How Systems Engineering and Human Factors can assist SMR Vendors with the Licensing Process

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ABSTRACT

There is growing interest in the development of small modular reactors (SMRs) as a cost-effective renewable source of energy. Most of the current conceptual designs propose advanced and automated control and monitoring technologies which would require complex human system interfaces. The proposals also include a reduction in the number of staff, and partial or full remote control of the facilities. The human factors challenges of such a design philosophy range from identification of information requirements of users to assessing workload to deciding on best information visualization techniques to ensure situation awareness is maintained in a remote control facility.

Addressing these challenges will require a systems engineering approach where user requirements are identified through a systematic approach for various contexts, including normal, abnormal, and accident conditions. A systems engineering process will integrate human factors as well as other specialty disciplines such as reliability and design optimization in a coherent fashion that would lead to realization of a successful system that addresses user requirements.

The licensing model in Canada is based upon a graded approach and is largely technology neutral. A key factor in ensuring effective licensing effort is identification of regulatory requirements. This paper discusses how adopting a systems engineering approach and early consideration of human factors principles and requirements will not only ensure an efficient design process, but will also help with developing a design that meets the regulatory requirements.

Key Words: Human Factors, System Engineering Process, Small Modular Reactor, Licensing

1 INTRODUCTION

There has been a growing interest in exploring alternative methods of producing nuclear energy with a focus on reducing capital investment and operational costs through development of small modular reactors (SMRs). A key driver of SMR development is the advantages offered by improved economies of scale where units can be prefabricated in a manufacturing plant. Greater reliance on inherent and passive safety, the smaller size of these reactors and their modern technology are also claimed to virtually eliminate the risk of accidents with significant off-site consequences.

There are, however, a number of challenges that need to be addressed; the most significant of which is the issue of licensing. Licensing requirements and regulations are historically developed for large reactors, preventing the simple deployment of several identical units in different countries [1]. This challenge is exacerbated by some of the complexities and uncertainties surrounding the proposed conceptual designs for SMRs.

Some of the supposedly advantageous features of these reactors also introduce significant human factors challenges. For instance, most of the proposed conceptual designs rely heavily on automation. Automation can theoretically eliminate the risk of human error during operation (there is still a risk of error during design, manufacturing, and commissioning). But by the same token, the system will be deprived of the ingenuity and flexibility of human problem solving.

The fundamental differences between SMRs and existing technologies means that the current body of knowledge in terms of applying human factors principles, and also with respect to licensing strategies and requirements, is not sufficient. Therefore, it is essential to ensure that the risks associated with various design concepts are evaluated in a structured and thorough fashion.

2 CHALLENGES FACING SMR VENDORS

2.1 Human Factors Challenges

Human factors has a long history in the nuclear industry which has led to establishment of robust procedures and guidelines. However, some of these guidelines and procedures for applying human factors may need to be adapted to address the differences between SMRs and existing plants.

Most of the current conceptual designs propose advanced and automated control and monitoring technologies which would require complex human system interfaces. This is part of the economic appeal of these technologies; they involve partial or full remote control of the facilities which could theoretically lead to reduction in number of staff. Moving towards a fully automated control room which is located remotely of the systems it intends to monitor and control requires establishment of a new concept of operations [2]. Establishing minimum staff complement may require a different approach to the current established methods used for larger plants [3]. Required competencies, skills, qualifications, and knowledge of staff that will interact with these complicated monitoring and control systems will need to be redefined. Automation can also negatively impact operator skills which could pose a threat if manual intervention is required during an emergency scenario [4]. Assessing workload also should consider issues of underload and how operators will be able to maintain situation awareness.

Another challenge is with respect to the design of the human system interfaces (HSIs). The conceptual designs often include software intensive and complex interfaces. While existing HF guidelines are sufficient for addressing changes to HSIs in current plants, there may be a need to develop new guidelines to address the requirements of the complicated and highly automated control systems proposed for SMRs. Identifying the correct information requirements to ensure that the passive task of monitoring the automated system is performed effectively will also require a systematic approach. Equally important are the design decisions about visualizations of this information; i.e., what information should be presented without operator initiative and what information should only be presented upon request, or how the information should be prioritized [4].

Human factors issues of managing an accident or a design extended condition are also considerable given the heavy reliance of the proposed concepts on automation. While there is a well-established and structured body of knowledge for large plants on strategies for dealing with different classes of accidents, SMR vendors have not reached the same level of maturity [3]. Therefore, identifying all accident scenarios through a structured method is essential for ensuring that effective barriers can be included in the design of the systems.

