to whatever degree, is largely attributed to

exceptional practice of what is now termed Crew Resource Management (CRM). Further, the opportunity to add a subject matter expert to an already-experienced crew greatly enhanced their problem solving abilities. Additionally, the ability of the local authorities to deploy many additional staff to assist in evacuation, triage, and treatment of passengers and crew improved the chances of survival.

The National Transportation Safety Board (NTSB) determined that the ultimate cause of this accident was the inadequate consideration given to human factors limitations in the inspection and quality control procedures used by the airline (National Transportation Safety Board, 1989). The lack of human factors consideration is believed to have resulted in the failure to detect fatigue cracks. The NTSB recommended improvements be made to the maintenance programs including simplifying, automating and adding redundancy (second set of eyes) for critical part inspection.

In addition to the human factors recommendations, the crash of flight 232 also implies that the addition of staff during BDBA is beneficial, provided everyone's input is effectively integrated. For nuclear BDBA, this would be analogous to having experts on call or within a short-distance in order to attend in the event of an emergency. The full support of ancillary organisations, in a 'surge' mode, will also be helpful when dealing with the downstream effects of the BDBA. The crash of flight 232 led to changes in Federal Aviation Administration (FAA) regulations, with CRM becoming a mandatory component of all airline training, subject to inspection and approval by the FAA.

2.2.3.2.2 Apollo 13

The Apollo 13 accident aborted man's third mission to explore the surface of the Moon. During this spaceflight an oxygen tank exploded due to damaged insulation on wires causing a short-circuit and igniting the insulation (NASA, 1970). This had the knock-on effect of limiting the power endurance of the Command Module of the spacecraft. The mission was aborted and a return to earth ordered, but various constraints acted to make this return extremely difficult to achieve. A number of different return trajectories were assessed against the constraints, permitting the options to be narrowed down and more detailed plans to be developed. As plans were developed, options were discarded until only the best options remained.

The situation required a great deal of novel problem-solving on the parts of the crew, the flight controllers, and support personnel. Although the safe return of the spacecraft to earth was the main objective, there were many smaller objectives that needed to be successfully met in order to safeguard the health of the crew. During the situation the flight controllers enlisted the assistance of outside agencies in solving the various challenges. Additional astronauts, engineers, and designers were enlisted to develop new procedures and a team of six engineers at University of Toronto developed a plan to separate the Command Module from the Lunar Module before re-entry.

As with Flight 232, the Apollo 13 accident indicates that the use of additional personnel during BDBA is beneficial to assist in problem-solving the many different facets of the accident. Although the specific CRM aspects of the accident response were not uncovered during this short review, it is assumed that all efforts were marshalled by the pursuit of the common goal: to

get the astronauts safely back to Earth. It is further assumed that roles were clearly defined (if only by acclamation) and inputs were effectively integrated. Communication, also highly constrained between the Earth and the spacecraft, must also have been effective.

2.2.3.2.3 Deepwater Horizon

The Deepwater Horizon was an ultra-deepwater, dynamically positioned, semi-submersible offshore oil drilling rig. Nearing the conclusion of drilling an exploratory well a jet of seawater sprayed onto the rig from the drill unit, followed by a combination of mud, methane, gas, and water. This mixture turned gaseous and exploded. The crew of the rig attempted to activate the blowout preventer, which failed, and the blind shear ram, but this failed to plug the well. The Deepwater Horizon sank approximately 36 hours later but the associated oil spill continued for nearly three months, until it was closed by a cap (U.S. Coast Guard, 2010).

Prior to the explosion and oil spill, British Petroleum had submitted an exploration and environmental impact plan for this exploration. Engineering protection systems were not fully implemented on this rig because they were not required by the regulator. The Deepwater Horizon had also received 18 citations in the past from the US Coast Guard (USCG). Immediately leading up to the explosion, drilling operations were running five weeks late. The Deepwater Horizon had also suffered a number of other mishaps and safety issues, many of which were unreported or involved falsified data. British Petroleum was felt to have chosen riskier procedures to save time or money, sometimes against the advice of its staff or contractors.

The Deepwater Horizon example is not a success story, nor is it necessarily a BDBA. However, the organisational culture and the prioritization of operations over safety impact the overall system design. The effect of these pressures on human decision making is well-established. Thus, the margin for safety in the whole system design was eroded to the point that a BDBA became much more likely, because the design only accommodated the most optimal of operations.

As a result of the Deepwater Horizon the role of the regulator in the maintenance of safety has come under examination. The Deepwater Horizon was registered in the Marshall Islands and, as such, listed its minimum crew in accordance with the requirements of the Marshall Islands. The rig was leased to British Petroleum, who submitted its exploration and environmental impact plan to the United States. Neither the Marshall Islands nor the United States were responsible for verification and validation that safety was being observed. Following the explosion and oil spill a brief moratorium on new drilling was enacted. In Canada, the National Energy Board sent letters to oil companies asking for explanation as to why they were resisting additional safety features. There seems to have been little in the way of substantive changes to regulatory requirements and verification policies in the aftermath of the Deepwater Horizon.

2.2.3.2.4 Typhoon Cobra

During World War II the US Navy Pacific Fleet was struck by a typhoon with sustained winds of over 160 km/h, high seas, and heavy rain. Of 30 ships, all were damaged, and three destroyers capsized and sank. A total of 790 lives were lost.

Subsequent investigations found that the strategy employed by the Commander of the fleet was flawed, although not negligent. Critically, however, warship design had eroded safety margins in the pursuit of faster, lighter, more agile and fuel-efficient craft. This had resulted in designs that were arguably ‘top heavy’ and prone to high degrees of roll with consequent possibility of capsizing.

As a result of the damage to the Pacific Fleet US Navy procedures in the face of severe storms changed (Sarchin & Goldberg, 1962; Pudduck, 2013). However, the practice of naval architecture also changed to the point where ships were built to withstand conditions they were unlikely to ever encounter. This engineering approach continues to the present day; no naval ship has been lost to weather conditions in the last 60 years.

2.2.3.2.5 Double-Engine Failure

There are a number of examples in which twin-engined aircraft have suffered a double-engine failure. The most famous of these include the so-called Gimli Glider (see Hoffer & Hoffer, 1989) and the Miracle on the Hudson (see National Transportation Safety Board Accident Report NTSB/AAR-10/3, 2010).

The Gimli Glider occurred when an Air Canada Boeing 767 ran out of fuel due to a combination of factors including the transition to a two-person crew, an inoperative fuel quantity indicator system, informal procedures concerning minimum equipment lists, and the conversion from imperial to metric systems of measurement. When a fuel pressure problem was indicated this was quickly followed by the shut-down of one engine. The second engine shut-down after they had declared their need to divert. Since the hydraulic system was powered by the engines, the crew also lost their ability to exert full and expeditious control over their aircraft. The crew accessed the emergency procedures written for the aircraft and found none for a double-engine failure. Thus, the crew had to control the aircraft, prepare it for landing, and find a new landing strip (since they were no longer able to reach their nominated diversion). One of the pilots remembered a retired military airfield at which the aircraft managed to land, with damage, narrowly missing people on the ground, who assisted in the evacuation of the aircraft and fighting the resultant fires. Although the pilots were suspended following the incident, subsequent investigations in a simulator found that the incident was almost impossible to resolve successfully. The pilots were reinstated shortly after.

The Miracle on the Hudson refers to a US Airways flight that suffered bird strikes resulting in a double-engine failure upon take-off from LaGuardia airport. Since the failure occurred at low altitude with the aircraft in danger of stalling (i.e. dropping from the sky) the pilots needed to respond quickly to mitigate the danger. The Captain declared an emergency to air traffic control who offered a diversion runway. The Captain stated that this was not possible due to their lack of power and low altitude and declared his intention to ditch the aircraft in the Hudson River.

In both these situations the pilots were required to develop a solution under intense time pressure and without the assistance of outside agencies. The pilots in both cases benefited from a general knowledge of the area to permit them to consider solutions that would not have been presented in authorised procedures. Both crews also had the benefit of previous military flying experience that typically affords the opportunity to experience emergency situations and

engage in problem solving while in the air. Simulators can and do provide this opportunity to civil airline pilots and, indeed, the Gimli Glider scenario is now a standard simulator exercise for all aircraft types. In contrast to the nuclear industry, the time periods in these examples are much shorter, making it impossible to obtain additional assistance (unless air traffic control can provide it). However, the nuclear industry requires authorised nuclear operators to be extremely well-trained and experienced which seems analogous to the general knowledge exhibited by the pilots in these examples. This breadth and depth of knowledge is the foundation of novel problem solving and decision making in BDBA.

In sum, similar industries were considered for examples of BDBA. BDBA is not a term that is in common usage beyond the nuclear industry so, instead, well-known examples of incidents from other industries were considered for the lessons that can be drawn from them. A total of 6 incidents were described from aviation (3), space (1), petroleum (1) and maritime (1). A variety of lessons were drawn from these incidents, including the advantages of having additional expert staff available and integrating them effectively with the 'core' staff, the value of staff having strong mental models of the system rather than following highly routinized procedures, and the impact vague lines of accountability. Additionally, some of these incidents resulted in fundamental changes to the way personnel are trained, such as the addition of crew resource management or design changes to the system in question, rendering the accident no longer 'beyond design basis' and therefore prevented by an additional defence in depth.

2.2.4 Standards

A common best practice, regardless of the domain reviewed, is the reliance on National and International human factors standards to guide the analytical process used to determine the MSC or to guide the design of the system or facility. For example these HF guides, standards and handbooks can be found within the Military, Transportation and Nuclear domains. In addition to the aforementioned IAEA safety standards there are numerous domain independent and domain dependent human factors standards that are relied upon as best practice in relation to MSC and manning. For example, the nuclear industry relies on International standards including IAEA (e.g. International Atomic Energy Agency, 1998), IEEE (IEEE 1023, 2004) and Electric Power Research Institute (EPRI) (Kincade & Anderson, 1987) in addition to National and International regulatory guides.

The Military relies on military standards and handbooks to guide human factors processes, analysis and design (e.g. MIL-STD 1472G; Department of Defense, 2012, and MIL-STD 46855, Department of Defense, 2011). In general, military standards and handbooks are relied upon across all military domains to conduct HFE work, including manning studies and determination of crew. For example, MIL-STD-46855A describes the HFE process for development and acquisition of military systems (note that MIL-STD-1472G is a design standard, as opposed to a process standard). According to MIL-HDBK-46855A, HFE should be applied during development and acquisition of military systems, equipment, and facilities to integrate personnel effectively into the design. This effort should be provided to (a) develop or improve all human interfaces of the system; (b) achieve required effectiveness of human performance during system operation, maintenance, support, control, and transport; and (c) make economical demands upon personnel resources, skills, training, and costs. The HFE effort should include, but not necessarily be limited to, active participation in the following three major interrelated

areas of system development: analysis, design and development, and test and evaluation (Department of Defense Standard Practice MIL-STD 46855A, 2011, p. 8). Although these standards do not focus solely on minimum crew issues they are congruent with the CNSC's G-278 which is referred to by G-323 and provides very similar guidance for conducting systematic analyses and validation on issues such as crewing (although not explicitly) throughout design, development and changes to military systems.

The civil aviation community relies on FAA and EASA to ensure that a formalized and standardized human factors program is followed (e.g. Department of Transportation Federal Aviation Administration Standard Practice, 2009). It can be argued that most related fields reviewed rely heavily on standards and guidelines, namely related to human factors and engineering domains, to ensure adequate analysis and validation have been complied with to ensure there is adequate staffing to support safe operations.

2.3 Tools

Numerous tools exist that can assist in determining the basis for MSC as well as assessing and validating any proposed changes to the MSC. The methods range from low fidelity tools, such as task analyses, to high fidelity tools such as a constructive simulation.

2.3.1 Function and Task Analyses

The traditional technique used for assessing staffing is a task and functional analysis. This technique is used to represent human performance for a specific task or within a particular scenario. The scenario is broken down into individual tasks in relation to the required human-human and human-system interactions. The analyst decides on a priori staffing levels to evaluate tasks and resulting workload in the new system. Potential problems are identified based on task overloading or periods where operators are under-involved. There are numerous task analysis techniques and the type chosen should depend on the objective and the type of data being analyzed. Some of these include hierarchical task analysis, cognitive task analysis, critical path analysis, and verbal protocol analysis (See Salmon & Stanton, 2004 for task analysis methodologies). One interesting approach is to provide investigators with human factors job aids or 'toolkits' used to aid in their evaluation of staffing levels which not only include human factors guidance but also briefing notes on the do's and don'ts related to reduction of staff at plants (Organisational Change and Major Accident Hazards: Staffing Levels, 2003). Throughout this literature review it is clear that this technique is most often recommended by the inspectors and human factors specialist as a best practice when determining and assessing MSC and by human factors specialist when studying MSC (Alaptite & Kozine, 2012; Brabazon & Conlin, 2001; CNSC, 2013; Hara, Higgins, & Fleger, 2011; Hiltz, 2005; Johnson, Osborn, Previc, & Li, 2005; Landsburg et al., 2008; Li, Reed, & Fuld, 2012; Nuclear Energy Institute, 2011; O'Hara et al., 2012, 1994; O'Hara, 2009; Of, Chief, & Naval, 2000; Perensky et al., 2004; Reniers, 2010b; A. Sebok & Plott, 2011; Senior, 2014; Young, 2012).

2.3.2 Live, Virtual and Constructive Simulation

Live, Virtual, and Constructive (LVC) 'Modeling and Simulation' is a taxonomy used to classify modeling and simulation activities. Regardless of the taxonomy one can think of live,

virtual and constructive simulation as lying along a continuum of simulation fidelity as there is no clear division between each. Across all types two variables are controlled, the level of human participation (in the simulation) and the level of fidelity (how realistic is the system being modeled or simulated). It should be noted that the terms “modeling” and “simulation” are used interchangeably in this field. According to DoD Directive 5000.59 (1994) modeling refers to “the application of the standard, rigorous, structured methodology to create and validate a system, entity or process” and simulation refers to a “method for implementing a model over time”. The domains in which modeling and simulation are leveraged includes; training (comprised of exercises, education and operations), analysis, and acquisition (including research and development, test and evaluation and production and logistics) (Vincenzi, Wise, Mouloua, & Hancock, 2008). Each type of simulation will be discussed in more detail below.

2.3.2.1 Live Simulation

A live simulation involves real people and real systems, but a simulated scenario (i.e. a simulation ‘stimulates’ the real equipment and real people). Therefore the scenario is fully controlled but the actors and artefacts participating in the simulation are real and may act in unexpected ways in response to stimulation or the inputs received from actors (people or systems) involved in the simulation. Live simulation is the most realistic facsimile of how tasks are accomplished; making this type of simulation the most fully immersive form available today. Examples of live simulation in the nuclear domain would include drills and exercises with human participation and can be relied upon to determine and assess MSC (Berntson & Budau, 2009; Hagen, L., Kelsey, S., Murray, J.L. & Scipione, 2010).

2.3.2.2 Virtual Simulation

A virtual simulation involves real people who are interacting with simulated systems. Virtual simulations inject a Human-in-the-Loop (HITL)¹⁰ into a central role by exercising motor control skills (e.g., flying a simulated jet), decision making skills (e.g., committing fire control resources to action), or communication skills (e.g., as members of a Command and Control team). Virtual simulations may execute in real-time, such as with first-responders working on-site at an incident, or they may execute in non-real-time, such as during a simulation for Emergency Operations Centre operators during a multi-day event that is run in compressed time by removing the dead time between stimulating events.

Virtual simulations are generally used when the HITL element plays a significant role in the outcome. As such, they have significantly more complicated requirements; for example, a user interface must be provided for the operator to interact with the synthetic environment and some software or equipment may be necessary to measure the desired operator-based metric.

2.3.2.3 Constructive Simulation

Constructive simulation involves simulated people and simulated systems. People can provide some inputs but are not directly involved in determining the outcomes. The benefit of this

¹⁰ Human-in-the-loop or HITL is defined as a model that requires human interaction.

approach is that simulations can be run much faster than real-time and many runs can be performed in order to obtain the desired number of statistical data points. Constructive simulation may use a variety of model types operating in a common synthetic environment. Models may include:

- Agent-based models – which model the actions and interactions of autonomous agents (both individual and collective entities such as organizations or groups) with a view to assessing their effects on the system as a whole.
- Computer Generated Forces/Teams – which model military unit or crew behaviour sufficiently so that teams will simulate actions automatically (without requiring man in-the-loop interaction).
- Discrete event models – describe processes where the time base is continuous but during a bounded time-span, only a finite number of relevant events occur and these events cause the state of the system to change.

Industry is now capable of developing virtual and constructive simulations of technology, physics, human biomechanics and human cognition that can work together to provide any domain with a complete understanding of the whole system before it is ever physically constructed. This provides the users with a capability to assess how technological solutions interact with human operators in system designs that are in question. Although this field can be considered ‘emergent technology’ within the nuclear domain, there are many lessons learned from its use in the Military and there is a breadth of HSI and HFE techniques that may be applied to the challenge.

2.3.3 Modeling and Simulation Use for MSC

This section is dedicated to simulation as it pertains to the nuclear domain in determining and validating MSC. Staffing requirements are most often evaluated by empirical research involving some form of HITL testing. These studies require a simulator and human system interface of the to-be-designed facility or system in question. In addition human participants, representative of proposed or current MSC, are required and human performance metrics are collected. Once the data is analyzed, staffing plans can be evaluated and altered, if need be (Sebok & Plott, 2011, p. 183).

Cognitive and physical performance can be modeled using a variety of techniques which are then used to predict performance based on any changes of the controlled variables. Human Performance Modeling or Human Behavior Representation (HPM or HBR), considered constructive simulation, uses engineering and psychological models of human performance to estimate performance over time and identify where a performance breakdowns or bottle-necks could occur. Both cognitive workload and Situation Awareness (SA) have been assessed using HPM. HPM is typically used when the methods of analysis traditionally used to gather data for a staffing analysis are inadequate due to lack of comparable operations or experience, or when a simulator is not available or too costly. Designers rely on HPM to support their HFE programs for a wide range of complex systems, including research and design of nuclear power plants

(Barnes & Laughery, 1998; Jiang, Gao, & Li, 2013; Laughery & Persensky, 1994; Laughery, Plott, Eng, Nash, & Scott-Nash, 1996; Lawless, Laughery, & Persensky, 1995).

