THE PRACTICAL ASPECTS OF INCORPORATING HUMAN FACTORS CONSIDERATIONS INTO DESIGN CHANGES AT NUCLEAR FACILITIES – A CONTRACTOR'S PERSPECTIVE

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Abstract

This paper describes, from a contractor's perspective, the practical aspects of incorporating Human Factors (HF) requirements into design changes at nuclear facilities. It is based on the experience of HF personnel at SNC-Lavalin Nuclear, the largest private nuclear engineering company in Canada, during several projects that required HF analysis based on CNSC and NUREG regulatory guidance (G-276, G-278, NUREG-0711).

The paper presents examples of practical considerations and challenges encountered, approaches taken, and lessons learned. By providing insight into the HF process within a contractor's organization, it helps other stakeholders better assess their role in expediting HF work in the future.

1. Introduction

The purpose of this paper is to describe, from a contractor's perspective, selected practical aspects of incorporating Human Factors (HF) requirements into design changes at nuclear facilities. These practical aspects pertain to not only the engineering and HF design considerations, but also, more importantly, to contractual, scheduling, and commercial issues, significant especially on large projects. The topic was chosen to share one contractor's experience, gained during several recently completed projects, with other members of the industry, in the hope that it will provide a starting point for combined efforts towards streamlining the HF design process in the future. This paper may also be of benefit to fledgling companies who may become involved in design work with an HF component as part of the New Build initiatives.

The paper is based on the experience of HF personnel at SNC-Lavalin Nuclear (SLN) during several large design modifications at nuclear power plants in Ontario. In the last 2 years, this included a Used Fuel Dry Storage project at Darlington (DUFDS), Auxiliary Power System and a D2O Storage Facility Modification project at Pickering (APS and D2O), and some 70 different engineering changes to the Balance of Plant design at Bruce A (BALP-BOP). In all 4 projects, SLN was a Contractor to Plant Owner, and two of the projects were project managed, on behalf of the Plant Owner, by a separate company acting as the project management contractor.

The DUFDS project entailed modifications required for underwater transfer of used fuel modules into Dry Storage Containers (DSC) and for preparing the DSC for on-site transfer to the new

Darlington Waste Management Facility. HF input was required to ensure that all the user interfaces and tools used during the transfer process supported safety and efficiency of operations.

The APS project involved an independent "Power Plant" located outside the protected area to supply portions of Class IV power in the event of a total loss of Class IV power across the Pickering site following a Loss of Bulk Electrical System (LOBES) event. The HF effort for this project was related to the MCR modifications including alarm and control of 4.16 kV breakers, and consisted of a design of a new APS control panel in the MCR.

The D2O project involved the installation of a system to store and transfer D2O, consisting of four storage tanks, piping, valves, instrumentation, and user interfaces required to monitor and control it. In total, there were over 180 components plus related signage in the field and the Upgrading Plant control room. The system operation was to be predominantly manual, with control room annunciation and pump shut down interlocks activating when abnormal conditions occur. Physical and cognitive ergonomic considerations were to be taken into account in the analysis of accessibility, usability and functionality of components that have user interfaces.

The BALP-BOP project consisted of more than 70 separate design scopes ranging from straightforward equipment replacements to more complex design improvements. Each scope required its own HF classification and the corresponding level of HF analysis and documentation. Scope descriptions generally pertained to one system or change but because of the interrelation of sub-systems in the power plant some cross-referencing at scope boundary points was necessary and added another dimension of complexity to the work.

The nature of HF work in all these projects varied from mostly ergonomic concerns to more complex analysis of the effects of a system design on operator cognition. It was heavily interdisciplinary and required the ability to quickly process information from a spectrum of specialties.

2. Overview of the HF regulatory framework

To provide proper context for the work described in this paper, below is a brief overview of the HF regulatory framework in the nuclear industry.

The process within which the HF activities take place is typically based on the 12 elements of the HF engineering program review model described in detail in NUREG-0711 (Human Factors Engineering Program Review Model), an internationally adopted guidance document. The 12 elements are illustrated in Figure 1. On the 4 SLN projects, several of these elements were outside the Contractor's scope of work: Staffing and Qualification, Human Reliability Analysis, Training Program Development, and Human Performance Monitoring.