2.2 Licensing Challenges

Licensing a first of a kind SMR will be a significant endeavor for SMR vendors. It is clear that licensing SMRs is key to demonstrating their safety. It is also argued that through the licensing process in some jurisdictions, the regulator can assess the proposed design to enable investments that are in the best interest of the public [5]. Licensing is usually a lengthy and costly process that involves detailed analyses and reviews. In most cases, the licensing process is geared towards large reactors and plants. Sainati, et al. [1] identify the following challenges with respect to licensing SMRs:

- Typology of the licensing process: A prescriptive based approach (which is the licensing approach adopted by most countries) would require development of new codes and standards so that specific characteristics of the SMRs are covered. This requires considerable effort and investment from all stakeholders.
- Duration and predictability of the licensing process: The novel technological designs of the SMRs may prolong the licensing which is already a lengthy process.
- Regulatory harmonization: The differences between legal and institutional systems as well as various licensing structures in different countries will constrain standardization of SMRs which is a key feature to their economic appeal.
- Ad hoc legal and regulatory framework: While this approach may be of benefit to the SMR vendors, it requires an overhaul of the legal and regulatory framework.

These challenges further complicate the advancement of SMRs as a financially viable energy solution. Changes to the licensing process and requirements take time and require considerable effort on the part of the regulator. This is expected as the consequences of an unreliable licensing process are grave. In order to address these challenges, SMR vendors should explore alternative and innovative licensing approaches to optimize application of existing processes in the short term.

3 SYSTEMS ENGINEERING APPROACH

The various challenges described in this paper can be addressed through implementation of the systems engineering method known as the Systems Engineering Process (SEP). The SEP is the traditional deductive approach for translating stakeholder requirements into a set of technical design requirements and a preferred concept system configuration for systems that are first-of-kind, i.e., systems that are being developed from scratch without the benefit of an existing reference design.

The SEP applies "systems thinking", i.e., the system of interest is viewed as a black box and its desired behaviour is determined by examining its interactions with other systems in its environment. The desired behaviour determines a set of functions that has to be implemented by the logical and physical architectures of the system. The SEP is a top-down approach, that is first applied for the system or Structure, System, and Component (SSC) of interest (SOI) as a whole and then consecutively at each level of the system hierarchy for the SSCs that make up the system architecture (subsystems, assemblies, components, etc.). Figure 1 illustrates the main stages of this process which include:

- Stakeholder Requirements Identification, i.e. the determination of the need for the new system in operational terms;
- Stakeholder Requirements Analysis, i.e. analyzing and interpreting the need to identify constraints on possible solutions and the major stages and events in the system's life;
- Functional Analysis to determine the functions that the system should perform in order to meet the need;
- Allocation of Characteristics involves quantifying the identified functions where necessary by supplementing them with measurable performance characteristics to form complete design requirements;
- Synthesis involves assigning functions to parts of the system that will implement them and identifying the interfaces between these parts to form an architecture; and
- Optimization involves performing trade-off studies and cost-effectiveness analysis to select the best architecture.