Task network modelling (TNM) is a form of HPM. It is a relatively straight-forward concept that uses the information gathered as part of a task analysis. TNM greatly increases the power of task analysis since it not only describes the task sequence but also provides the ability to predict human performance. These analyses can be used to create cognitive and behavioural models of operator performance using the existing system to create predictions of operational performance, mental workload or failure effects. The software can constrain task performance, based on the current or proposed MSC, plausibly based on knowledge of human abilities and limitations. Discrete event Modeling and Simulation (M&S) software, such as the Integrated Performance Modelling Environment (IPME) can be used to model operators and systems to evaluate performance that can be compared to observational data. This technique has great potential for the nuclear industry as it provides a low-cost simulation capability that can help conduct HITL experiments and validation exercises. The ability to distinguish between the operator and the system helps the user answer questions about operator performance across a variety of scenarios. Of course, the model output is only as accurate as the input, which can be a limitation. TNM is used to accurately model the human contribution (including potential delays and errors) to system performance which can increase the fidelity of any simulation. TNM has been used to model the impact of human interactions in U.S. Navy and Coast Guard vessels and the outputs have been used to estimate workload and fatigue. More specifically researchers simulated various crew sizes and configurations to investigate how to optimize manning and task allocations across the crew (Wetteland, Bowen, & French, 2002).

According to O'Hara (2009) HPMs are suitable for evaluating staffing levels and are starting to be used as such for nuclear plants and other complex systems outside of the Naval domain. During the evaluation of staffing levels HPMs can be used to address issues such as personnel response time and workload, availability of personnel considering other activities that may be ongoing and for which operators may take on responsibilities outside the control room (e.g., fire brigade), and the effect of overall staffing levels and crew coordination for risk-important human actions. Applicants to U.S. Nuclear Regulatory Commission (NRC) can and are using HPMs in their submittals for design certifications, operating licenses, and license amendments (O'Hara, 2009). Given that this tool is becoming more widely used as a means for implementing change of MSC it will be important for the CNSC to assure that these models are verified and validated if they are to be used to propose the basis or changes to MSC. Using HPMs improperly may generate misleading or incorrect information, entailing safety concerns. See O'Hara (2009) for additional guidance on the verification and validation of HPMs.

2.3.4 Emergent Technologies

There are numerous types of emergent technologies that have the potential to aid in the analysis, validation and maintenance of MSC including M&S tools, Virtual Environments (VE) and Virtual Reality (VR), and automation to name a few. O'Hara et al (2009) conducted a survey that identified over 100 new human factors engineering methods and tools, some of which could be applicable to MSC (see ANNEX C). The methods and tools were compared to identify general trends and three trends were found to be applicable to the commercial nuclear industry and expected to impact safety reviews. These trends were: the analysis of cognitive tasks; the

use of virtual environments and visualizations; and the application of HPMs. This study identified 64 issues which were organized into seven topic areas, with one topic area being staffing and training. The objective of a staffing and qualifications review is to “verify that the applicant has systematically analyzed the number and qualifications of personnel needed to perform human roles and responsibilities and has demonstrated a thorough understanding of task and regulatory requirements” (O’Hara et al., 2009, p. 30). Job definitions, skills and qualifications, MSC and effects of shift durations and schedules are all considered during the review. The military has created an entire class of tools for doing these types of analyses, and typically refer to the analyses as manpower and personnel analysis. Training needs, or the identification of training gaps based on skill needs and personnel characteristics, are also often included along with these analyses (O’Hara et al., 2009, p. 30)¹¹.

The NRC and the nuclear industry have developed and used human performance models for the evaluation of plant staffing issues. Research on staffing alternatives that used task network modeling techniques have been conducted (Barnes & Laughery, 1998; Laughery et al., 1996) which led to the development of a modeling tool called the Plant-Human Review and Effectiveness Decision Tool (PHRED). This tool relies on discrete event simulation specifically for use in modeling nuclear power plants based on Micro Saint Sharp technology. This tool was developed with and for the NRC. PHRED automates many of the complexities of human performance modeling and affords the user to design specific models based on the scenarios and data in question to assess significant human errors. Supported by these results, modeling has been identified as a means of evaluating the reduction of licensed staff required in the control room as per 10 CFR 50.54(m) (O’Hara et al., 2009; Persensky et al., 2004). It should be noted that CAE is not aware of these tools being extended to include field operations in order to validate the licensed and non-licensed operators as part of the MSC.

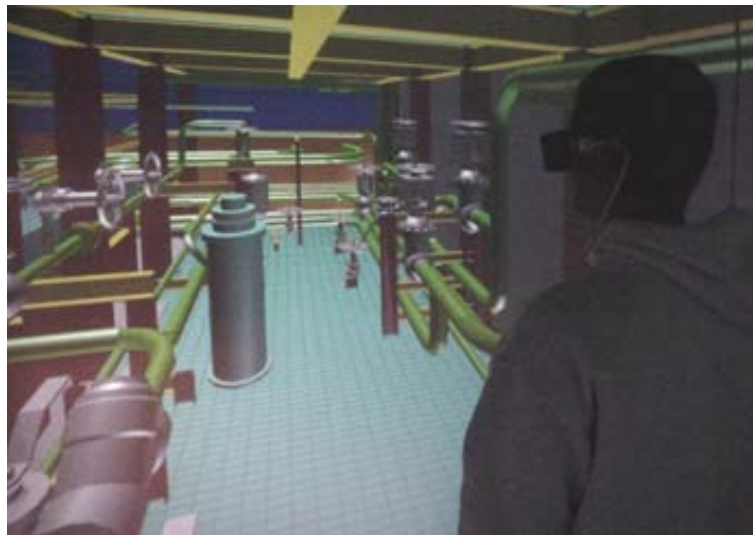
An NRC staffing study conducted by Hallbert and Sebok (2000) evaluated the effects of crew staffing levels and advanced versus conventional plant type on operator and system performance. The purpose of the study was to evaluate if a reduced-size crew could adequately control an advanced style plant. This experiment was interesting in the fact that two cases were investigated. One used a traditional experiment with a simulated control room (conducted by the OECD Halden Reactor Project/Institute for Energy Technology) and a second investigated the same data relying instead on modelling efforts (performed by Micro Analysis and Design).

The independent variables were plant type (advanced versus conventional) and staffing level (normal versus minimal). The experimental findings revealed that the advanced plant supported better crew performance and enabled a smaller crew to handle the plant better than larger crews. As the empirical research was underway, the staffing issue was also being evaluated by HPM with the purposes of accurately predicting operator workload and event times and to evaluate HPM as a way to extend experimental studies (Hallbert et al., 2000). This study involved building, calibrating, and running models based on two of the scenarios used in the empirical study. The model predictions were compared with experimental data. In general, it

¹¹ A table with 11 tools that are typically found in the military domain but are very applicable and are being used in the nuclear domain are provided in O’Hara et al’s report (2009). Annex C provides a list and key features of the tools O’Hara has identified as applicable to nuclear staffing analyses.

was found that the models were able to predict task timing information and offered a powerful instrument for detecting differences among staffing levels (Hallbert et al., 2000). For example, the model was able to predict delays in a three person crew that were significant enough that they could affect plant safety. Limitations of the model were revealed and should be of some concern to the CNSC during model validation. As discussed previously the data is only as good as the input and HPMs are abstract representations of human behaviour and therefore there is “room for error”. In addition, as complexity of the model increases and performance measures are added (e.g. visual, auditory, cognitive, and psychomotor values) the more prone to error the model may be. Therefore, as accurate as each element may be individually, the full model may not be. For further limitations see O’Hara et al. (2009). When HPMs are used to support NPP design, the NRC’s staff should review them to ensure that they are appropriately validated and properly used. In general it can be concluded that HPM can provide a valuable tool as it is fairly simple and cost effective tool that can be used to analyze a range of scenarios including MSC.

VE and VR are artificial environments created with computer hardware and software to make it appear and feel like a real environment by way of sound, motion, or tactile feedback, etc. (Vincenzi et al., 2008, p. 24). The level of immersion refers to how “immersed” in the simulation the person is made to feel by way of tools such as Heads-Up-Displays (see Figure 2-2), goggles and haptic gloves. Although desktop and virtual simulated environments have been used in the nuclear industry, CAE is unaware of any in use to determine or assess MSC.



**Figure 2-2: An Example of an Immersive VR of a Nuclear Power Plant.
Taken from (Yerrapathruni, Messner, Baratta, & Horman, 2003, p. 3, Figure 3).**

VR has been used in the nuclear industry in the design phase to evaluate features, control room layouts, radiation exposure management (Louka, M., Rindahl, G., Bryntesen, T., Edvardsen, 2008), and decision support tools (Hanes, 2004). Interestingly there have been a few full-scale immersive VRs created (Vaughn, E., Whisker, III, A., Baratta, T., & Shaw, 2004; Yerrapathruni et al., 2003) of specific spaces within the Westinghouse AP1000. These were created to gain insight into how VRs could contribute to design, construction, and operation of future nuclear

power plants. CAE sees the potential to be able to assess aspects of MSC using VR post design, for example, modeling the time taken to conduct parallel operations in the field and MCR. However, the CNSC should consult the EPRI guidance document that presents guidance for the use two and three dimensional VR and visualization technology in the nuclear industry (Hanes, 2006).

2.4 Summary of Literature Reviewed

It is clear that the nuclear and related industries reviewed rely on human factors standards and guidelines when conducting research and analysis required to determine the MSC, although the approaches and focus are divergent. The majority of domains reviewed rely on human factors assessments to determine staffing levels and involve similar phased approaches as outlined in the CNSC's G-323 and G-278: scenario selection, analysis and validation. Best practices related to scenario selection include:

1. manning should be based on the functions performed within the selected scenario (International Maritime Organization, 2000b, p. 15; ; Reniers; 2010a);
2. methods used to determine or reduce staffing levels should be based on worst-case scenarios and optimization should be based on tasks required to fulfill functions related to these events (Reniers, 2010b); and
3. concurrent procedures should be considered in the scenario selection.

Reniers (2010) suggests that the sequence of tasks is considered and numbers are lowered based on the ability to serially conduct tasks and procedures or raised if parallel tasks are required to be executed by the same operators. Analysis should be systematic and include all functions and tasks that must be performed within the selected scenario. The validation exercises should be observed by external evaluators. For example Transport Canada is authorized to test crew competency by asking questions related to safety, emergency, and survival procedures at any time. Transport Canada inspectors may require a test voyage during which the crew will prove their competence in all aspects of safe operation of their vessel, similar to the CNSC observing validations onsite. In addition drills and exercises should be conducted that integrate MSC regularly as a way to ensure MSC is continuously being validated.

To ensure that the regulator's expectations are transparent, tools and checklists have been provided for users within some domains. For example, Reniers (2010) provides an evaluation tool, in the form of a checklist, to consider safety critical tasks in the control room as well as in the field. The checklist provides best practice guidance for collecting accurate information to support the evaluation of the current staffing levels in a consistent and traceable format. CAE recommends that a series of checklists associated with each review step in G-323 be provided. These checklists should enable efficiency, transparency and consistency between and within the regulatory body and the licensees (O'Hara et al., 1994; Reniers, 2010b; The Energy Institute Safety Bulletin no 3, 2005). Within each checklist (organized by step) CAE also recommends that a summary of the item being reviewed is provided, as well as an indication box to check off whether the licensee has complied with the review criteria and whether there is supportive

data/information, what the data is, and comments associated with the item in terms of actions required.

The military and civil transportation domains focus on the design and procurement phases when determining MSC and attend less to implementation, procedures regarding MSC, reviews and changes requested unless the change is a design change. Within the military domain it can be argued that the Navy may be most congruent to the CNSC's approach based on the level of research, analysis and focus on crewing issues. This focus on MSC is most likely driven by the fact that ships need to have all crew that are required to complete the missions and damage control on-board upon embarking as it is very difficult to call upon more crew after the ship has sailed. The aviation industry is also very similar in the analysis required when determining MSC as the evaluators rely on standards for process guidance which specify steps similar to G-323 including submission of a test plan that details a systematic approach, validation approach, data collection and analysis and reporting of results. Given the consistent emphasis on crew workload and capability during emergency conditions found during the literature review, the best practice during the initial determination of MSC is to include a significant consideration of human factors standards.

There is less detail across the related domains reviewed surrounding the issues of implementation, periodic review and change requests for MSC. The chemical industry does provide some guidance in terms of changes to manning levels. For example, experts investigate the potential impact of the suggested manning level changes by evaluating the new design with proposed manning levels against the current situation with current manning levels. For this purpose, a checklist is used and every item experts consider relevant regarding the impact of staffing level changes is examined and analyzed further.

From the review of the military, aviation, and maritime industries' setting of crew complements, two approaches were particularly emphasized: simulation and exercises. In the aviation industry (military and civilian) the different emergency conditions are known through historical accident reports and engineering analyses. These conditions are tested in the simulator to ensure that the prescribed crew can recover from them. These simulator sessions are measured and the data is submitted to the certifying authority as part of the certification package. From a human performance perspective, this evidence focuses on workload; too much workload is liable to render the situation unrecoverable, either because the pilot cannot perform the required tasks in the time available, or because in carrying out tasks in the time available the pilot makes critical errors.

In the maritime industry (military and civilian) there is also a great deal of historical knowledge of possible emergency conditions. While simulation of a full ship is difficult (although, with distributed simulation, it is becoming more common) ships will engage in damage control and evacuation exercises (effectively rehearsals) while in port and underway. These exercises are held frequently and with regularity. Exercises are based on the documented procedures and establish that all involved in the response are capable of carrying out their assigned duties and thus contributing to an acceptable outcome. If the required standard is not met, additional training is undertaken or, if it is deemed impossible to meet the standard, the procedures are changed. As with simulation in the aviation industry there are performance thresholds that must be met in order for the exercise to be considered successfully completed. Exercises in the

maritime industry are undertaken regularly and are completed with MSC to ensure adequate staffing is in place even in the worst-case scenarios.

Carrying out minimum shift assessments either pre, during or post design phase can be a very complex activity. Although the CNSC can obtain best practices and lessons learned from other related domains it should be noted that these domains are extremely diverse in terms of their organizational culture (military, publicly traded, crown corporations) and features (size, activities, structure). It should also be noted that because of the culture and various needs of the industry, MSC in related domains is not always of primary concern leading to a less stringent process of defining and validating MSC. Currently the CNSC provides guidance to support the regulatory requirement that licensees shall provide a sufficient number of qualified staff. This guidance addresses the various facets of MSC related issues (determining the basis, implementation, etc.) and includes all operator types. This type of guidance is provided to support 'post design' analysis and seems to be sufficient to meet the needs of the nuclear industry. Other industries may rely on pre-design determination of MSC, require much more rigor in terms of the evaluation (e.g. high fidelity simulation or real flight tests to verify airworthiness) and carry out validation by way of simulation since the engineering and design of the ship relies on these analyses – once the ship is built it is almost impossible to make more room for additional crew. Conversely, in a nuclear power plant one can determine the final crew size once the design has been determined as there are less manpower restrictions post design.

A list of best practices and recommendations acquired from related domains that are currently applied or may be applied to future revisions of G-323 is presented in Table 4-1. Recommendations regarding sections 5.1 through 5.5 in G-323 are captured in Table 4-2 through Table 4-6 respectively. In the next chapter interview results with external and internal CNSC stakeholders will be presented.

3 STAKEHOLDER INTERVIEW METHOD AND RESULTS

3.1 Method

Interviews were conducted by human factors specialists to obtain G-323 stakeholder feedback. A semi-structured interview approach was followed whereby the majority of the questions and their order was pre-determined, but the interviewer also had the flexibility to direct the interviews as new issues and topics emerge.

CAE developed two sets of interview questions, one geared towards the experience of external stakeholders (licensees and consultants) and one towards internal CNSC stakeholders. In collaboration with the CNSC, CAE created an informed consent form (ANNEX D), interview approach and questions for external and internal stakeholders (ANNEX E and ANNEX F). The protocol was piloted with two external and two internal participants to acquire feedback regarding clarity of instructions and questions. Note that the results of the 4 pilot interviews were used in the final results as there were no significant changes made post-pilot. The majority of interviews were conducted by phone, with one external consultant interviewed in person. The protocol consisted of reading an oral consent form script and, once the participant agreed, questions were administered. Each interview took approximately one hour.

An MS Excel file was used to compile the data. External and internal stakeholder data was housed in separate Excel file sheets and included the following columns of data:

1. Question number;
2. Questionnaire Section (i.e. Determining MSC, Implementation of MSC etc.);
3. Participant response;
4. Frequency; and
5. Theme (e.g. recommendation, barrier, feedback etc.).

CAE reduced the interview data to conduct a qualitative analysis. Qualitative research categorizes data into patterns (i.e., thematic analyses) as the primary basis for organizing and reporting results. The data obtained was streamlined and coded into finite themes. These were then entered into a word document under the appropriate questionnaire section according to G-323 sections with the frequency of occurrence of each statement provided. This data was submitted to the CNSC for review and feedback and was then summarized at a higher level, for which the results can be found in the following sections.

Results and recommendations were developed related to the project scope and objectives and included the following categories in relation to sections within G-323:

- Basis for MSC (Section 5.1);

- Implementation of MSC (Section 5.2);
- Compliance with G-323 (Section 5.3);
- Periodic review of MSC (Section 5.4); and
- Changes to MSC (Section 5.5).

In addition a Beyond Design Basis Accident section was included.

A summary table with a list of recommendations can be found in Table 4-2 through Table 4-7. These are presented by G-323 section (5.1 to 5.5, plus BDBAs) and category (tools, clarification required, references, etc.).

3.2 Results

3.2.1 Demographics

A total of 19 stakeholders were interviewed and included end-user licensees (n=8), contractors (n=5) and regulators (n=6). A summary of demographic results including Participant ID#, Participant Type, Role, and Experience with G-323, can be found in Table 3-1. Roles included human factors and technical specialists, Operations and Operations management, Emergency Preparedness and Site Inspectors. Licensee experience with G-323 included those with direct experience implementing G-323 from a range of Class 1 Canadian Nuclear Power Plants, those involved with refurbishment activities, those involved in decommissioning and one stakeholder who has experience applying G-323 during new reactor designs. Contractors interviewed included human factors specialists who had direct experience with the analysis and validation phase of implementing G-323 at Nuclear Power Plants and a research reactor. CNSC stakeholder experience included power reactor site specialists, safety analysts, and human factors specialists.