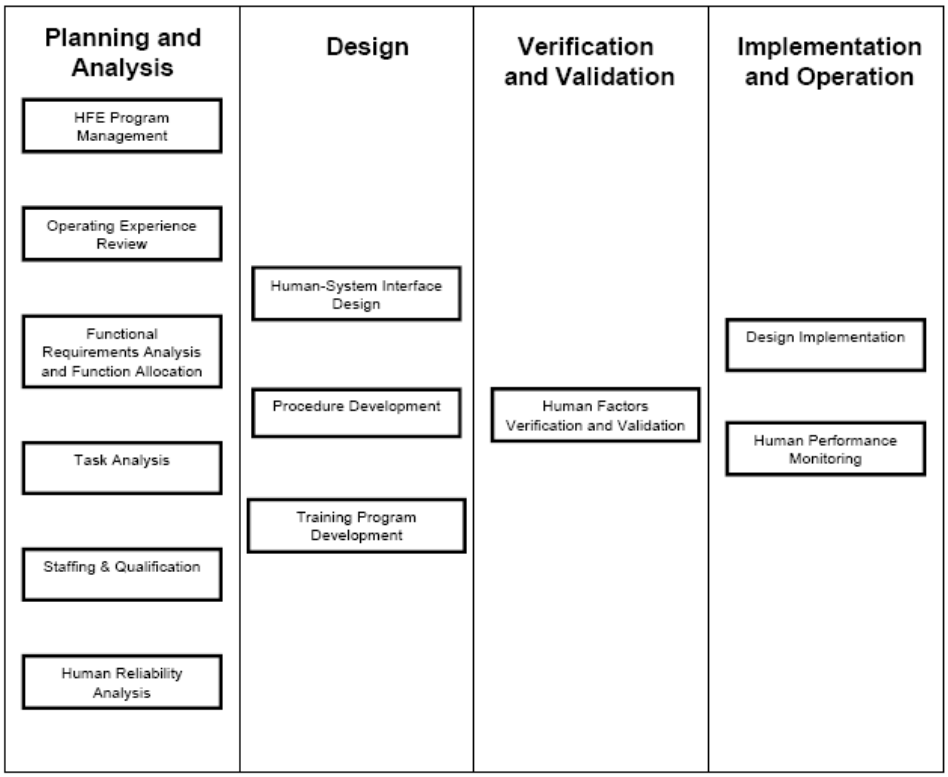

Figure 1 Elements of the HF Engineering Program Review Model

In addition to NUREG-0711, other documents that provide guidance for addressing the HF aspects of a design modification are CNSC Regulatory Guides G-276 (Human Factors Engineering Program Plans) and G-278 (Human Factors Verification and Validation Plans), and IEEE Standard 1023 (IEEE Recommended Practice for the Application of Human Factors Engineering to Systems, Equipment, and Facilities of Nuclear Power Generating Stations and Other Nuclear Facilities). Some of the most important expectations described therein include:

- Program plans should include methods to screen and prioritize HF involvement. Since the application of HF affects interrelated life cycle activities, HF should be considered as early as possible.

- Industry and facility operating and maintenance experience should be reviewed and lessons learned should be incorporated into proposed designs.

- Proposed design changes should consider HF impact and requirements. Engineering change control processes should include formal confirmation that HF considerations were addressed.

- For significant Human-Machine Interfaces (HMIs), the detailed activities performed by users to accomplish necessary tasks should be analyzed, and the requirements for successful task performance should be identified. Task analysis should consider the full range of plant conditions. Consideration should be given to how errors in performance may be avoided, and barriers should be applied to prevent errors with unacceptable consequences.

- In considering usability, the most practical source of information about equipment and its operation is often experienced users. Input from end users should be sought as early as possible, their concerns should be addressed, and the users should be asked to evaluate the acceptability of the proposed designs.

- Required documents such as technical manuals and procedures should be specified and prepared prior to operation.

- A method should be developed for recording, categorizing, tracking and responding to issues and recommendations that arise as a result of HF analyses.

- Traceable records of HF work performed on significant HMIs should be maintained.

3. Practical aspects of incorporating HF considerations into design changes

In order to satisfy the above requirements, there are a number of practical considerations that must be taken into account when developing a method of incorporating the HF activities into the overall design change process. These practical considerations relate to the determination of the amount of HF effort required on a given project, the inclusion of this work in the overall project schedule, the procurement-related aspects of HF requirements, and the communication of HF design input to other disciplines within an organization. Other significant factors include the coordination of the involvement of vendor's representatives and Subject Matter Experts from power plant Operations, the logistics of performing Function and Task Analysis, and the method of handling scope changes arising from HF work.

For each of these topic areas, an attempt is made to present both the main challenge and the lessons learned and recommendations for the future. Some of this information and the nature of the HF-related processes may be unique to SLN and its specific projects, but most of it is likely relevant to other companies as well. Sharing this insight should help other stakeholders better assess their role in expediting HF work on new projects.