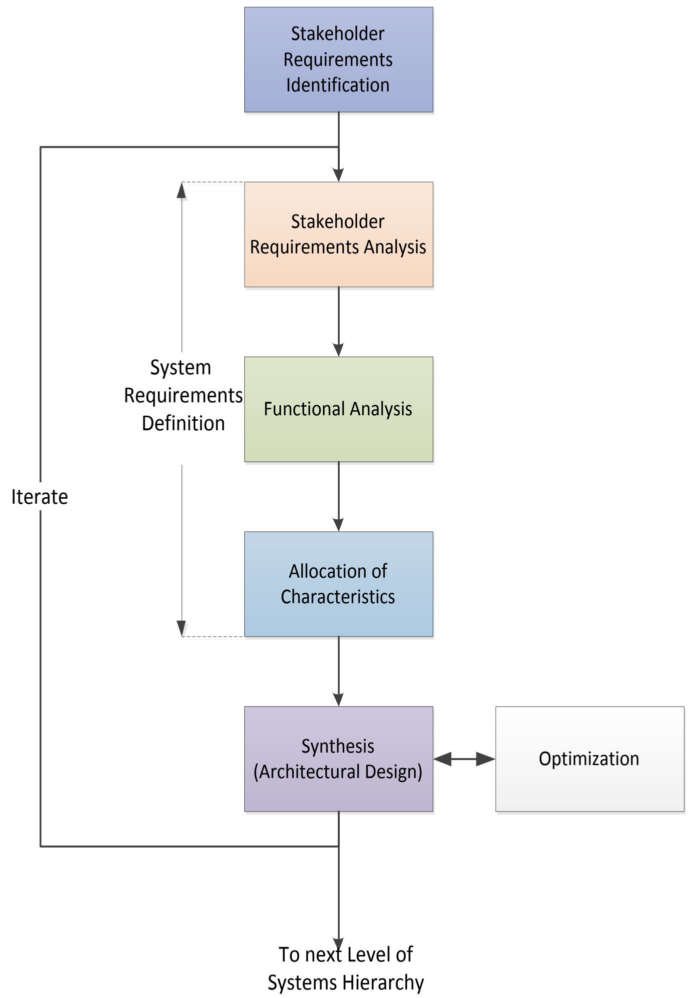

Figure 1 - Steps in the Systems Engineering Process

The Systems Engineering Process is a systematic approach: both in the sense of resulting in an integrated coherent whole and in the sense of being methodical in terms of a planned procedure. SEP provides the vendors with the necessary tools to address the issues associated with increased complexity of the technological design. Through detailed analyses of system requirements, the designers can ensure that increased complexity and performance expectations of the new systems are systematically considered. Focusing on the functions of the system as opposed to their implementation will enable vendors to objectively assess various design options before settling on a certain solution. Additionally, the technological complexity of SMRs means that very specialized experts will have to work and interact with other experts in larger design teams which could lead to potential miscommunication of design requirements. Through following a SEP approach, the vendors can structure the design process in a way that design decisions are made in the context of the overall requirements.

3.1 Addressing Human Factors and Licensing Challenges

Systems engineering is based on the following principles:

- A clear expression of the need for the new system in operational terms;
- A functional approach to the derivation of technical design requirements that are traceable to the need;
- Assigning the derived functions in various ways to technology that can be used to implement the functions leading to a number of alternative design concepts;
- Selection of the best alternative concept through trade-off studies and cost-effectiveness analysis; and
- A rigorous engineering management program comprising configuration management, design reviews, baseline management, testing and evaluation, etc., to ensure the design requirements are met during development of the detailed design.

Through implementing a systems engineering approach, SMR vendors can satisfy the requirements of the licensing process in an efficient manner. This process enables SMR vendors to adopt a more flexible approach to addressing licensing requirements without taking shortcuts by ensuring that:

- Regulatory requirements are identified early on during the conceptual design phase and are used to help shape the design;
- Alternative means for meeting the requirements are explored through a systematic review of available options; and
- A graded approach is adopted so that interpretation of requirements and uncertainties commensurate with the size of hazard.

More importantly, following a systems engineering approach facilitates process-based licensing which is technology neutral. This is in contrast to the prescriptive based approach which focuses on detailed technology driven standards. By adhering to key safety principles and focusing on the top-down technology neutral SEP, the regulator can assess licensability of the proposed designs at an early stage and provide valuable feedback to the vendor based on process rather than prescriptive standards.

Human factors by definition is concerned with understanding limitations and capabilities of humans and applying this understanding to design of systems to ensure safety and efficiency of operations. Systems engineering offers a functional perspective of the system that views the human as just another "technology". Therefore, similar to how other technologies are assessed and analyzed, systems engineering will ensure that factors affecting the performance of this technology; i.e., limitations and capabilities of humans, are taken into account in deriving design requirements. In other words, adopting a systems engineering process will automatically ensure effective consideration of human-centered design principles in the design process.

Additionally, the rigorous engineering management program which is an essential element of implementing the SEP will ensure that specialty disciplines such as human factors are integrated in the design process at the right time; i.e., during the conceptual design which would in turn address many of the traditional challenges faced by human factors practitioners.

4 CONCLUSIONS

Small modular reactors offer very exciting potentials to address the energy challenges faced by many nations and are particularly of interest as an efficient source of clean, safe energy. However, their advantages will not be realized if the regulators and more importantly the public are not convinced of their safety and reliability. A tested method to address the licensing challenges described in this paper is through following a Systems Engineering Approach as it offers a technology neutral functional based approach that facilitates effective and accurate identification and implementation of design requirements through a rigorous and systematic management system.

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