Table 3-1: Summary of Participant Demographics

#	Participant Type	Role	Experience with G-323
1	Licensee	Human Factors Consultant	Validation of MSC using G-323 across multiple projects.
2	Licensee	Section Manager and Human Factors Specialist	Validation of MSC using G-323 across multiple projects.
3	Licensee	Operations Superintendent	Validation of MSC using G-323 across multiple projects.
4	Licensee	Manager, Days Based Maintenance	Led a "Days Based Maintenance" Initiative to validate the minimum complement staffing required to respond to the most resource demanding accident scenarios for each work

#	Participant Type	Role	Experience with G-323
			group. This included analysis and field simulations using human factors standards.
5	Licensee	Regulatory Affairs, Emergency Preparedness Manager	Relied on G-323 to review and revise Emergency Response Procedures.
6	Licensee	Manager - Support, Operations Production Department	Coordination of various G-323 Validation Exercises.
7	Licensee	Operations support, Documentation	Was responsible for revising Shift Minimum Complement documents for the station.
8	Licensee	Department Manager – Operations Support	No significant involvement in analyzing MSC.
9	Consultant	Human Factors Consultant	Validation of MSC using G-323.
10	Consultant	Senior Human Factors Analyst	Involved with G-323 two Minimum Shift Complement Projects. Projects included performing and documenting the systematic analysis to establish the Minimum Shift Complement (MSC) and developing the plan for validation of the MSC.
11	Consultant	Senior Human Factors Analyst	Involved in numerous Minimum Shift Complement Projects.
12	Consultant	Section Manager, Human Factors Engineering	Involved in numerous Minimum Shift Complement Projects.
13	Consultant	Technical Lead, HFE and Control Centre Design Nuclear Power Plants	Provided input into new build projects (mostly MCR) and supported an HFE integration safety review.
14	Internal	Senior Power Reactor Site Inspector	Involved in G-323 development based on experience as a Control Room Operator.
15	Internal	Senior Human and Organizational Factors Specialist	Involved in numerous MSC reviews, evaluations and inspections.
16	Internal	Senior Power Reactor Site Inspector	Participated in a CNSC inspection of a G-323 validation, performed a detailed technical review of selected scenario procedures, and led inspections on severe accident response exercises post Fukushima response.
17	Internal	Technical Specialist	Involved in MSC evaluations (Type 2 inspections).
18	Internal	Human and Organizational Factors Specialist	Involved in MSC evaluations (Type 2 inspections).

#	Participant Type	Role	Experience with G-323
19	Internal	Human Factors Specialist	Involved in MSC evaluations (Type 2 inspections).

3.2.2 General Knowledge Regarding MSC

This section provides the reader with results regarding the level of knowledge of different types of complements; normal, minimum scheduled and minimum shift complements, as well as what the stakeholders feel is the most important contributions that the MSC makes to the stations.

Normal staff complement: The majority of stakeholders stated that normal staff complement reflects the regular daily shift numbers. The numbers for this complement are determined to support the work and maintenance completed during normal operations and is often dictated by monetary considerations, not safety. According to the external stakeholders this number should be left up to the licensee. Interestingly one stakeholder believed that their normal staff and MSC were synonymous, and two licensee stakeholders were unsure how, and if, it differed from minimum staff complement.

Minimum scheduled complement: Internal and a few external stakeholders stated that the minimum scheduled complement was the MSC plus a few additional positions providing a buffer between MSC and any illness or other reason MSC could fall below its required numbers. The majority of external stakeholders had not heard of this term.

Minimum staff complement: All stakeholders stated that the MSC is the “bare bones” staffing level required to operate the plant at a safe state. This is well understood and managed and is tied to the license to operate.

In previous years these three complements were in practice; however, currently this is not a requirement. It is recommended that this should be reinstated for good management and best practice to reduce the possibility of falling below MSC. Regardless of stakeholder type, they all feel that the most important contribution that the MSC makes to the stations is that it ensures that the licensee has the right people with the right qualifications to respond to normal, transient and abnormal events.

3.2.3 Basis of MSC - Section 5.1

Participants were asked to provide feedback regarding the approach followed and challenges faced when determining the basis for MSC using G-323. Feedback was requested regarding any changes or clarifications required for a future revision of G-323 section 5.1. Internal CNSC employees were asked similar questions, but the focus was on the evidence provided to prove section 5.1 compliance.

The use of G-323 to conduct the basis of MSC analysis and validation was most often triggered by a request from the CNSC to refer to and comply with the guideline. However, this request frequently lined up with other related activities the licensees were conducting such as validating

Abnormal Incident Manuals or emergency procedures, or reducing the MSC due to decommissioning (for specific results regarding decommissioning refer to section 3.2.8). In addition, G-323 has been used by stakeholders during the design phase of Class 1 nuclear facilities and refurbishment activities.

In general licensees felt the resources required to comply with G-323 Section 5.1 were significant (e.g. staff, equipment, simulation room, procedures, etc.) and that the majority did not have enough staff or a dedicated team to support the activities. Instead they had to outsource the tasks, which was expensive. The resources and skill sets required were a drain on the organization. External stakeholders also felt that the CNSC also lacked the resources to fully support this activity.

There was a consensus regarding the method used to analyze and validate the MSC basis which included three phases: scenario selection; a human factors analysis of the scenario and associated tasks; and validation of the numbers using MSC. Internal stakeholders consistently relied on a fourth phase which was reviewing the source documents. Source documents mentioned by stakeholders include the safety and Probabilistic Safety Assessment to identify all credible failures that can affect response and Operating Procedures to address all identified events. Although external stakeholders did not state the use of these sources explicitly, one can assume that they also rely on these as sources of information.

The following steps are followed by external stakeholders when determining the basis:

1. Select the most resource intensive scenarios. A short list of scenarios was typically reviewed by the CNSC in order to ensure compliance early on in the analysis process so that they could continue the validation with the correct and agreed-upon scenario(s).
2. Conduct a human factors analysis which includes an execution plan (Human Factors Verification and Validation Plan) relying on G-278. This again was reviewed by the CNSC in terms of the scenario 'stopping points', metrics, and method relied upon. Licensees often stated that at this point in the process they would rely on external consultants to construct and conduct the analysis as they either did not have the resources or the human factors skills and knowledge to conduct the analysis. The plans typically included a task analysis with some stakeholders relying on the method outlined in NUREG 0711. This resulted in the identification of tasks and operators and a subsequent calculation of the numbers required to complete the tasks.
3. Validate the MSC through field walk-downs to assess the organisation's ability to meet G-323 objectives listed for each task in each procedure of the chosen scenario. The majority of the licensees and consultants relied on a custom table to check off items in G-323 to ensure compliance along the way.

The approach internal stakeholders felt licensees should follow mimicked the approach that the external stakeholders described. Specifically, internal stakeholders described providing support to the licensee and contractors in selecting the appropriate scenario, observing the validation exercise, and reviewing the report.

Documents relied upon by stakeholders to analyze and validate the basis for MSC include:

1. CNSC G-278, Human Factors Verification and Validation Plans (2003);
2. CNSC G-276, Human Factors Engineering Program Plans (2003);
3. plant specific Safety analysis/Probabilistic Safety Assessment (PSA);
4. plant specific procedures and processes;
5. NUREG 0711, Human Factors Engineering Program Review Model (2012);
6. NUREG/CR-6393, Advanced Information Systems: Technical Basis and Human Factors Review Guidance, (2000);
7. Nuclear Safety and Control Act (1997);
8. plant specific event analyses;
9. International Atomic Energy Agency standards;
10. previously submitted G-323 MSC analysis report, including validation results (used by the CNSC to evaluate the MSC analysis method and results), and
11. table top/field walk-downs/integrated exercise internal worksheets.

External stakeholders felt that adequate guidance was provided by G-323 when determining the basis for MSC and that it was useful. The information regarding the systematic analysis was helpful and was used to convince the right departments to use a more rigorous human factors method in-house when analyzing MSC. Some licensees even found that this exercise uncovered issues that triggered positive changes (e.g. improved safety related action times, changes to plan configuration, improvements to task execution, etc.) and increased preparedness.

Stakeholders were asked whether G-323 provided enough support to determine the basis and to evaluate the licensees and the majority felt that it was not adequate as is. External stakeholders felt that interpretations differed significantly between licensees and the CNSC during reviews. It is suggested that more guidance from the CNSC in terms of expectations is provided within G-323 Section 5.1 as external stakeholders felt that they spend a significant amount of time discussing issues, methods, objectives and metrics with the CNSC that could have been included with G-323 with respect to acceptance and rejection criteria (e.g. licensees find 'acceptable delays', 'achievable workload', and 'timely manner' hard to quantify). In addition, external stakeholders felt that some requirements were unclear including the validation objectives, what would be considered a "credible event", definition for cut-off times, and the level of rigor required for non-emergency scenarios. One licensee felt that the operators that should be included in the analyses was also unclear and assumed that licensed MCR operators were relevant, but was not confident that all field operators needed to be included in the validation. On a related note, one internal stakeholder felt the need to educate the licensee regarding this

issue and convince them that they needed to include all non-licensed operators listed in the MSC as well in the analysis and validation activities.

Licensees and consultants also felt that the CNSC could be more prescriptive in terms of the level of fidelity required for the validation to be acceptable, perhaps providing some examples as well. Some examples include when Personal Protective Equipment (PPE) should be worn and when it does not need to be, and suggestions regarding accurate timing predictions for tasks that the operators can only simulate (e.g. using a wrench to open valves). One common question included “It is not clear in G-323 if minimum complement numbers need to cater to potential worker injuries, and if it was to require this, how would the number of simulated injuries be determined, and from which work groups?” Internal stakeholders felt that it is hard to justify requests for further analyses and validation data given that G-323 is only a guidance document. Specific recommendations for Section 5.1 can be found in Table 4-2.

3.2.4 Implementing MSC - Section 5.2

External participants were asked questions regarding the approach followed and challenges faced when documenting the MSC analysis and implementing the MSC procedure. Feedback was requested regarding any changes or clarifications required for a future revision of G-323 regarding the implementation of G-323. It should be noted that the majority of licensees indicated that they were unfamiliar with G-323 Section 5.2 and consequently were not sure of its content or how to comply. Internal CNSC employees were asked similar questions; however, the focus was on the evaluation of evidence provided that the MSC procedure was compliant and documented appropriately.

In reference to section 5.2.1, documenting the MSC analysis, the majority of licensees were unsure of where their MSC analysis was documented. Those that were familiar with the document were in some way directly involved in the analysis. Consensus from all types of stakeholders was that section 5.2.1 is too brief to stand alone and can be confusing as it is distal from the analysis requirements. The requirement for documenting the analysis results could be stated in Section 5.1 to reduce confusion.

The MSC procedure is captured in the organization’s documentation system. External stakeholders referred to this as an information document, operational basis document, operations line of conduct, or operations division document (these were stated alone and in combinations). The MSC procedure typically includes qualifications, operations roles and responsibilities, suggested MSC, normal staff complement and internal procedures that clearly state the MSC and how to ensure it is respected at all times. These documents or procedures often provide a reference to the actual analysis completed and can be found in a separate report, and could be considered best practice. This finding is consistent with how the internal stakeholders view the process. Specifically they stated that the MSC basis should be within their policy for procedures and/or the license condition handbook may point to the procedure.

A shared challenge among licensees and the CNSC include checking the qualifications for each MSC position. Specifically there may be separate MSC numbers (tables); for example one for operations and one for ERO. The CNSC stakeholders felt that the procedures are difficult to evaluate as there are numerous MSC tables/numbers that are based on various workgroups

and that the numbers tend to come from different sources pointing at different workgroups and procedures. This variability makes it difficult to maintain, review and analyze the procedures

Overall, the majority of licensees felt that G-323 is adequate as guidance, but they are unsure in terms of implementing the MSC as they have not used it to implement, revise or review the procedure. However, the majority of internal stakeholders interviewed felt that G-323 is not adequate as guidance for implementing MSC and requires significant revision. For example, one internal stakeholder suggested that licensees struggle with the type of training required for each MSC position to be considered qualified and suggests that this section should explicitly refer to the appropriate regulatory documents regarding training. For further recommendations regarding Section 5.2 refer to Table 4-3.

3.2.5 Compliance with MSC - Section 5.3

External participants were asked questions regarding the approach, methods and tools used when complying with their MSC procedure. Feedback was requested regarding changes or clarifications required for a future revision of G-323 regarding compliance. Internal CNSC employees were asked similar questions; however, the focus was on the evaluation of evidence provided that the licensee was complying with the MSC procedure and that MSC was filled at all times.

A broad range of approaches, tools and methods are used by licensees to ensure all MSC positions are filled. These include:

1. Electronic software used to track positions and sign in/out times. This tool was internally developed and upgraded to comply with G-323.
2. White board sign in for MSC positions manually or with name tags.
3. Face-to-face turnover; for example the Shift manager or supervisor ensures MSC is met at the beginning of each shift hand-over (typically using roster sheets) and is responsible to ensure any MSC gaps are filled.
4. If MSC is going to be violated workers are "held over" into the next shift until relief comes. Therefore they also ensure that there are supplies and resources for longer stays at the plant if required (e.g. sleeping quarters and food).
5. Have people on call.
6. Administrative position responsible for scheduling personnel for MSC based on training and qualifications required to ensure people with the appropriate qualifications are on-site.
7. Warning system which detects automatically when they are approaching MSC and warns supervisors. This warning system provides feedback regarding three states:
 - a. When a person badges out and causes the complement to drop below minimum complement, the person receives a warning saying that they should not leave the site. If they continue to badge out, the duty Shift Manager and the duty SATS (Shift Advisor

Technical Support) receive an instantaneous email telling them what position dropped below minimum complement, and the name of the person that has caused this.

- b. Every morning, minimum complement software scans the complement for the next 14 days (28 shifts) and sends a warning email to the stakeholders, flagging shifts that would be below scheduled complement. If there are any gaps, the duty SATS and the first line maintainers do the required “step-ups” or bring people in on overtime to cover those positions.
 - c. Certain positions have a minimum complement of zero on nightshifts and a complement of 1 or 2 on dayshifts. If the dayshift people are not in the station by 8 am, the duty Shift Manager and the duty SATS receive an instantaneous email, warning that the station is below minimum complement.
8. Utilize training, i.e. to have enough qualified workers they give some operators specialized training (e.g. cross-training on mechanical skills) on select credited "actions" that would be required of them if they were to be considered a component of MSC. Note: this item was identified by an internal stakeholder only.

The key factors that could lead to a MSC position not being filled include:

1. illness/epidemic;
2. weather;
3. when the plant is already running with MSC, such as a holiday;
4. unexpected emergency (including family);
5. tardiness;
6. on the job injury;
7. not listening to automatic warnings or not having warnings on night shift;
8. staff did not meet MSC qualifications;
9. too many people on training at one time; and
10. attrition.

The majority of external stakeholders¹² have not relied on G-323 as a guidance document to ensure that MSC positions are filled as it is too high level. They ensure that they comply, but it is not “used” actively as the licensees feel that they take the MSC procedure very seriously and for

¹² Consultants interviewed had no comment on this section as they have had no experience to date applying Section 5.3 in the field.

G-323 to be useful it would have to be much more prescriptive to facilitate any changes required to their current procedures. Internal stakeholders felt that G-323 is sufficient as is. Specific recommendations for Section 5.3 can be found in Table 4-4.

3.2.6 Periodic Review of MSC - Section 5.4

External participants were asked questions regarding the approach used when completing a periodic review of their MSC and any challenges faced. Feedback was requested regarding any changes or clarifications required for a future revision of G-323 regarding periodic reviews of MSC. Internal CNSC employees were asked similar questions; however, the focus was on the evaluation of evidence provided that the licensee was conducting periodic reviews of MSC in compliance with G-323.

The majority of external stakeholders were unaware of any approach their facility used to conduct periodic reviews. They believe that any HF review and MSC analysis should be triggered by an event (Station Condition Record) or changes to equipment, or procedures (e.g. AIMS) that would impact staffing or procedures. Some believe that their documentation reviews have a time-based trigger, but were not certain, and the rest admitted that an approach did not exist for periodic reviews currently. The licensees stated that the MSC analysis is maintained and should be reviewed by way of either a time-based periodic review or triggered by a change that would impact staffing or procedures. However, some licensees stated that this is a weak spot in their documentation system.

Given that the majority of external and internal stakeholders have not applied Section 5.4 they did not have significant feedback in terms of changes required to this section. When prompted, some internal stakeholders stated that they believe facilities have yet to conduct this type of review as it is too resource intensive and not a current priority. Specific recommendations for Section 5.4 can be found in Table 4-5.

3.2.7 Changes to MSC - Section 5.5

External participants were asked questions regarding the approach used when requesting a change to their MSC. Feedback was gathered regarding any changes or clarifications required for a future revision of G-323 regarding changes to MSC. Internal CNSC employees were asked similar questions; however, the focus was on the evaluation of evidence provided that the licensee was complying with the MSC change request outlined in G-323.

The majority of external stakeholders simply follow Section 5.1 in G-323 when requesting a change to MSC and this statement was mirrored by the internal stakeholder responses. They may provide additional justification, including a task analysis on procedures or PSA.

The majority of external stakeholders believe Section 5.5 is too high level to be of any value, and contains insufficient details. They would like to see more guidance provided in support of reducing the numbers of MSC based on the appropriate analyses. External stakeholders stated that they had to make major assumptions regarding procedures, scenarios and mitigation which were incorrect as identified by the CNSC upon review. Request for further analyses required significant communication between the licensee and the CNSC to clarify expectations and

requirements. Perhaps to reduce this burden on external and internal resources this section should be more descriptive and provide additional detail to increase clarity. Specific recommendations for Section 5.5 can be Table 4-6.

3.2.8 Decommissioning

When a Nuclear Power Plant is transitioning from an operating to a maintenance plant there tends to be different needs associated with implementing G-323 as they are constantly changing (namely reducing) MSC, according to licensees. Similar to the majority of external stakeholders, those involved in the analysis of a decommissioned site also follow Section 5.1 in G-323 when requesting a change to MSC; however, their approach was slightly different. In reference to decommissioning a site, the power plant must be in a particular state when operators are not on site. Therefore the approach was slightly different in that these stakeholders identified the finite group of systems that need to be running during decommissioning and analyzed all associated procedures. They then identified tasks, roles and competencies associated with these systems, analyzed the associated training materials and identified the relevant sections to make sure that people have the competencies to perform the tasks required to support the remaining systems.

Two significant issues were identified with regards to decommissioning. First, the current version of G-323 does not make any reference to the possibility that there may not be staff on site on a continuous basis. For decommissioned sites, there may be on-call staff only and therefore the procedure will change accordingly and eventually take into account fatigue, alcohol consumption (fitness for duty), distance and delay. Therefore it is recommended that there is some reference to the concept that minimum staff may be on-call with pre-established delays relying on clear criteria to determine this window of time.

Second, licensees involved in decommissioning activities felt that G-323 could provide a separate sub-section with custom details regarding validation activities related directly to reducing the numbers of MSC. Although they felt that section 5.1 was very useful, they believe that they required more details specific to the decommissioning phase. For example, licensees found that the notion of acceptable time taken to reach the decommissioned plant from offsite is hard to quantify. Licensees also recommended that requirements are not too prescriptive, allowing them to perform the analyses based on their specific needs.

3.2.9 Beyond Design Basis Accidents

Although not included in G-323's current version, definitions and scope, the CNSC was interested in obtaining feedback and information regarding the strategies and methods currently used by licensees to prepare for and respond to BDBA. Potential changes to G-323 related to BDBA were also investigated. External participants were asked questions regarding the approach, methods and tools used currently to ensure the availability of people with necessary qualifications to manage severe accidents. Feedback was requested from all stakeholders regarding potential extensions G-323 would require to address BDBAs with respect to guidance regarding qualified staffing levels and strategies to support these.

The current approaches described by external stakeholders to ensure the availability of people with necessary qualifications to manage severe accidents were diverse. The majority feel that the current MSC and training is sufficient. However, contrary to the previous statement the external stakeholders also stated that drills and exercises have been conducted to identify issues related to BDBAs, revealing the need for cross-training and reduced task complexity, specifically simplifying the task through design changes (e.g. hook up an easy-to-use adapter) so that it can be completed by anyone. In addition licensees have taken the initiative and have created Severe Accident Management-Guidelines (SAM-Gs) post Fukushima which outline the processes, systems and equipment (generators and water pumps, etc.) to be put in place to manage these accidents. For example, one licensee stated that although BDBAs are not accounted for in the MSC basis, MSC members have completed training about systems and procedures to respond to BDBAs (for example, flash floods with a complete loss of power to the supply systems).

Internal stakeholders are aware of the SAM-G initiative and stand behind it. Some CNSC stakeholders interviewed feel that they are lagging on integrating BDBA's into their guidelines and regulation and that they need to catch up to the licensees. Currently internal stakeholders rely on Regulatory Document 2.10.1 (Canadian Nuclear Safety Commission Regulatory Document 2.10.1, 2013) to ensure the availability of people with necessary qualifications to manage severe accidents. This regulatory document should be referenced in G-323. Although some internal stakeholders believe that MSC is mutually exclusive to severe accident management, most agree that further education is required for both external and internal parties on BDBAs and how to approach them.

Through discussions with the CNSC staff and a few internal stakeholders interviewed it may also be important that G-323 provide a link to Regulatory Document 2.5.2 Design of Reactor Facilities: Nuclear Power Plants (Canadian Nuclear Safety Commission Regulatory Document 2.5.2, 2014) in reference to BDBAs. REGDOC 2.5.2 section 8.6.12 states that Design Extension Conditions (DECs) are a subset of BDBAs that are considered in the design that should be identified during design. Stakeholders and the CNSC staff recognize that a link should be drawn between DECs and G-323 if BDBAs are considered.

Regardless of what methods are currently used, the majority of external stakeholders feel strongly that the CNSC should address BDBA within G-323. Some believe the most significant issue affecting minimum shift complements at both multi-unit and single unit facilities currently are the lessons learned from the Fukushima event of 2011. They suggest that for the extension to work the requirements need to be:

1. simple;
2. scenarios need to be clearly defined;
3. scenarios required need to be reasonable (e.g. no stacked scenarios);
4. scenarios need to include constraints based on risk based rationale and cut-offs; and
5. the level of fidelity expected needs to be clear.

It is worth noting that two external stakeholders felt that G-323 is not the place for BDBAs as it is complex enough already. They suggest instead that G-323 could provide some references (list of external organizations to consult in case of a major event, such as civil protection, army, international organizations like IAEA) but it could be housed in a different document.

Internal stakeholders state that G-323 provides a great opportunity to incorporate BDBAs, as the CNSC does need confidence that licensees and applicants will be able to handle the event within the first few hours. A plan based on time, strategy, priorities, and qualifications (e.g. are the right people there for cooling, containment and venting) could potentially be requested for BDBAs. Additionally the CNSC stakeholders feel that strong and clear links needs to be drawn between G-323, the SAM-G's and Regulatory Document 2.10.1 (Canadian Nuclear Safety Commission Reguatlory Document 2.10.1, 2013). It is suggested that licensees should rely on G-323 and Regulatory Document 2.10.1 for BDBA preparedness and the sufficient number of qualified staff. It is recommended that these documents reference each other and be used in combination. In addition the two documents should use consistent terminology as it will matter significantly. Specific recommendations for BDBAs can be found in Table 4-7.

3.2.10 Summary of Interview Results

All stakeholders believe that G-323 offers a formalized process from which all parties benefit. It affords the licensees the opportunity to create and support a more rigorous, scientific-based approach to determining the MSC. They can rely on G-323 to aid in continuous improvement of their processes and analyses through compliance and eventually through periodic reviews. An affirmative outcome stated by the licensees through interviews and publications relating to their experiences implementing G-323 (Berntson & Budau, 2009; Shoukas et al., 2011) is the opportunity to engage a multidisciplinary team that spans numerous departments to a greater depth which revealed weaknesses in human performance, processes and equipment with some believing this to be the biggest value. An internal stakeholder also noted the requirement and benefits of relying on an integrated multidisciplinary team; however, they also felt that this brings difficulties as the team lead has no authority over the team across departments and found it difficult to obtain the right information at the right time.

In general stakeholders feel that this would be an appropriate time to move G-323 from a guideline to a regulatory document with some caveats, particularly that the CNSC's expectations be more clearly defined for each requirement and clear definitions are provided. CNSC's regulatory documents include both requirements and guidance. As stakeholders did recommend that G-323 should move towards a regulatory document, it would be interesting to understand what information the stakeholders would like to see listed as a requirement versus guidance. Unfortunately this topic was not an explicit question and was therefore not covered in any detail. It is recommended that further feedback be acquired regarding this topic from similar stakeholders.

In terms of definitions provided, similar feedback from stakeholders in other domains was found and included "guidance would benefit from better definitions of terms used" and "the method is easy to understand as long as the definitions of what you are assessing are clearly stated" (Brabazon & Conlin, 2001). In addition there is confusion regarding the requirements (e.g. licensees find "acceptable delays", "achievable workload", and "timely manner" hard to quantify)

and differences of interpretation between external and internal stakeholders. Therefore, it has been suggested that more guidance from the CNSC in terms of expectations is provided within G-323, Section 5.1. A significant amount of communication between the CNSC and licensees has been required regarding the CNSC's expectations and different interpretations on various topics including; definitions, acceptable methodology, objectives, metrics, level of fidelity and accept/reject criteria. Some stakeholders have gone so far as suggesting a list of strict pass/fail criteria. This practice has been implemented in other domains and is discussed in section 2.2 (Brabazon & Conlin, 2001; Reniers et al., 2007; Reniers, 2010b). According to feedback stakeholders would like to see a clear and concise document with requirements that have only one interpretation regardless of reader type. They would also like access to tools in the form of checklists or flowcharts to guide them through the process. Therefore, CAE recommends that the CSNC should provide more guidance in section 5.1 that addresses the basis for the MSC, particularly in the areas of general definitions and acceptable methods, objectives, metrics, and level of fidelity.

Three sections, 5.3 – Compliance, 5.4 – Periodic Review and 5.5 – Changes to MSC, are used infrequently and in less depth when compared to Sections 5.1 and 5.2.; therefore less constructive feedback was provided by both stakeholder types. It is suggested that these three sections be reviewed for content and usefulness and perhaps removal or reassignment of these sections is required to create a more concise and useful guideline or regulatory document.

Although not currently part of G-323, all stakeholders seemed to be very interested in how BDBAs were going to be handled by the CSNC in the future. Currently, the licensees are developing ways to respond to BDBAs with a sufficient number of qualified staff in the absence of new regulatory requirements; however, some believe that G-323 along with their current MSC is sufficient to also respond to BDBAs. The most consistent suggestion to integrate BDBAs and the sufficient number of qualified staff required into requirements by the CNSC is to add a separate section or annex relating to BDDBA. Items that are important to stakeholders when integrating BDBAs include the links to the CNSC's regulatory framework, license to operate, DEC's, SAM-Gs and how they all interact, as well as scenario selection and associated constraints and objectives.

Recommendations specific to each Section of G-323 can be found in Table 4-2 through to Table 4-7 in Chapter 4.

4 BEST PRACTICES AND RECOMMENDATIONS

This section provides the amalgamated best practices and recommendations resulting from the literature review and interview results. A complete list of general best practices and recommendations are provided in Table 4-1:

Table 4-1: A Summary of Best Practices Captured in the Literature Review and Interviews.

Ref #	Best Practice/Recommendation	Notes
1	<p>A list of all required definitions should be provided and terminology should reflect the level of knowledge of the user.</p> <p>CAE recognizes that the CNSC is following this best practice in general; however, results from the interviews indicate that further clarification is required for specific terms which will enhance clarity.</p> <p>It is recommended that the following terms are provided with further definitions and/or clarification:</p> <ol style="list-style-type: none"> 1. 'Resource intensive' is not defined well. For example, does it include the field operations or just MCR? 2. 'Validation' is not defined and should be as it is misunderstood, and a reference to G-278 is typically not enough guidance. 	<p>Documentation found in this literature review that is used by stakeholders to conduct crewing analyses contain exhaustive list of definitions that reflect the level of knowledge of the user to ensure transparent understanding of terms used by the writer (Civil Aviation Authority Safety Requirements CAP 670, 2014; Department of the Navy Bupersinst 5450.49C, 2007; European Aviation Safety Agency, 2012; Navy Manpower Analysis Center (NAVMAC), 2000; O'Hara et al., 1994; Reniers, 2010b; Senior, 2014; U.S. Marine Corps, 2004).</p> <p>Feedback from stakeholders on other methods used to analyze minimum crew included "guidance would benefit from better definitions of terms used" and "the method is easy to understand as long as the definitions of what you are assessing are clearly stated" (Brabazon & Conlin, 2001).</p>
2	<p>It is recommended that a list and detailed explanation of all assumptions related to the scenario chosen is provided and/or requested. The use of assumptions will help ensure that the requested information is developed and is consistent with the CNSC's expectations, regulations and guidance.</p>	<p>Assumptions related to the assessment of staffing levels are listed in detail in Young (2012). For example, "A large-scale external event occurs that results in; all on-site units affected, extended loss of AC power, and impeded access to the units".</p>
3	<p>All related references should be provided in the document. The CNSC is following this practice. However, a more detailed list is recommended of related references and standards and when and why they should be referenced. See Table 4-2 for a list of references that stakeholders</p>	<p>For example, in G-323, page 7, there is a reference to international standards and guidelines but G-323 does not provide a list of these.</p>

Ref #	Best Practice/Recommendation	Notes
	recommend be added to G-323.	
4	It is recommended that the systematic method to assess MSC should explicitly consider the technical factors (physical assessment), individual factors (workload, SA, teamwork, knowledge, skills and qualifications) and organizational factors (the management of operating procedures, change, continuous improvement, safety management). This may be implicit in G-323, but the classification used by Brabazon & Conlin (2001) is worth further exploration.	Related references include (Brabazon & Conlin, 2001).
5	Results from the literature review and interviews indicate that a more transparent method of evaluation is required. It is recommended that as a best practice, tools in the form of checklists for each review step, etc., are provided which may help increase consistency, directness and traceability of MSC evaluations. This will also help to ensure that all areas of evaluation are considered (e.g. training, SA, teamwork, willingness to act, management of change, etc.) in an MSC proposal or change request. Specific recommendations regarding various tools that may be provided can be found in Table 4-2.	As a best practice, the HSE uses a transparent method of evaluation to ensure both parties are aware of what and how items will be evaluated which enforces consistency across inspectors and licensees (Brabazon & Conlin, 2001; Energy Institute, 2004; Reniers, 2010b for examples). Review checklists are also provided as an annex in NUREG 1791 (Persensky, Plott, Barnes, & Szabo, 2005), which enable efficiency, transparency and consistency between and within the regulatory body and the licensees. Within each checklist (organized by step) there is an indication box to check off whether the licensee has complied with the review criteria or data/information required or not (or not applicable), a summary of the item being reviewed, and comments associated with the item.
6	Best practices for integrating continuous improvement in staffing arrangements are being followed currently and can be found in G-323. These include learning from past internal and external experiences relating to staffing and best practices. However, it is recommended that the CNSC investigate the addition of information in G-323 or add a reference regarding guidance for continuous	This is a general best practice followed by most related domains reviewed such as aviation (Federal Aviation Administration AC 23.1523, 2005), nuclear (Berntson & Budau, 2009; Sebok & Plott, 2011; Senior, 2014; Shoukas et al., 2011), military (Department of the Army Regulation 570-4, 2006), and chemical (Brabazon & Conlin, 2001) to name a few. As suggested by Brabazon and Conlin (2001), a best practice for continuous improvement would be

Ref #	Best Practice/Recommendation	Notes
	<p>improvement and peer reviews. G-323 should ensure that licensees demonstrate that they have considered the use of:</p> <ol style="list-style-type: none"> 1. operating experience feedback; 2. internal and external lessons learned; 3. relevant international standards and guidelines, and, 4. identified problem areas that may require additional validation analyses. 	<p>to actively seek ways to improve staffing arrangements and strive to surpass current best practices. They also suggest that a peer review is conducted that may help to highlight any biases or omissions in the assessment. Any change to the plant that alters the original systematic analysis should be re-evaluated prior to implementation and changes to staffing levels.</p> <p>It is believed that the CNSC does follow this best practice; however, following the interviews it is not clear that licensees are provided with enough guidance on continuous improvement and review of the MSC analysis. Results from the interviews indicated that external stakeholders do not, as a best practice, review external experiences and lessons learned or share their own on a regular basis.</p>
7	<p>Based on results from Reniers (2010b) a best practice is to ensure that the sequence of tasks is considered in the evaluation and the MSC numbers are lowered based on the ability to serially conduct the tasks or raised if parallel tasks are required to be executed. It is believed that the CNSC is currently following this best practice as outlined in G-323 section 5.1.1 #5.</p>	<p>See Reniers (2010b) for more information.</p>
8	<p>Based on results from Reniers (2010b) a best practice is to ensure that operators are able to move from one point to another within certain time limits. Any restrictions for specific staff with respect to certain locations should be considered. It is believed that the CNSC is currently following this practice as outlined in G-323 section 5.1.1 #12.</p>	<p>The consequences resulting when operators are not able to be in a particular place within a given time should be identified and the reliability of the supporting equipment and the supporting documentation is questioned.</p>
9	<p>Human factors standards and guidelines should be followed as a best practice when determining and assessing MSC. It can be argued that most related fields reviewed rely heavily on standards and guidelines, namely related to human</p>	

Ref #	Best Practice/Recommendation	Notes
	factors and engineering domains, to ensure adequate analysis and validation have been complied with to ensure there is adequate staffing to support safe operations. This best practice was universal across all domains reviewed.	
10	It is recommended that the CNSC further consult the EPRI guidance document (Hanes, 2006) that presents guidance for the use of 2 and 3D VR and visualization technology in the nuclear industry. It is also recommended that this be provided as a reference within G-323 when referring to validation.	See Hanes (2006) for guidance.
11	Be aware of emerging technologies such as M&S capabilities, which may be used by stakeholders more frequently to evaluate and validate the MSC. It may also be important to be aware of the associated limitations of these tools and technologies when assessing the outputs. It is recommended that the CNSC request the models and outputs of these validation tools if used in order to evaluate them effectively and assure the regulator that they are valid models.	
12	<p>It is recommended that G-323 provide reference to three papers that provide an overview of the experience of implementing G-323 from a licensee and contractor perspective. These references have the potential to be used as a tool for future G-323 implementation and provide lessons learned for new users. These include:</p> <ol style="list-style-type: none"> 1. Implementation of the CNSC Regulatory Guide G-323 At Pickering Nuclear Generating Station: (Shoukas et al., 2011); 2. Implementing Maintenance Complement Changes and Experience with Regulatory Guide G-323 (Berntson & Budau, 2009), and, 3. Human Factors Analysis of the 	

Ref #	Best Practice/Recommendation	Notes
	Minimum Staff Complement at a Nuclear Generating Station (Vieira & Phyland, 2015).	
13	Based on results from the literature review and interviews, it is recommended that the CNSC explore the reintroduction of the concept of more than one (MSC) level. These complements may be based on previously used normal, minimum scheduled and minimum shift complements or be based on recommendations by Renier (2010a) who describes 5 possible manning levels that may also support the nuclear industry needs.	
14	The interviews included one contractor responsible for implementing G-323 within new builds. Based on the lack of data and this particular persons' experience implementing G-323 in new builds CAE cannot provide specific recommendations regarding the range of new facility types and whether G-323 should provide specific details for this type of user. Therefore it is recommended that the CNSC collect further data related to new reactor design and experience in the implementation of G-323.	
15	Based on the literature review it is suggested that the provision of extensive analysis and justification via validation to support requests for a reduction in staffing is a best practice shared across several domains.	
16	The Department of Defense Architecture Framework (DODAF) may be applicable as a tool in determining MSC and as part of the analysis to support MSC. While DODAF should not be explicitly recommended in G-323, CAE recommends that the CNSC personnel should be open to proposals and reports that incorporate DODAF views as part of the submission in support of setting and validating the MSC for a nuclear facility.	

Recommendations specific to each section in G-323 are captured in Table 4-2 through to Table 4-7. Each table contains the following columns;

1. ID number.
2. Category: the recommendations were categorized into patterns (i.e., thematic analyses) to aid in organizing and reporting results.
1. Recommendation: CAE's suggested rectification based on results from interviews.

Table 4-2: Recommendations for Section 5.1 - Basis for MSC

ID #	Category	Recommendation
1	Lack of clarity	It is recommended that more guidance from the CNSC in terms of expectations is provided within section 5.1. External stakeholders feel that they spend a significant amount of time discussing issues, methods, objectives and metrics with the CNSC which could have been included within G-323. It is recommended that information related to acceptance and rejection criteria could be listed in a table. Therefore, it is recommended that section 5.1 is written more descriptively and is exemplary in its clarity.
2	Lack of clarity	It is recommended that G-323 state explicitly and early in the document that applicants are permitted to propose an approach to MSC that accommodates the applicant's unique circumstances and satisfies the CNSC's requirements concerning the MSC basis, implementation, compliance and periodic review. It should also be stated clearly that the CNSC personnel will collaborate with the applicant to ensure this approach meets the CNSC requirements.
3	Lack of clarity	It is recommended that any requirements such as the proposed method, objectives, metrics, and performance criteria that may have a "pass/fail" or "accept/reject" associated with them for validation of MSC should be defined and provided for transparency and increase in clarity regarding what is an adequate analysis and validation.
4	Lack of clarity	There are differing interpretations of items in G-323 section 5.1.2.2 which need further clarification by way of descriptions and/or examples including: <ol style="list-style-type: none"> 1. timeliness; 2. effectiveness; 3. appropriate; 4. maintain awareness; and 5. achievable.
5	Objective criteria	It is recommended that the CNSC state clear performance criteria associated with each objective (task analysis, timelines of events, workload analysis, 'control of the situation', etc.) so that licensees can conduct a more rigorous scientific based validation. It is understood that the CNSC cannot be too prescriptive, but ideas on how to measure objectives may be valuable so that

ID #	Category	Recommendation
		there is more agreement between regulators and licensees. For example, regarding the timings used in the analysis and validation, when would the CNSC consider the actions "a success"?
6	Scenario selection	It is recommended that the scenario boundaries and the method to be used to determine the appropriate scenario are clarified. G-323 should investigate the need to include shut-down conditions and any other states required, and the performance of concurrent credited actions.
7	References	Recommend a more comprehensive list of references for stakeholders to refer to when conducting the analysis and validation of MSC. These should include; <ol style="list-style-type: none"> 1. NUREG 0711 rev 3; 2. A Defense in Depth reference (e.g. INSAG-10: Defense in Depth in Nuclear Safety; International Nuclear Safety Advisory Group, 1996); 3. CNSC Regulatory Document 2.10.1, Nuclear Emergency Preparedness and Response (Canadian Nuclear Safety Commission Regulatory Document 2.10.1, 2013); and, 4. REGDOC-2.3.2, Accident Management (Canadian Nuclear Safety Commission Regulatory Document 2.3.2, 2013).
8	Level of fidelity	It is recommended that more guidance is provided with respect to the level of acceptable fidelity for the validation of MSC. It is recommended that examples are provided, e.g. when donning PPE is required and when it is not or suggestions regarding accurate timing predictions for tasks that the operators can only simulate (e.g. using a wrench to open valves). Further recommendations in relation to this recommendation from internal stakeholders include: <ol style="list-style-type: none"> 1. equipment should not be staged ahead of time; 2. participants in the validations should be blind to the scenario and upcoming actions to avoid any "pre-practice"; 3. the plant should not be placed in the "ideal" situation and set up; it should be left "as is"; 4. communications during validations should be subjected to "failures"; 5. clarification should be provided for each action being validated that requires a safety person and ensure that this is assessed within MSC requirements; and 6. the validations should include at least one impairment (fatality, or high radiological conditions) while keeping participants blind to assess how they will respond.
9	Non-licensed operators	It is recommended that non-licensed operators (e.g. field operators, fuel handlers, stores, etc.) should be incorporated into G-323 more explicitly. This recommendation is based on feedback that stakeholders do not tend to take field operations into account as it was not clear about how rigorous they had to be to include these positions and it is not easy to address them. This may require education regarding non-licensed actions for all stakeholder types.

ID #	Category	Recommendation
10	Source documents	<p>It is recommended that the CNSC list the source documents that should be referred to when determining the MSC basis and describe their links to MSC, for example;</p> <ol style="list-style-type: none"> 1. safety analysis; 2. PSA; 3. procedures and processes; 4. NUREG 0711; 5. NUREG 6393 (O'Hara et al., 2012); and, 6. event analyses.
11	License to operate	<p>It is recommended that G-323 be expanded to more explicitly include the consideration of events which may affect more than one unit.</p>
12	Governance	<p>It is recommended that there is an explicit requirement that the CNSC must approve the plan for the analysis and validation, and review the submitted plan prior to observations taking place.</p>
13	Reports required	<p>It is recommended that there be a requirement for an end product (analysis report) to be submitted as a reference document basis for licensing. This would give licensees and the CNSC a baseline to which to compare any future changes.</p>
14	Tools	<p>It is recommended that the CNSC share any checklists they rely on for MCR or field walk-down validations.</p>
15	Tools	<p>To increase transparency it is recommended that the CNSC provide a compliance table so licensees can ensure compliance prior to and following validations.</p>
16	Tools	<p>To enhance ease of use and compliance with G-323 it is recommended that the CNSC provide a flow chart of the steps to follow, deliverables associated with each step and when items need to be reviewed by the CNSC.</p>
17	The CNSC and observations	<p>It is recommended that CNSC provide more structured and robust feedback to the licensees and contractors regarding compliance with G-323 after attending observation/validation events.</p>
18	The CNSC and observations	<p>It is recommended that only required staff from the CNSC attend the observation/validation events as the feedback from licensees and contractors indicates that they feel there are too many people in attendance and licensee staff state that they are nervous and felt as if they were being 'judged' by the CNSC, which may bias the results.</p>

Table 4-3: Recommendations for Section 5.2 – Implementation of MSC

ID #	Category	Recommendation
1	Evaluation criteria	Similar to Section 5.1, it is recommended that the CNSC include explicit evaluation criteria to ensure the licensee can satisfy the expectations of G-323. The regulatory document should not prescribe what to do but should specify what to include.
2	License to operate	It is recommended that a statement is added to ensure that the MSC numbers that are displayed in the licensee’s MSC charts, procedures and license to operate are consistent. Procedures can be difficult to evaluate as there are numerous MSC tables/numbers that are based on various workgroups and the numbers tend to come from different sources pointing at different workgroups and procedures.
3	MSC Audit	It is recommended that the CNSC require a link between the licensee’s Human Performance Program and training database to ensure that the qualifications for MSC are up to date at all times, i.e. training status should be monitored in real time for those on MSC.
4	MSC compliance	It is recommended that a sub-section within Section 5.2 is added that speaks directly to what the licensees may do when MSC cannot be maintained.
5	MSC compliance	In Section 5.2.2 Bullet 5 states: "A description of the measures in place to monitor compliance with the minimum staff complement and to prevent non-compliance with the minimum staff complement." It is recommended that this section make explicit reference to severe weather in case staff is required to stay on site to ensure coverage during a forecasted period of severe weather that may make it difficult for incoming staff to travel to work safely.
6	Lack of clarity	It is recommended that Section 5.2.1 (documenting the MSC analysis) is removed, amalgamated into Section 5.1 or expanded upon. <ul style="list-style-type: none"> The majority of external stakeholders were unclear as to whether there was a difference between sections 5.2.1 and 5.2.2. They also felt that a separate section 5.2.1 is not required as it is only one sentence and were confused by the brevity of it and its meaning.
7	MSC Roles	It is recommended that a statement be added to ensure all staff on MSC is aware of their associated qualifications and roles.

Table 4-4: Recommendations for Section 5.3 – Compliance with MSC

ID #	Category	Recommendation
1	MSC Audit	It is recommended that there is an explicit requirement for licensees to document an auditable trail of the people on MSC at all times with their current

ID #	Category	Recommendation
		(at time of MSC) qualifications.
2	Tools	<p>Internal stakeholders show some concern regarding the electronic MSC compliance software used by licensees. It is recommended that this tool is reviewed or validated by the CNSC to ensure compliance with G-323. Some concerns include:</p> <ul style="list-style-type: none"> Uncertainty regarding how the system interprets the MSC, what rules it uses, etc. The system removes the need for a face-to-face hand-off which could be a valuable source of communication regarding the plant state and any crewing issues. Concern that staff could pick up others' badges, report for duty and not be the qualified person. Or other people could badge each other in as a favour. The system should be auditable with regards to who was on MSC at a specific time in the past. The system relies on current training qualifications. If this link is not maintained and current it could be incorrect. What is the mitigation strategy for this if the plant lost power, how would the licensee ensure MSC?

Table 4-5: Recommendations for Section 5.4 – Periodic Reviews of MSC

ID #	Category	Recommendation
1	Triggers for use of section 5.4	It is recommended that a list of triggers is provided to aid in deciding when to conduct a periodic review of MSC. This could include items such as time passed since last review, procedural changes that affect MSC, changes to Emergency Response Procedures and changes to license to operate.
2	Lack of clarity	It is recommended that the CNSC provide users with further information regarding what should be reviewed when and to what level of detail. For example, at what point does the CNSC need to see a full validation or just a light, table-top or SME review.

Table 4-6: Recommendations for Section 5.5 – Changes to MSC

ID #	Category	Recommendation
1	Lack of clarity	It is recommended that in general more guidance is provided to the licensees and applicants for this section. Stakeholders feel that this section should be more descriptive regarding what the CNSC thinks is important to include in the report; what are the proposed changes; what is the impact and what are the

		mitigation strategies.
2	Non staffed site	Given the greater frequency of use of this section by plants entering or in the decommissioning phase, it is recommended that a subsection dedicated to issues and lessons learned regarding decommissioning, and sites that are not staffed around the clock, be added. For example the current version of G-323 does not make any reference to the possibility that there might not be someone on site continuously.
3	Scalability	It is recommended that Section 5.5 be scalable and support minor and significant changes to MSC.

Table 4-7: Recommendations for BDBA MSC Extension

ID #	Category	Recommendation
1	Include in G-323	It is recommended that BDBA be included as an appendix or subsection within the next revision of G-323.
2	References	It is recommended that Regulatory Document 2.3.2 (Canadian Nuclear Safety Commission Regulatory Document 2.3.2, 2013) is referenced in this section.
3	Links	Clear links and interactions need to be made between BDBA MSC requirements and other procedures including: <ol style="list-style-type: none"> 1. emergency preparedness; 2. SAM-Gs; 3. Mitigation Equipment Procedures; 4. DEC's; and 5. the regulatory framework (how BDBA are reflected in the framework and how it affects MSC).
4	Scenario selection	It is recommended that the CNSC provide guidance regarding constraints surrounding the scenario selection for BDBA to aid in the selection of appropriate scenarios.
5	Methodology	It is recommended that the CNSC require that licensees have a plan in place for a defined amount of time beginning with the onset of the BDBA describing how they will prioritize actions and link this plan to Regulatory Document 2.3.2. Mitigation should include what they will do if they cannot get people to the plant.
6	Method	It is recommended that the CNSC require the licensees to consider the staffing strategy they will use to transition between design basis accidents to BDBAs.

5 CONCLUSIONS

To support the first objective, regulatory requirements, industry practices and scientific literature related to minimum staffing from a range of related industries were reviewed. Findings of this review led to a collection of best practices and recommendations. To support the second objective, feedback from a range of CNSC and external stakeholders from licensed facilities and contractor organizations was collected and synthesized to gain insight about their experience implementing G-323. These results were collated and provided as recommendations. The results of this project will be considered when G-323 is reviewed and updated.

Under the umbrella of the IAEA all nuclear regulators and licensees recognize staff as one of the defences incorporated as part of their fundamental safety principles. However, upon review it is clear that the approaches to MSC differ across regulators. Therefore these approaches were reviewed and relevant best practices collected. Results indicated that each regulator takes a slightly different approach to determining, validating, and implementing MSC. Results indicate that the majority of international regulators reviewed in this document have in place some requirements concerning staffing numbers, but do not appear, in the open literature at least, to have a regulatory requirement to set, validate, and maintain MSC to the same degree as the CNSC.

MSC practices were reviewed from a range of industries with traits similar to nuclear. Significant differences are drawn between those that use the number of minimum staff as a design objective (e.g. aviation and maritime) and those that do not (e.g. nuclear and chemical). Likewise, a distinction is drawn between the nuclear industry and organizations such as the army, marines, or joint forces whose staffing is based on defined organizations with no consideration of the tasks individuals have to do and how they scale to the overall system goal. It is clear that the nuclear and related industries reviewed rely heavily on human factors standards when conducting research and analysis to support the determination and validation of the MSC, and that some (nuclear, chemical, civil maritime) require extensive analysis and justification via validation to support requests for reduction in staffing. The military and civil transportation domains differ from nuclear in that they focus on MSC during the design and procurement phases but attend less to implementation, procedures regarding MSC, reviews and changes requested unless the change affects the design. Within the military domain it can be argued that the Navy (as distinct from civil maritime) may be most congruent to the CNSC's level of research, analysis and focus on crewing issues to address the fact that it is very difficult to call upon more crew after the ship has sailed. The aviation industry is also very similar in the analysis required when determining MSC since evaluators rely on standards for process guidance. These process guides specify steps similar to G-323 including submission of a test plan that details a systematic approach, validation approach, data collection and analysis and reporting of results.

The chemical and petroleum industries appear to be the most analogous to the nuclear industry but they do not appear to have a regulatory requirement to set, validate, and maintain MSC. Rather, inspectors and licensees are provided with detailed guidance and tools regarding how to implement effective staffing arrangements. Such guidance and tools may serve as useful examples for inclusion in future iterations of G-323.

Although this review was able to identify best practices and lessons learned from related domains it is important to note that MSC is not always of primary concern or is considered at different points and with different levels of rigour in the procurement process. Therefore these variances in organizations may lead to a different or less stringent process of defining and validating MSC. Amongst the regulators and related domains reviewed the CNSC may be the most comprehensive for the following reasons: their guidance is distinct from other documents (stands-alone) and explicitly addresses periodic reviews, MSC change requests and licensed and non-licensed workers.

CAE recommends that as the best practices and recommendations put forth in this review are considered, the CNSC should be careful to add the “right” amount of detail and description and avoid being over-prescriptive. An overly-prescriptive document is unlikely to be ‘all things to all people’. For reasons of facility size, nature of operation, location, etc. a comprehensive guidance document may be largely irrelevant to some applicants. Likewise, such a comprehensive document may be unwieldy for all users, making it difficult to use by all but those who work with it on a continuous basis. The aviation industry provides less guidance to applicants, but works closely with them to develop a program that suits both the applicant and the regulator. This practice puts pressure on representatives of the regulator to clearly communicate their requirements, but it permits greater flexibility within the CNSC’s regulatory framework to formulate a MSC approach that is within the capabilities of the applicant and satisfies the requirements of the regulator. While it is difficult to say what the “right” amount of detail and description should be it should likely include descriptions of the desired output that will permit the CNSC to adequately assess the applicant’s MSC, as well as recommended steps in a process to achieve the desired output.

The international nuclear community was also surveyed for their approach to MSC for BDBA. Following the incident at Fukushima-Daiichi a number of international analyses and ‘lessons-learned’ initiatives have been carried out. In Canada and the United States these activities have led to a number of recommendations, some of which have concerned staffing specifically, but the status of published regulatory requirements related to staffing have not yet changed significantly in response to Fukushima. Other industries were also considered for examples of BDBA. BDBA is not a term that is in common usage beyond the nuclear industry so, instead, well-known examples of incidents from other industries were considered for the lessons that can be drawn from them. A total of 6 incidents were described from aviation, space, petroleum, and maritime. A variety of lessons were drawn from these incidents, including the advantages of having additional expert staff available and integrating them effectively with the ‘core’ staff, the value of staff having strong mental models of the system rather than following highly routinized procedures, and the impact of vague lines of accountability. Additionally, some of these incidents resulted in design changes to the system in question, rendering the accident no longer ‘beyond design basis’ and therefore prevented by an additional defence in depth.

The review considered tools that are used by various industries to set and maintain a MSC. All industries concerned with MSC used some form of task analysis to guide consideration of time required to carry out tasks and error potential in order to support decisions regarding staffing. Increasingly, however, industries are making use of live, virtual, and constructive simulation. In practice, these different types of simulation exist on a continuum and involve variable amounts of human involvement and/or simulation of systems. The use of M&S, especially elements of

constructive and virtual simulation, hold great promise to the nuclear industry to assist in the use of systematic approaches to setting the MSC and validating the MSC for both design basis accidents and beyond design basis accidents.

Feedback from stakeholders collected indicated that G-323 is a necessary and useful document and that MSC is an important defence against accidents. There was, however, a lack of clarity amongst stakeholders regarding the definition of terms associated with MSC. A comprehensive list of definitions, compatible with those used in other regulatory elements of the nuclear industry, is recommended based on this finding as well as best-practices identified during the literature review. In addition, the experience of those in the decommissioning phase of operations resulted in a recommendation that G-323 should include a specific section concerning the MSC process during decommissioning.

Looking forward into the next revision of G-323 it is recommended that it is moved from a guideline to a regulatory document with some caveats:

- the CNSC's expectations are more clearly defined for each requirement;
- clear definitions are provided; and
- include tools in the form of checklists or flowcharts to guide them through the process.

Referring to the discussion above about the creation of a comprehensive document, this indicates that stakeholders wish to err on the side of more guidance, not less. Therefore, the approach taken in G-323 should provide sufficient flexibility to accommodate a licensee's unique circumstances while meeting the CNSC's requirements for setting, implementing, complying and periodically reviewing the MSC. Less frequently used sections should be reviewed for content and usefulness and perhaps removal or reassignment to create a more concise and useful guideline or regulatory document. Finally, although not currently part of G-323, BDBAs should be included by an additional section or annex regarding CSNCs expectations for handling BDBAs. Items that are important to stakeholders when integrating BDBAs include the links to the CNSC's regulatory framework, license to operate, Design Extension Condition's (DEC), SAM-Gs and how they all interact, as well as the scenario choice and associated constraints and objectives. Over 50 best practices and recommendations have been provided in this report resulting from the literature review and interview data.

6 LIST OF ACRONYMS

AIM	Abnormal Incident Manual
ASN	Nuclear Safety Authority (France)
BDBA	Beyond Design Basis Accidents
CARs	Canadian Aviation Regulations
CEA	French (Atomic Energy Commission)
CNSC	Canadian Nuclear Safety Commission
CRM	Crew Resource Management
DEC	Design Extension Condition
DRDC	Defense Research and Development Canada
DTAES	Department of Technical Airworthiness
EASA	European Aviation Safety Association
EPRI	Electric Power Research Institute
ERO	Emergency Response Organization
FAA	Federal Aviation Authority
HBR	Human Behavior Representation
HFE	Human Factors Engineering
HFES	Human Factors and Ergonomics Society
HITL	Human-in-the-loop
HOP	Human and Organizational Performance
HPM	Human Performance Modeling
HSE	Health and Safety Executive
IAEA	International Atomic Energy Agency
IMO	International Maritime Organization
IPME	Integrated Performance Modelling Environment
LVC	Live, Virtual, and Constructive
MCR	Main Control Room
METI	Ministry of Economy, Trade and Industry
MODUs	Mobile Offshore Drilling Units
M&S	Modeling & Simulation
MSC	Minimum staff complement

MSMC	Minimum Safe Manning Certificate
NAVMAC	Navy Manpower Analysis Centre
NEI	Nuclear Energy Institute
NRA	Nuclear Regulation Authority
NRC	U.S. Nuclear Regulatory Commission
NSC	Japan's Nuclear Safety Commission
NSCA	Nuclear Safety and Control Act
NTSB	National Transportation Safety Board
NTTF	U.S. Near-Term Task Force
NUREG	U.S. Nuclear Regulatory Commission Regulation
ONR	Office for Nuclear Regulation
OSVs	Offshore Supply Vessels
PHRED	Plant-human Review and Effectiveness Decision Tool
PSA	Probabilistic Safety Assessment
R&D	Research and Development
SA	Situation Awareness
SAM-G	Severe Accident Management-Guidelines
SAPs	Safety Assessment Principles
SQEPs	Suitably Qualified and Experienced Persons
TA	Technical Authority
TAGs	Technical Assessment Guides
TCB	Type Certification Basis
TNM	Task Network Modelling
USCG	U.S. Coastguard
VE	Virtual Environment
VR	Virtual Reality

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ANNEX A BEST PRACTICES AND FINDINGS FROM RELATED DOMAINS

This Annex provides the reader with an overview of the guidelines and research that can be found in related domains which included, defense (Army, Navy, Air Force, Marines, Joint), civil transportation (maritime, aviation), chemical, and Coast Guard/Petroleum.

A.1 Defense

A review of military standards and practices for determining minimum staff complement was carried out which comprised of five military domains:

Army (a self-contained organization that is land-based and potentially includes some aircraft and water craft);

Navy (a self-contained organization that focuses on operations on the water, but potentially includes aircraft);

Air Force (a self-contained organization that focuses on operations in the air);

Marines (a self-contained organization that operates across the boundaries of land, sea, and air); and,

Joint (an organization that integrates the contribution of all the other military domains to achieve mission objectives in a more effective fashion).

Each of these domains is discussed individually below regarding MSC and includes a brief summary of each military domain.

A.1.1 Army

An Army determines its manpower requirements on an organizational basis. The Army is a hierarchically arranged organization where each level of the hierarchy consists of defined numbers of its subordinate levels. This organizational definition of manning requirements does not take account of the specific numbers of personnel required to complete its mission, instead applying coarse organizational units of measure and mapping these against an estimate of the geographical 'spread' of the manpower. This approach is defined in a nation's military doctrine. Nevertheless, the US Army has published guidance on manpower requirements (Department of the Army Regulation 570-4, 2006) and has a US Army Manpower Analysis Agency which engages in specific Research and Development (R&D) on manpower issues concerning specific contexts and missions. These studies represent R&D and are not used as a basis for certification of that context or mission.

The exception to this approach is US Army Aviation. US Army Regulation 95-1 (Department of the Army, 2014) stipulates that the minimum crew of an aircraft will be in accordance with the operator's manual, which is certified by either the Federal Aviation Authority (FAA) (in the case of commercially-derived aircraft) or the military airworthiness authority (in the case of military

aircraft). The approach to certification of military aircraft is described in Section 2.2.2.1.3. The approach to certifying civilian and commercially-derived aircraft is described in Section 2.2.2.2.2.

In general, Armies and their equipment are not certified for staffing arrangement. This makes it difficult to make simple comparisons between the Army's method of calculating manpower requirements and that of licensed nuclear operations.

A.1.2 Navy

Navies of the world have employed the philosophy that you must be able to battle while engaging in damage control, expressed in the term 'Float-Move-Fight' (Directorate of Maritime Strategy, 2001). This reflects a historical view where a damaged ship had no option but to save itself while continuing in battle or risk losing the ship and the crew, since there was little hope of escaping the enemy and being subsequently rescued. More recent experience has seen a shift toward ceasing operations until damage is contained. The need to only pursue one objective has reduced the manning requirement in the Navy but at some cost. During the Falklands war the UK lost 6 ships and sustained serious damage to a further 11, but the Royal Navy has continued to reduce crew sizes by improving the damage control training of crew and changing philosophy (i.e. cease operations until the damage is under control). This view is countered, however, by anecdotal evidence indicating that the fire aboard Her Majesty's Canadian Ship (HMCS) Protecteur was only contained due to the prodigious efforts of the full crew, and that without the full crew the ship would have been lost along with many lives. Unfortunately during the course of this review documentary guidance concerning the determination of crew sizes for Royal Navy ships was not found in open-source repositories.

Recent direction in Canada concerning the design of a new class of Navy ship has included a blanket statement that traditional manning levels should be maintained (i.e. in the region of 200 – 250 personnel for a ship of approximately 5000 tonnes). However, there are efforts by the Directorate of Naval Personnel and Training to consider the systems on the ship with respect to optimizing manning and crew configurations while still achieving mission success (Lawrynczyk & Lamoureux, 2015). These efforts are currently being scoped but include studies and constructive simulation. In the future, this work may include live and virtual simulation to validate the evidence from the studies and constructive simulation (for more information see section 2.3.2).

The US Navy currently has a Manpower Analysis Centre, which was created to develop and document manpower requirements for all fleet activities within the Navy (Department of the Navy Bupersinst 5450.49C, 2007). In effect, the Navy Manpower Analysis Centre (NAVMAC) has responsibility to conduct the technical work to support the Office of the Chief of Naval Operations Instruction (Department of the Navy Opnavinst 1000.16J CH-1, 2002), which lays out the process by which crew size, roles and responsibilities should be defined for the US Navy. In general, this process involves three steps:

1. Analyse, validate, and assess the supportability of manpower requirements associated with new acquisitions;

2. Validate and monitor revisions, update manpower estimates for new ships, aircraft and systems throughout the defence system acquisition process, exercising approval authority over statements of manpower requirements and methodologies used to determine manpower requirements; and,
3. Ensure manpower implications, including life-cycle costs, are adequately addressed in the mission needs statements, operational requirements documents, analysis of alternatives, and other documents required during the acquisition process.

It should be noted that the acquisition process continues until the ship is released to service. OPNAVINST 1000-16J also outlines the elements to be considered in manpower studies, including:

1. Directed manpower elements (management);
2. Watch stations (e.g. combat, engineering, damage control);
3. Preventative maintenance;
4. Corrective maintenance;
5. Facilities maintenance;
6. Staffing standards to be applied;
7. On-site workload measurement and analysis;
8. Utility tasking;
9. Allowances; and,
10. Training.

Although not prescriptive in the tools and techniques to be applied, the instructions specify that evidence of an analysis and validation must be provided. Based on the worst-case scenario (typically a battle damage scenario involving fire and hull breach, while continuing to engage in defensive actions), the number of work hours is calculated. These calculations are then used to determine the crew size required for the ship. It should be noted that the manpower for ships is calculated prior to and during the design and procurement phase, congruent to what an applicant may be faced with when applying for a nuclear license to operate. However once the ship is procured, there is no prescription or guidelines followed for manning safety even if significant changes to the ship have been made. If the ship went through significant modifications that changed its size, plant, or control systems a review of manning might be undertaken as part of the design process, but typically these types of fundamental changes are not made through the life of a ship.

One other factor should be noted about ship manning is that when off-duty, members of the ship's personnel remain onboard, meaning that at any given time there is the ability to increase

the number of people available to deal with an unforeseen event. This is a contrast to any other system wherein personnel typically leave the system when not actively working.

A.1.3 Air Force

The air force in Canada and its allies determine manpower requirements based on the number of people required to maintain and operate the aircraft fleets. However, when an aircraft is not flying, it is in a stable state and therefore the number of staff for maintenance operations is not subject to minimum staffing requirements. When airborne, however, aircraft can represent a hazard to others in the area and minimum flight crew is regulated and certified before being released to normal service.

Flight crew requirements for the air force represent a design objective by the aircraft manufacturer. As such, the aircraft systems, functionality, controls and displays are all developed after the number of crew and the roles and responsibilities of each crew member are defined. As with the organizational method of determining staffing requirements, using the number of flight crew as a design objective represents a different approach to that adopted by the nuclear industry. In spite of the differences, the process adopted by the aircraft manufacturers to prove that the stated flight crew number assumptions is relevant to the nuclear industry and mirrors that of the civilian aviation authorities. Specifically, they consider whether the crew are able to recover the aircraft to safety (i.e. land the aircraft) from all flight regimes (including all failure conditions).

The US Air Force Air Force Policy Directive (2010) lays out a process that involves the development of a tailored set of airworthiness certification criteria specific for developing aircraft. This process is elaborated by flight standards defined in MIL-HDBK-516B (2008). In brief, this process involves a collaborative effort by the aircraft manufacturer and the airworthiness authority to determine the basis of certification. Once this is agreed upon, it is up to the manufacturer to provide evidence supporting the basis of certification, which the airworthiness authority will review for compliance. This evidence will usually include data from simulators, including crew workload ratings, using an identified and validated workload rating tool, for example the Modified Cooper-Harper (Wierwille & Casali, 1983) or the Bedford Rating Scale (Corwin et al., 1989). After this evidence is accepted, flight trials are undertaken from which evidence is also collected in support of the basis of certification.

The European Defence Agency includes a Military Airworthiness Authority which published the European Military Airworthiness Requirements. These cover initial aircraft certification, aircraft maintenance, and maintenance training organizations, maintenance personnel licensing, and continuing airworthiness management. In this process, the National Military Airworthiness Authority will contact the aircraft manufacturer after the capability requirements have been established. A tailored approach is developed through negotiations between the two organizations which include standards drawn from civilian and military sources. The outcome is an agreed certification basis against which the company will be required to design the aircraft. Toward the end of the design and development process the National Military Airworthiness Authority will review and evaluate evidence from the company that the design meets the requirements in the basis of certification. Assuming the evidence is sufficient, a permit to fly is granted which will allow the company to begin test flying the aircraft. Test flights provide further

evidence that the basis of certification is satisfied. A Military Type Certificate is then issued but a Production Organisation Approval must also be held by the aircraft manufacturer before the aircraft can be manufactured in larger numbers by the manufacturer. The Production Organisation Approval is based on an investigation and audit of the company's processes, procedures and systems. Every individual aircraft that is manufactured must also be inspected to ensure it complies with the approved design.

The UK Ministry of Defence Regulatory Article 1500 (2014) describe a similar approach to that of the European Defence Agency, consisting of 6 phases:

Phase 1 – Identify the requirement for, and obtain, organizational approvals.

Phase 2 – Establish and agree the Type Certification Basis (TCB).

Phase 3 – Agree the Certification Programme.

Phase 4 – Demonstrate compliance with the TCB.

Phase 5 – Produce Final Report and issue Certificate.

Phase 6 – Undertake post-Certification actions.

This approach must be adopted for both a new type of aircraft and a major change to an existing type.

In Canada the Department of National Defence Military Airworthiness Authority is the Department of Technical Airworthiness (DTAES). DTAES' Technical Airworthiness Manual and Airworthiness Design Standards Manual describe a very similar process to that of the European Defence Agency.

The key advantage the aviation industry has in certifying a design is that 'worst-case' conditions can be tested in a simulator and measured using validated measurement instruments. The use of simulation in aviation has a long and successful history.

A.1.4 Marines

The Marines are similar to the Army in that they base their manpower calculations on organizational norms, rather than study and analysis of workload. The requirements for manpower calculations for the US Marine Corp are outlined in the US Marine Corps total force mobilization, activation, integration, and deactivation plan (2004).

A.1.5 Joint

In common with the Army and the Marines, Joint organisations are staffed according to organizational needs rather than based on an analysis of workload, roles and responsibilities. The requirements for manpower calculations for US Joint operations are outlined in Joint Publication 1-0: Joint Personnel Support (2011).

In general, military standards and handbooks are relied upon across all military domains to conduct HFE work, including manning studies and determination of crew. For example, MIL-STD-46855A provides HFE requirements for military systems. According to MIL-HDBK-46855, HFE should be applied during development and acquisition of military systems, equipment, and facilities to integrate personnel effectively into the design. This effort should be provided to (a) develop or improve all human interfaces of the system; (b) achieve required effectiveness of human performance during system operation, maintenance, support, control, and transport; and (c) make economical demands upon personnel resources, skills, training, and costs. The HE effort should include, but not necessarily be limited to, active participation in the following three major interrelated areas of system development: analysis, design and development, and test and evaluation (Department of Defense Standard Practice MIL-STD 46855A, 2011, p. 8). Although these standards do not focus solely on minimum crew issues they are congruent to CNSC's G-278 which is referred to within G-323 and provides very similar guidance for conducting systematic analyses and validation on issues such as crewing (although not explicitly) throughout design, development and changes to military systems.

A.2 Civil Transportation

Each nation has a transportation standards organization responsible for safety and standards for conveyances within their jurisdiction. This section focuses on the certification of ships and Aircraft by different authorities around the world.

A.2.1 Maritime

In Canada minimum crew size of small commercial vessels is based on two factors (Transport Publication TP14070 E, Chapter 4 (2010);

1. Crew required to carry out specified safety-related tasks including emergency situations and routine safety oversight (radio and deck watch) and
2. Size of the ship (with certain exemptions).

The regulations also specify that crewing must be maintained continuously during operations. Crew members must also have appropriate qualifications for the safety-related tasks to which they are assigned. In practice, most crew have as their second and/or third duties the safety-related tasks, meaning most crew are cross-trained (the exception is the operator and engineer, who must be separate individuals on vessels greater than 20 metres length). This allows marine operators to sail with reduced crews.

Transport Canada is authorized to test crew competency by asking questions related to safety, emergency, and survival procedures at any time. Transport Canada inspectors may also require a test voyage during which the crew will prove their competence in all aspects of safe operation of their vessel. Further, Transport Canada requires certificates of competency and/or operators cards which are awarded following completion of a specific syllabus of qualifications, which may include a practical test or a period of practical experience.

In contrast to the Transport Canada approach, many maritime authorities have settled upon a standard number of crew based on tasks for different sizes of ships (e.g. http://www.mpa.gov.sg/sites/port_and_shipping/port/licensing_of_craft/laying_up_a_vessel_in_port.page, Marshall Islands guidance). However, as evidenced by a discussion paper out of the UK, this is demonstrably not enough when fatigue and modern security requirements are factored in (Lloyd, 2007). Maritime operations, like those of a licensed nuclear facility, are a 24/7 engagement and must provide for sufficient numbers of qualified staff to cover continuous operations including breaks, fatigue, abnormal incidents, unexpected illness, etc..

The International Maritime Organization (IMO) defines safe manning as “a function of the number of qualified and experienced seafarers necessary to ensure the safety of the ship, crew, passengers, cargo and property for the protection of the marine environment” (International Maritime Organization, 2015). In addition the ability of seafarers to maintain observance of the requirements is dependent upon conditions relating to training, hours of work and rest, occupational safety, health and hygiene and the proper provision of food (International Maritime Organization, 2015). The IMO released a principles of safe manning document in 2000 (International Maritime Organization, 2000) that outlines issues that should be observed in determining the minimum safe manning of a ship. At a high level, the minimum safe manning level of a ship should be established based on the following:

1. Size and type of ship;
2. Number, size and type of main propulsion units and auxiliaries;
3. Construction and equipment of the ship;
4. Method of maintenance used;
5. Cargo to be carried;
6. Frequency of port calls, length and nature of voyages to be undertaken;
7. Trading area(s), waters and operations in which the ship is involved;
8. Extent to which training activities are conducted on board; and
9. Applicable work hour limits and/or rest requirements.

In addition the manning should be based on the functions performed including navigation, cargo handling, ship operations and care for on-board persons, marine and electrical engineering, radio communications, and maintenance. Proposals for minimum safe manning levels are submitted to the IMO Administration who then evaluates the levels to ensure that the complement is adequate for the safe operation and protection of the ship and its emergency procedures. A template is provided that includes all of the information that IMO will require to adequately assess the MSC (International Maritime Organization, 2000, p. 15).

A.2.2 Aviation

As noted under the Air Force Section above the crew size is a design objective when developing a new aircraft. However, aviation authorities have developed standards for cabin crew that are independent of the design of the aircraft; these are based on research concerning aircraft evacuation and the role of cabin crew during abnormal events. Only by conducting an evacuation trial of a new aircraft, and demonstrating that passengers can evacuate an aircraft within prescribed time limits, can exceptions to the national minimum numbers of cabin crew be certified (JAR-OPS 1.990 (ACJ OPS 1.990)).

The FAA is a worldwide leader in the certification of new aircraft, owing in part to the number of aircraft developed in the United States. Europe and the European Aviation Safety Association (EASA), follow closely due to their development of aircraft and, in practice, the two organisations share much of their approaches. Part of the certification for new aircraft includes establishing that it is possible for the posited crew to operate the aircraft in all flight regimes. In particular, this concerns recovering the aircraft safely from emergency situations. The design objectives regarding crewing are subject to extensive testing following a defined process. The FAA's AC23-1523 (2005) process guidance specifies the following steps:

- Submission of an evaluation test plan;
- Detail concerning the analytical approach (the FAA offers time line analysis as an example, and suggests others listed in appendices);
- Details of testing (scenario-based direct comparison, indirect comparison, standalone), and
- Data collection and analysis.

The FAA's standard provides guidance, references, methods, and forms required for submission. This is subject to review by qualified airworthiness authorities at every stage to ensure that manning is sufficient. The FAA also provides general guidance concerning workload which states that "the minimum flight crew must be established so that it is sufficient for safe operations considering:

- (a) The workload of individual crewmembers, and in addition, for commuter category airplanes, each crewmember workload determination must consider the following:
 - (1) Flight path control.
 - (2) Collision avoidance.
 - (3) Navigation.
 - (4) Communications.
 - (5) Operation and monitoring of all essential airplane systems,
 - (6) Command decisions, and

- (7) The accessibility and ease of operation of necessary controls by the appropriate crewmember during normal and emergency operations when at the crewmember flight station.
- (b) The accessibility and ease of operation of necessary controls by the appropriate crewmember and;
- (c) The kinds of operation authorized under 23.1523 including normal, non-normal and emergency procedures.

Further, there is an extensive list of specific factors that must be examined when considering workload for minimum crew determinations. These include

1. The impact of basic airplane flight characteristics on stability and ease of flight path control. Some factors such as trimmability, coupling, response to turbulence, damping characteristics, control breakout forces and control force gradients should be considered in assessing suitability of flight path control. The essential elements are the physical effort, mental effort and time required to track and analyze flight path control features, and the interaction with other workload functions.
2. The accessibility, ease, and simplicity of operation of all necessary flight, power, and equipment controls, including emergency fuel shutoff valves, electrical controls, electronic controls, pressurization system controls, and engine controls.
3. The accessibility and conspicuity of all necessary instruments and failure warning devices such as fire warning, electrical system malfunction, and other failure or caution indicators. The extent to which such instruments or devices direct the proper corrective action is also considered.
5. The complexity and difficulty of operation of the fuel system, with particular consideration given to the required fuel management schedule necessitated by e.g. structural, or other airworthiness considerations. Additionally, the ability of each engine to operate continuously from a single tank or source that is automatically replenished from other tanks if the total fuel supply is stored in more than one tank.
6. The degree and duration of concentrated mental and physical effort involved in normal operation and in diagnosing and coping with malfunctions and emergencies, including accomplishment of checklist, and location and accessibility of switches and valves.
7. The extent of required monitoring of the fuel, hydraulic, pressurization, electrical, electronic, de-icing, and other systems while en route and recording of engine readings, and so forth.
8. The degree of automation provided in the event of a failure or malfunction in any of the aircraft systems. Such automation should ensure continuous operation of the system by providing automatic crossover or isolation of difficulties and minimize the need for flight crew action.
9. The communications and navigation workload.

10. The possibility of increased workload associated with any emergency that may lead to other emergencies.
11. Passenger problems.
12. Incapacitation of a flight crewmember whenever the applicable operating rule requires a minimum flight crew of at least two pilots.

The EASA guidance is contained within their Airworthiness of Type Design document (Leroy, 2013). This document describes how EASA discharges its technical process responsibilities for certification activities of new aircraft. EASA may also choose to accept the certification of National Aviation Authorities (e.g. the Civil Aviation Authority in the UK) but such an acceptance will generally have followed a process that is acceptable to EASA. The certification process is divided into the following five phases:

Phase 0 - Definition and agreement of the working methods with the applicant: The objective of this phase is to check applicant's eligibility and establish a Team of experts.

Phase I – Technical Familiarisation and establishment of the Initial Certification Basis: The objective of this phase is to provide technical information about the project to the Team of experts to enable the definition of an agreement on the initial EASA Certification Basis.

Phase II – Agreement of the Certification Programme and Level of Involvement: The objective of this phase is the definition of and the agreement on the proposed means of compliance for each requirement of the Certification Basis and the identification of the Certification Team's Level of Involvement.

Phase III – Compliance determination: The objective of this phase is to demonstrate compliance with the applicable Certification Basis and environmental protection requirements and provide the Agency with the means by which such compliance has been demonstrated and declare that compliance has been demonstrated.

Phase IV- Technical closure and issue of the Approval: The objective of this phase is to technically close the investigation and issue the Certificate.

Canadian Aviation Regulations (CARs) govern the minimum crew requirements when certifying aircraft. There are several different sections in Part V – Airworthiness, covering:

- Normal, utility, aerobatic and commuter aircraft (chapter 523);
- Transport aircraft (chapter 525);
- Rotorcraft (i.e. helicopters) (chapter 527); and,
- Transport rotorcraft (chapter 529).

These sections generally have the same format:

- 1) The workload on individual crew members considering the following:
 - a) Flight path control,
 - b) Collision avoidance,
 - c) Navigation,
 - d) Communications,
 - e) Operation and monitoring of all essential aircraft systems,
 - f) Command decisions, and
 - g) The accessibility and ease of operation of necessary controls by the appropriate crewmember during all normal and emergency operations when at the crewmember flight station.
- 2) The accessibility and ease of operation of necessary controls by the appropriate crew member; and
- 3) The kinds of operation authorized under the chapter in question.

Note that the criteria required by the CARs are identical to those of the FAA. There is no guidance available to the public on how any of the data that would be submitted would be deemed acceptable. However, it does seem clear that sufficient evidence would need to include a task analysis and sufficient data aggregated to form overall conclusions regarding acceptable numbers for the flight crew.

Aviation authorities also have standards for duty periods for flight crew. CAP371 (Safety Regulation Group, 2004) from the UK CAA governs maximum Flying Duty Period. For long-haul flights a relief pilot may be carried allowing for between $\frac{1}{3}$ and $\frac{1}{2}$ of the rest period to be added to a flying duty period. For instance, fly for 6 hours, rest for 6 hours, fly for a further 3 hours for a total of 9 hours of active work during a 15 hour flight. Second pilot would fly for 12 hours then have the rest of the flight off. Third pilot would have the first 6 hours off then fly for the second 9 hours.

Aviation authorities also provide guidance concerning qualifications of flight crews. Again, from the UK CAA, CAP 553 Issue 207 Chapter A8-9 Approval of Organisations for Flight under 'B' Conditions – Group F1, F3 and F4 States: 3.6 Flight Crew: The number and qualifications (including licences where applicable) of the minimum flight crew shall be subject to agreement between the Organisation and the CAA for each type or category of aircraft (as appropriate) concerned. Although this arrangement must not prejudice the minimum flight crew finally specified in the Flight Manual. The flight manual is also defined in regulations as: a document prescribed by the International Civil Aviation Organisation intended primarily for use by the flight crew. The Manual contains limitations, recommended procedures and information such that adherence to it will enable the level of safety which is intended by the Airworthiness Requirements and the Air Navigation legislation to be regularly achieved. The Flight Manual, by

definition in the Air Navigation Order, forms part of the Certificate of Airworthiness” (from CAP 553, Chapter A7-2).

A.3 Chemical

As production increases in the chemical and allied industries employment has been decreasing (Alaptite & Kozine, 2012; Reniers, 2010a). Most modern chemical plants have undergone extensive pressure to be as lean as possible resulting in reduced staffing levels. A lack of qualified operational personnel in unusual conditions and the resulting lack of process control can trigger a series of internal or external accidents, eventually leading to a major accident (Reniers et al., 2007). Though this seems to be of concern to the research community (typically human factors and safety), literature on this subject is limited. According to Reniers (2007) accident reports and research to date within this domain tend to omit any investigation into the relationship between incidents and staffing levels.

The Energy Institute, the professional body for the energy industry in the UK provide a “Human Factors – Staffing Arrangements” webpage where they provide high level best practices for implementing safe staffing arrangements. The webpage was developed to provide those in the oil and gas and other high-reliability industries with the resources required to determine staffing arrangements in control rooms and other locations. The webpage provides general best practice guidance, research, case studies and useful links. In addition they refer to the document titled “Safe Staffing Arrangements – User Guide for CRR348/2001 Methodology: Practical application of Entec/HSE process operations staffing assessment methodology and its extension to automated plant and/or equipment” (Energy Institute, 2004).

As of 2010, the HSE document written by Brabazon and Conlin (2001) is cited as the most important work on the topic within the chemical and allied industries. Brabazon and Conlin (2001) introduced a method for assessing the manning levels in the control room at chemical plants. The method provides a staffing assessment to ensure that the plant can prevent and respond to hazardous events based on the worst-case scenarios, comparable to the nuclear industry. The methodology addresses a wide range of human factors issues associated with operating process plants. It should be noted that the intention of this document is not to determine MSC, but to flag where staffing arrangements may not be sufficient enough to respond to worst-case scenarios, therefore post build.

Brabazon and Conlin’s method consists of two types of assessments, a “physical assessment” and a “ladder assessment”. The physical assessment is used to evaluate technical factors, i.e. whether the design of the process control equipment (e.g. control room) and support equipment (e.g. mobile communication equipment) allow incidents to be detected, diagnosed and responded to in time (Brabazon & Conlin, 2001, p. 23). Whereas the ladder assessment is used to evaluate individual and organizational factors, i.e. do the operators have the knowledge and capabilities to detect, diagnose and respond to incidents in time and are there appropriate policies and procedures in place (Brabazon & Conlin, 2001, p. 24).

The physical assessment method relies on scenario selection which should be bound by the following statements;

1. Worst case scenarios requiring implementation of off-site emergency plans;
2. Incidents which could escalate without intervention to contain the problem on site, and
3. Lesser incidents requiring action (representing a high workload) to prevent the process becoming unsafe.

These scenarios are then defined in detail and further assessed on six fundamental principles used to assess control room manning levels. These include:

1. Supervision/intervention possibility;
2. Distractions;
3. Information;
4. Communication links;
5. Assisting personnel, and
6. Recovery operations.

These 6 principles are grouped into three sets based on the three parameters that are important for monitoring safety in most high-reliability industries, i.e. detection (1,2), diagnosis (3,4) and recovery of problems (5,6). The physical assessment is organized in terms scenarios chosen and specific questions that are binary (yes/no) are asked. These are arranged across eight trees; the first three trees cover issues with detection and the rest with diagnosis and recovery. An example tree is provided in Figure A-1. The assessment of each principle is captured in a table format and includes scenario number, description, data on the pass/fail outcome, why it failed and recommendations on how to mitigate the issues. Figure A-2 provides an excerpt from a physical assessment completed on a small toxic gas leak scenario and associated crewing issues.

Figure 5.1 Example Tree from the Physical Assessment

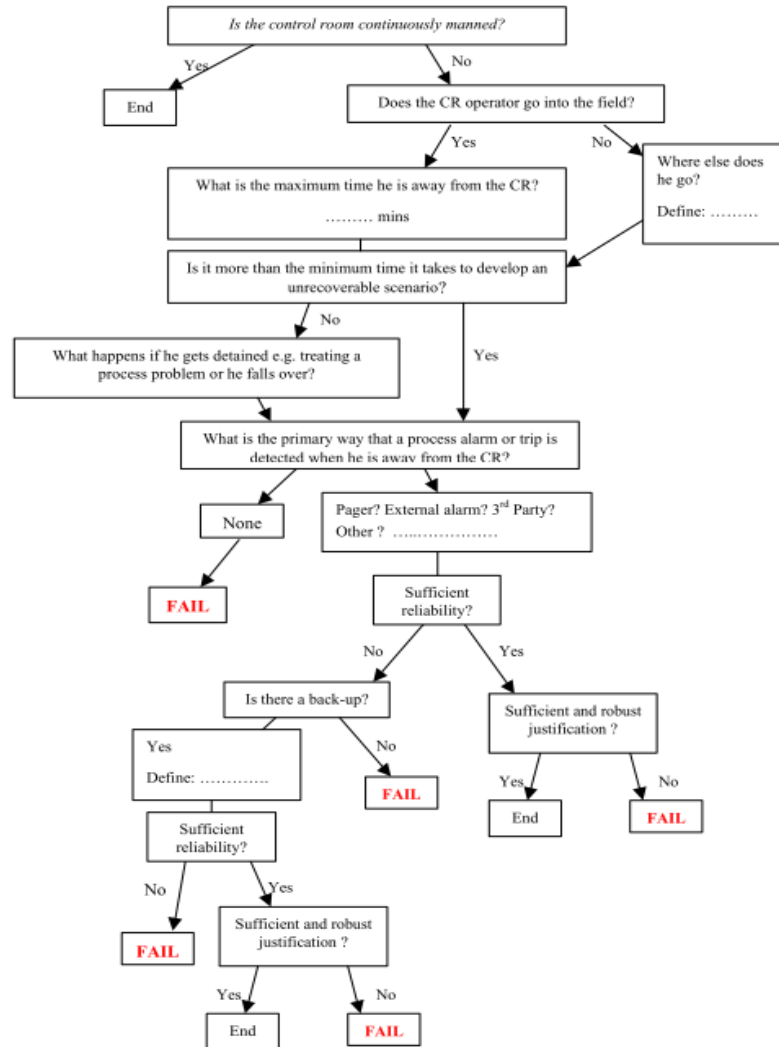


Figure A-1: An Example of the Physical Assessment Tree (Brabazon & Conlin, 2001. p.37)

Scenario No.	Scenario description	Pass	Fail	Physical assessment failed on	Actions required
4	Small toxic gas leak with no obvious control screen indication (relies on third party detection)	✓		N/A	Additional detection on night shift as there is only the shift team to detect a leak. During the day shift there are numerous personnel moving around the plant who could detect a leak. Assess the maximum time it would take for the unit patrol operator to detect a leak on their unit and decide whether it is acceptable. If not, consider whether additional cameras would help.

Figure A-2: An Example of a Physical Assessment (From The Energy Institute, 2005).

The ladder assessment is then used to evaluate eleven general human factors issues concerning staffing arrangements and include:

1. Situation awareness,
2. Teamwork,
3. Alertness and fatigue,
4. Training and development,
5. Roles and responsibilities,
6. Willingness to initiate major hazard recovery,
7. Management of operating procedures
8. Management of change
9. Continuous improvement of safety
10. Management of safety, and
11. Automated plant and/or equipment.

The ladders of interest from the list of eleven are selected to be assessed during the study. For each ladder selected “introductory statements” are reviewed. The CRR348/2001 methodology report provides introductory statements for each of the ladders which describe the boundaries for the assessment based on best practices. For example, the training and development ladder would be anchored on one end with the best practice statement “Process/procedure/staffing changes are assessed for the required changes to operator training and development programs. Training and assessment is provided and the success of the change is reviewed after implementation” and on the other end with a poor practice statement “There is no evidence of a structured training and development program for operators. Initial training is informally by peers”. This ladder assessment example is found in Figure A-3. Everything above the dotted line is deemed acceptable and therefore an inspector can position the plant on the ladder by comparing best practices to those used by the plant being analyzed.

Table 5.1 Example ladder (for training & development)

Grade	Description	Explanation of progression	Rationale supporting assessment
A	Process/procedure/staffing changes are assessed for the required changes to operator training and development programmes. Training and assessment is provided and the success of the change is reviewed after implementation.	The training and development system is dynamic and integrated into the management of change process.	
B	All operators receive simulator or desktop exercise training and assessment on major hazard scenarios on a regular basis as part of a structured training and development programme.	Operators get a regular opportunity to practice major hazard scenarios through physical walk through's or simulators or by desk-top talk throughs.	
C	There is a minimum requirement for a 'covering' operator based on time per month spent as a CR operator to ensure sufficient familiarity . Their training and development programmes incorporate this requirement.	It has been recognised that anyone covering the control room must be competent and their skills kept up to date.	
D	Each operator has a training and development plan to progress through structured, assessed skill steps combining work experience and paper based learning and training sessions. Training needs are identified and reviewed regularly and actions taken to fulfil needs .	The training and development needs are identified, provided and reviewed on an individual basis allowing operators to improve and extend their skills and understanding. It provides operators with a motivation to improve and continue to develop.	

W	All operators receive refresher training and assessment on major hazard scenario procedures on a regular, formal basis.	The need for formalised regular refresher training for major hazard scenarios has been recognised as essential when they are such infrequent events with severe consequences.	
X	New operators receive full, formal induction training followed by assessment on the process during normal operation and major hazard scenarios	Full training and assessment for new operators, it is formalised and covers normal operation plus major hazard scenarios.	
Y	There is an initial run through of major hazard scenario procedures by peers .	Only an informal briefing on major hazard procedures is provided to new operators.	
Z	There is no evidence of a structured training and development programme for operators. Initial training is informally by peers.	Poor practice, staffing arrangements do not fulfil any of the rungs above.	

Figure A-3: Example of a Ladder Assessment for Training and Development. (From Brabazon & Conlin, 2001, p.39)

Ladder assessments address issues that are generally more subjective than those covered by the physical assessment. The aim is for the assessment team to achieve a consensus of how they perceive current performance of the various human factors assessed, and the potential impact of proposed changes. The facilitator has a key role in ensuring the team discusses all issues fully and that the participants agree with the outcome of the assessment on each ladder used. The assessment is carried out, starting at the bottom rung of the ladder (See Figure A-3). The next rung is considered only if the team agrees that the appropriate staffing arrangements are in place or planned to achieve those described in the decision tree (See Figure A-1). To date, the most significant result of these assessments is the identification of bottle-necks in the control room (Brabazon & Conlin, 2001).

Feedback from users of this proposed method resulted in a need for a guiding document that provided a best practice approach to following the method. Therefore, HSE produced a user guide (Energy Institute, 2004) that accompanies the method. A high-level overview of the method and user guide can be found in a bulletin released by The Energy Institute (The Energy Institute Safety Bulletin no 3, 2005).

This method also provides some high level guidance regarding continuous improvement, peer review, and changes to staffing levels. As suggested by the authors, the best practice for continuous improvement would be to actively seek ways to improve staffing arrangements and strive to surpass current best practices. They also suggest that a peer review is conducted that may help to highlight any biases or omissions in the assessment. Any change to the plant that alters the original physical and ladder assessments should be re-evaluated prior to implementation and changes to staffing levels. The document provides an overview of the type of changes and how they may impact the original staffing assessment. Other areas of interest to CNSC, such as implementation and procedures are “embedded” in the physical and ladder assessment statements.

An emerging theme through this literature review is the lack of inclusion of field operations in the determination and assessment of the MSC. This conclusion is mostly founded within the chemical industry as it is the most similar in terms of a contained facility that requires field operators. As stated in section 2.2.1.2 it is not uncommon to focus on the licensed operators within the MCR. Similarly the assessment tool developed by Brabazon and Conlin (2001) fails to evaluate tasks related to field operations and does not instruct users to include a range of safety critical scenarios and tasks, as noted by Reniers et al (2007). Reniers also states that there have been no directives on safety critical staffing levels within the Chemical plant domain nor have any best practices been established to determine the quantity and quality of minimum staff required being onsite to ensure plant safety and therefore the responsibility still lies within each individual company.

A paper written by Reniers (Reniers, 2010b) suggests a practical method to evaluate safety critical staffing levels required to meet safety critical activities, such as loss of containment (LOC). The hope is that this method can provide inspectors with evidence that the plant offers staffing levels that can support safety critical operations such as a 4-day hostage crisis, terrorist threat, and a BDBA. The activities designed to ensure safe operations at chemical installations can be divided in terms of the different situations in which they must be executed and include standard safety activities (pre-accident warnings, or ‘high alarms’), safety critical activities (may

lead to final line of defense, or 'high high alarms') and finally emergency activities (situations resulting from a LOC). Staffing levels are typically based on production and safety requirements. Reniers (2010a) describes 5 possible manning levels that support the industry needs and are described in descending order.

1. Full staffing: number of personnel to guarantee production (composed of field and control room operators as well as support staff).
2. Standard Safety Staffing: minimum number of personnel required to guarantee that the production team will fulfil all necessary activities (safety critical tasks and standard tasks – not emergency tasks).
3. Safety Critical Staffing: minimum number of personnel required in a production team to fulfill production and all safety critical tasks including emergency tasks.
4. Minimum Staffing: minimum number of personnel required in a production team determined from the safety viewpoint, i.e. safety is guaranteed but production is not.
5. Emergency Staffing: The minimum number of personnel required in a production team to take care of all emergency tasks.

Comparable to G-323, Reniers (2010a) suggests that the methods used to reduce staffing levels should be based on worst-case scenarios and that optimization be based on tasks required to fulfill functions related to these events. Also comparable to G-323, Reniers (2010) suggests that the sequence of tasks is considered and numbers are lowered based on the ability to serially conduct the tasks or raised if parallel tasks are required to be executed by the same operators. Reniers provides an evaluation tool, in the form of a checklist, to consider safety critical tasks in the control room as well as in the field (See Figure A-4). Whether operators are able to move from one point to another within certain time limits, the consequences resulting when operators are not able to be in a particular place within a given time are identified and the reliability of the supporting equipment and the supporting documentation is questioned. The information obtained while using the checklist can vary significantly between and within facilities. Therefore, the checklist provides best practice guidance for collecting accurate information to support the evaluation of the current staffing levels in a consistent and traceable format.

vessel personnel (seafarers) and the safe and efficient operation of vessels on which they work. Vessels may be operated safely and efficiently when they are manned by certified seafarers in sufficient number¹⁴. More relevant to the current review, Subpart 14(A), entitled "Manning of Vessels", establishes the framework for the development of guidelines for the creation of a Minimum Safe Manning Document which details the number of each type of certified seafarer required to adequately man a vessel. Example items include;

1. The principles of safe watchkeeping (navigational, engineering, and cargo operation);
2. Effective mooring and unmooring of the vessel;
3. Operation of all firefighting and life saving equipment;
4. Maintenance of all vessel equipment including navigational, cargo, engineering, fire fighting, and life saving;
5. Operation and maintenance of the vessel in a safe and clean condition to minimize the risk of fire;
6. Provisions for medical care aboard the vessel;
7. Continuing training and certification of seafarers; and
8. Work hour limitations and rest period requirements and factors that contribute to crew fatigue.

Regardless of the Model Code, there is a great deal of attention to staffing in the offshore oil production industry since 2010. According to Alaptite and Kozine (2012) the staffing levels have dwindled down slowly over the years and they believe safety is compromised. One such example is the explosion of the Deepwater Horizon oil rig in the Gulf of Mexico. As companies are allowed to treat rigs as "ships" they have flexibility in terms of what type of vessel they register them as, as well as their location. Unfortunately the location is often within impoverished nations with very minimal standards of inspection (Hamburger & Geiger, 2010). According to Hamburger and Geiger (2010) experts and survivors of the explosion that led to the massive spill say foreign registration allowed for understaffing which may have contributed to the disaster. The crux of the issue seems to be that different types of rigs are classified differently, and the Marshall Islands assigned the Deepwater Horizon to a category that permitted lower staffing levels (Alaptite & Kozine, 2012).

Recently there has been a drive by the USCG to begin looking into inspection and staffing issues of offshore supply vessels (OSVs) and mobile offshore drilling units (MODUs). The coastguard has focused on expanding its maritime safety training requirements to cover all persons other than crew. According to the new proposed rules (U.S. Coast Guard Federal Register, 2014) these new rules are necessary to enhance the ability to respond to emergencies

¹⁴ <http://www.uscg.mil/international/affairs/Publications/MMSCCode/english/Chap14.htm>

such as fire, personal injury, and abandon ship situations in hazardous environments (2014, p. 1). As MODUs become increasingly large and navigated farther from shore, the USCG is particularly concerned with whether there are an adequate number of engineers and mates assigned to these vessels that are able and qualified to respond to emergency situations.

According to the official USCG investigation report on the Deepwater Horizon accident, its owner, Transocean, have had serious safety management system (SMS) failures and a poor safety culture, which culminated in the casualties on April 20, 2010. The company failed to support proper risk assessment, and maintenance of safety critical equipment, and did not ensure that the crew was trained and ready to respond to emergencies (USCG Investigation Team, 2010). According to the USCG the crew onboard failed to identify the consequences of their decisions and lost situation awareness regarding the overall safety of their vessel. Unfortunately the international standards and Coast Guard regulations described in this report do not properly address the current design, operation and manning found aboard these vessel types. The number of personnel did not seem to be an issue as the owners provided a copy of their crew complement as required by The Republic of the Marshall Islands manning standards. It was found that all Maritime Crew members held the necessary licenses and documents for their assigned positions and complied with the Minimum Safe Manning Certificate (MSMC). However, inadequate training and emergency response preparation via drills and exercises was partly to blame. The U.S. Coast Guard provided numerous recommendations regarding personnel and processes including better management of its safety culture. Unfortunately, many well-known gaps in the “maritime safety net”¹⁵ aligned that day and failed to prevent this event.

¹⁵ established to ensure safety on offshore drilling MODUs on U.S. on the U.S. Outer Continental Shelf

ANNEX B INTERNATIONAL MARITIME ORGANIZATION MODEL FORM OF MINIMUM SAFE MANNING DOCUMENT

APPENDIX

MODEL FORM OF MINIMUM SAFE MANNING DOCUMENT

MINIMUM SAFE MANNING DOCUMENT

(Official seal)

(State)

Issued under the provisions of regulation V/13(b) of the
INTERNATIONAL CONVENTION FOR THE SAFETY OF LIFE AT SEA, 1974, as amended

under the authority of the Government of

.....
(name of the State)

by

.....
(Administration)

*Particulars of ship**

Name of ship

Distinctive number or letters

IMO number

Port of registry

Gross tonnage:

National

International Tonnage Convention, 1969

Main propulsion power (kW)

Type of ship

Periodically unattended machinery space yes/no

* Alternatively the particulars of the ship may be placed horizontally.

Trading area**

The ship named in this document is considered to be safely manned if, when it proceeds to sea, it carries not less than the number and grades/capacities of personnel specified in the table(s) below.

Grade/capacity	Certificate (STCW regulation)	Number of persons

Special requirements or conditions, if any:

Issued at on the day of
(month and year)

Date of expiry (if any)

(Seal of the Administration)

.....
(Signature for and on behalf of the Administration)

** Where a trading area other than unlimited is shown, a clear description or map of the trading area should be included in the document.

ANNEX C LIST OF 11 TOOLS APPLICABLE FOR STAFFING AND QUALIFICATION ASSESSMENTS. ADAPTED FROM (O’HARA ET AL., 2009)

Method	Key features	Description
Command, Control & Communication - Techniques for Reliable Assessment of Concept Execution (C3TRACE)	Manpower and personnel in team communications	C3TRACE is a modeling environment that can be used to evaluate the effects of different personnel architectures and information technology on system and human performance. It includes a graphical user interface for easy configuration of organizations, personnel and their tasks, a communications and scenario module, a discrete event simulation engine (Micro Saint Sharp), and data analysis module. Within C3TRACE, any organization, the people assigned to that organization, and the tasks and functions they will perform can be easily represented. Communications within and outside of the organization can be represented. Organizations and their personnel can be evaluated with "what-ifs" to see the impact of the different configurations on C2 without the need for a live exercise or experiment. Important performance considerations for each organization include task times, information quality on which tactical decisions can be based, and workload levels.
Complex Cognitive Assessment Battery (CCAB) Fatigue	Cognitive abilities definition	CCAB is a performance evaluation tool which allows users to test the effects of various stressors on cognitive performance and listed in the United Kingdom's Ministry of Defence Standard 00-25 as a tool for conducting workload analysis (Ministry of Defense, 2004). In addition, CCAB is useful in task analysis, and is considered a standard tool for conducting cognitive task analysis in air traffic management by the European Organization for the Safety of Air Navigation. The appropriate uses of CCAB vary with the user. For users in industry, CCAB's flexibility permits configuration of specialized batteries for jobs with different cognitive profiles.
Improved Performance Research Integration Tool (IMPRINT)	Army manpower and personnel	IMPRINT was developed by the Human Research & Engineering Directorate of the U.S. Army Research Laboratory and is a network modeling tool designed to help assess the interaction of soldier and system performance throughout the system lifecycle--from

		<p>concept and design through field testing and system upgrades. Imprint supports the analyst in developing clear system performance requirements and conditions so that hardware/software designers will know what the system will have to do to achieve mission success. This is accomplished by using a discrete event simulation tool as the engine to perform task analysis, and subsequent soldier-system task allocation.</p> <p>IMPRINT provides a Personnel Constraints Estimation Aid - The purpose of this product is to provide designers with a description of the significant personnel characteristics that explain and limit the probable operator and maintainer populations.</p> <p>In addition it contains a Manpower and Personnel Based System Evaluation Aid. The purpose of this product is to determine the number of soldiers per job required to operate and maintain system hardware. This product predicts the operations and maintenance jobs required and the number of operations and maintenance personnel per job per system.</p>
<p>Integrated Simulation Manpower Analysis Tool (ISMAT)</p>	<p>Navy manpower and personnel</p>	<p>ISMAT is a discrete-event simulation tool used to evaluate system manning concepts early in development. ISMAT is currently used by the Naval Small Business Research Initiative (SBIR) to evaluate both new classes of US Navy ships and to modernize older ships. ISMAT addresses the allocation of functions and tasks to humans and to advanced technologies. It can identify additional training requirements resulting from the introduction of new technologies.</p> <p>ISMAT incorporates task characteristics, task timelines, situational awareness, as well as operator Knowledge, Skills and Abilities (KSA's) into a dynamic human performance simulation framework. ISMAT also assists designers in assessing the impact of reduced manning levels on performance in various dimensions of the system. These include the levels of automation required, and the allocation of tasks to human operators of the system. Through iterative use, ISMAT can help analysts determine the best allocation of tasks to personnel and the level of automation necessary to handle crew overload situations. By performing this analysis before the prototype stage and by varying assumed</p>

		level of automation, task allocations, crew characteristics, mission scenarios, and execution goals, considerable time and expense can be saved by eliminating faulty design options.
Plant-human Review and Effectiveness Decision Tool (PHRED)	Nuclear manpower and personnel Based on IMPRINT	See detailed information regarding PHRED in Section 2.3.
WinCrew	Crew workload analysis	WinCrew is a task and workload analysis tool. It predicts system performance as a function of human performance. It models behaviors in response to workload levels which may affect performance. WinCrew predicts and assesses changes in system performance as a result of varying function allocation, number of operators or crew, level of automation, task design, mode of information presentation, and response to high workload. Through iterative use, determine high drivers affecting human and system performance. This data can then be used to conduct statistical analyses testing such as sensitivity analysis. WinCrew has been used to investigate options for reduced manning, effects of different levels of automation, and workload imposed on human operators by system design concepts.



ANNEX D ORAL CONSENT SCRIPT

Hello, my name is _____ and I am a Human Factors Consultant from CAE.

During this project I am collecting feedback from a range of stakeholders to gain insight about their experience implementing the CNSC's regulatory guide, G-323 entitled *Ensuring the Presence of Sufficient Qualified Staff at Class I Nuclear Facilities – Minimum Staff Complement*. The results of this project will be considered when G-323 is reviewed and updated. Funding for this project is being provided by the Canadian Nuclear Safety Commission.

This project involves one 60 minute interview. During the interview, I will be asking questions about your experience related to the minimum staff complement and implementation of G-323. I will take precautions to protect your identity by keeping all responses anonymous.

You may withdraw from this project at any time, up to May 6th, 2015 by letting me know. If you choose to withdraw, all of the information you provided will be destroyed.

With your agreement, I will record this interview. All data, notes and voice recordings are stored in a locked office at CAE and all information gathered from you will be kept confidential and anonymous. All data that may include individual identifiers will be encrypted. Data collected during the project will be destroyed within four months of completion of the project.

Should you have questions or concerns related to your involvement in this project, you can contact me or the Project Manager, _____, whose contact information was in the e-mail I sent to you.

Do you have any questions or need clarification?

Do I have your permission to begin and to record this interview: ___Yes ___No

Date: _____

Participant's name/Pseudonym/Initials: _____

Interviewer's Signature:

ANNEX E EXTERNAL STAKEHOLDER INTERVIEW QUESTIONS

MSC Basis (analyzing/validating):

1. What has triggered you (the licensee) to perform a MSC analysis?
2. Please explain the approach your organization follows when conducting the **systematic analysis** to determine the MSC.
3. Please explain the approach your organization follows when establishing the validation scenarios and **validating** the MSC.
 - a. Did you use any of the CNSC's regulatory documents other than G-323 when validating the MSC?
4. Did the CNSC provide enough guidance to support the selection of validation scenarios and objectives of validation exercises?
5. Were there aspects of G-323 that were particularly **useful** or **problematic** when you conducted the systematic analysis or validated the MSC requirements?

Implementing the MSC:

1. How is the MSC basis captured in your organization's documentation system?
2. Please explain the approach your organization follows to maintain the basis for the analysis of the MSC.
3. G-323 requires that minimum staffing requirements are formalized in a procedure. Please explain any challenges you have encountered when implementing the station's MSC procedure.
4. Does G-323 provide enough guidance about what should be included in a minimum staff complement procedure?
5. Are you familiar with the terms normal staff complement, minimum scheduled staff complement and minimum staff complement? If yes, how are the terms applied in practical terms at your site?

Compliance with the MSC:

1. Please explain the approach your organization follows to ensure all MSC positions are filled.
 - a. Based on your experience, what are the key factors that could lead to a MSC position not being filled?
 - b. Do you use any tools or methods to support ensuring that MSC positions are always filled?
2. Does G-323 provide enough guidance for ensuring that MSC positions are filled in any situation?

Periodically reviewing the MSC:

1. Please explain the approach your organization follows when reviewing the MSC periodically.
2. Does G-323 provide enough guidance to support periodic reviews of the MSC?

Changing the MSC:

1. If you have been involved with requesting a change to the MSC in your license, please explain the approach your organization took when the changes were requested.
2. Does G-323 provide enough guidance to support you when you plan for a change to the MSC?

Beyond Design Basis:

1. Although not included in G-323 definitions and scope, what strategies or methods do you currently use to ensure the availability of people with necessary qualifications to manage severe accidents?
2. What extensions to G-323 do you think are necessary to address beyond design basis accidents? Is G-323 the right document to provide guidance about staffing levels and strategies for Beyond Design Basis Accidents?

Wrap-up Questions:

1. What is the most important contribution that the MSC makes to the station?
2. In your experience, what are the difficulties to implementing the current version of G-323?
3. What facilitates the implementation of G-323 and the resulting MSC?
4. Based on your experience, what do you believe are the most important elements of G-323?
5. Do you use any other guidelines/resources/**tools** regarding MSC (includes analysis, validation, implementation and monitoring) inside or outside of the nuclear domain? If yes, explain.
6. What changes, if any, would you recommend for G-323?
7. Is there anything else you would like to discuss regarding changes required to G-323?

ANNEX F INTERNAL STAKEHOLDERS INTERVIEW QUESTIONS

General Background Questions:

1. Can you list the facilities where you have evaluated implementation of G-323?
2. What is the most important contribution that the MSC makes to the station?
3. Based on your experience, what do you believe are the most important elements of G-323 guidance that should be known and understood by licensees?
4. Describe, at a high level, the ideal process licensees/applicants should follow to apply G-323.

MSC Basis (analyzing/validating):

1. Please describe a systematic analysis that you have been involved with and the approach you followed when evaluating the **adequacy of a systematic analysis** to determine the MSC?
 - a. Did G-323 provide enough guidance to support you when you reviewed the systematic analysis? Please explain.
2. Please describe an example of validation activities that you have been involved with and the approach followed when evaluating the adequacy of the validation of the MSC.
 - a. Did G-323 provide enough guidance about validation scenarios and exercises to support you when you reviewed the validation activities?
3. Please explain other sources of information or resources you use when reviewing systematic analyses or validation activities of licensees.
4. How do regulators ensure that the objectives of the validation exercises have been met by the licensees/applicants? (e.g. facility can be monitored effectively, workload is achievable, procedures can be implemented in a timely manner etc)
5. What changes, if any, would you recommend for G-323 related to the systematic analysis or validating the MSC requirements?

Implementing the MSC:

1. How is the MSC analysis basis captured in licensees' documentation system?
 - a. Please explain the approach that you would expect licensees to follow to maintain the basis for the analysis of the MSC (e.g., updating the analysis to account for changes in the organization, roles and responsibilities, equipment design, risk assessments, procedures etc.).

2. G-323 requires that minimum staffing requirements are formalized in a procedure. Please explain any challenges you have observed with licensees implementing the station's MSC procedure.
 - a. Does G-323 provide enough guidance about what should be included in a minimum staff complement procedure?
3. Are you familiar with the terms normal staff complement, minimum scheduled staff complement and minimum staff complement? If yes, how are the terms applied in practical terms by licensees?

Compliance with the MSC:

1. Please explain the range of approaches you have seen organizations implement to ensure all MSC positions are filled.
2. Based on your experience, what are the key factors that could lead to a MSC position not being filled?
3. What tools or methods have you seen licensees use to support ensuring that MSC positions are always filled (e.g., electronic sign-in, face-to-face turnover)?
 - a. Do you feel there is one system in particular that supports monitoring MSC the best?
4. Does G-323 provide enough guidance for the implementation of the MSC in any situation?

Periodically reviewing the MSC:

1. Please explain the approach licensees apply when reviewing the MSC periodically.
 - a. Does G-323 provide enough guidance to support periodic reviews of the MSC?

Changing the MSC:

1. If you have been involved with reviewing a change to the MSC requested by a licensee, please explain the information provided by the licensee.
2. Did G-323 provide enough guidance to support your review of the MSC change?
3. Do you have specific example of your work related to MSC or G-323 for either licensing or compliance?
 - a. Can you explain the process? (was it complex, clear)
 - b. Did you rely on G-323 in this work? If yes, how?
 - i. And if yes, was it useful?
 - ii. Can you recommend any improvements?

Beyond Design Basis:

1. What strategies do licensees currently use to ensure the availability of people with necessary qualifications to manage severe accidents?
2. Is the review of G-323 the right opportunity to clarify CNSC's expectation on staffing for Beyond Design Basis Accidents?
3. What extensions to G-323 do you think are necessary to address Beyond Design Basis Accidents?
4. Are there any methods not currently within the scope of G-323 that should be considered for ensuring the presence of a sufficient number of qualified workers for accidents that extend beyond the design basis?

Wrap-up Questions:

1. What do you believe are the most crucial issues with G-323 that should be addressed in the next update?
2. What mechanisms are in place to ensure consistent interpretations of G-323 between different CNSC representatives?
 - a. What is your experience with this?
3. In your experience, what are the difficulties implementing the current version of G-323? (barriers to using it, organizationally, process-based, and within G-323 itself).
4. Should G-323 process be more or less prescriptive regarding the activities that must be undertaken by licensees/applicants?
5. Is there anything that is unclear to you as a representative of the CNSC in G-323?