3.1 Determination of the amount of HF effort

Classifying the amount of HF effort into the Minor or Major category is a preliminary step to the Human Factors assessment process. The purpose of the classification is twofold: to assist in defining an approach to the analysis and in determining the type of documentation required to satisfy regulatory standards. It establishes to what extent and to what level of rigor a scope of work will be examined from an HF perspective.

There are several possible situations where the classification of HF effort may become challenging.

- The first is when a Request for Proposal or the Contract document is not specific enough about the Client's expectations with respect to HF and it does not identify the types of HMIs

involved, the regulatory standards to be followed, and the type of documentation and deliverables that will be required. There is then no context provided by the Client for the Contractor to define and classify the HF work up-front, and this leads to inefficiencies and delays in the overall design. In some cases, even though the HF component may not be explicitly mentioned in the Contract document, the HF work may require hundreds of hours to complete, but this is not known until the screening and evaluation by an HF Specialist takes place.

- The second arises when a scope of work changes as the project progresses and as new HF related information presents itself throughout the duration of the project. On larger projects, this is to some extent inevitable as it takes some time for all disciplines to acquire a good grasp of what a particular scope of work will demand. It is then quite possible that as more design details are developed, the HF scope of work will also expand.

- A third possibility is that HF misclassification occurs because the available information is not properly communicated between different disciplines, typically, between the design engineers and the HF personnel. This type of poor communication prolongs analysis and creates more change related paperwork. As a result, HF experts are diverted from completing analysis and are instead occupied by administrative tasks involving additional paperwork. It is a well known fact that the engineering work in the nuclear industry is heavily documented, and revising the paperwork can become very time consuming.

One of the most effective ways of ensuring that there is the required understanding of the HF process within an organization is through training. Proper training can not only educate representatives of other disciplines about the field of HF, but it should also ensure their support of and proactive participation in the entire HF process from screening through analysis to the HF design validation.

To avoid the three sorts of challenging situations described above, this training should cater to two types of audiences: the management staff involved in contract preparation and contractual negotiations, and the various engineering disciplines involved in the detailed design work. It may take the form of sporadic presentations, lunch-and-learn sessions, or courses, depending on the needs of the organization. Periodic refresher training may be needed due to staff changes.

Explaining the HF regulatory requirements and processes to the management personnel will help them to better define HF expectations within the contract documents. It may also result in stronger support for HF work in general. Explaining the HF review and analysis process to Design Engineers will enable them to expedite the correct classification of HF by clearly identifying the HMIs involved in the design work.

In addition to training, another way of resolving initial difficulties associated with categorizing the amount of HF effort required for a particular project is to organize a separate meeting dedicated to clarifying the HF scope. This meeting should be attended by all the affected stakeholders from the Client organization, including HF specialists, management representatives, and technical and operations staff familiar with the details of the requested modification.

Once it is known whether the modification is Minor or Major, the HF Specialist should prepare as detailed a plan of all anticipated HF activities as possible, and then ensure that they are well integrated into the overall project schedule. This should include the identification of HF deliverables and milestones and their inter-dependences with other engineering activities. Even though on a large project the schedule is typically a living document so some adjustments to it throughout the design process are to be expected, it is nevertheless extremely important to specify the required HF items up-front. This not only ensures the recognition of the HF component of the overall design effort, but also facilitates the HF work and its smooth integration with the work of other disciplines as the design evolves.

3.2 Including HF aspects in procurement

For a successful integration of HF into the overall schedule of a large project, it is also necessary to incorporate HF requirements into procurement-related activities. This includes the preparation of Technical Specifications, Engineering Quotation Requests (EQR), and Purchase Orders (PO).

In order for this process to be effective, most of the HF analysis and design work should be completed before Technical Specifications and EQRs are prepared, or at the latest before the PO is issued to a third party, i.e., the vendor organization. Having completed the function and task analysis and the HMI design, and having validated the design with end users would enable the Contractor to include in these documents a detailed description of the HF requirements. However, due to the iterative nature of HF work this is in many cases quite challenging. In practice, some aspects of the HF work cannot be completed without information from the vendor, and the vendor cannot finalize the design before the HF analysis is complete.

One possible solution to this problem is to include in the Technical Specifications only the list of relevant HF design guidelines, alerting the vendor to the need of accommodating HF requirements in the design. Another is to stipulate in the PO that the vendor is to assist the Contractor and the Client's representatives in completing the HF analysis and HMI design. These two approaches or their combination need to be tailored to the unique characteristics of each individual project as the nature of the vendor's role in the design process can vary greatly between different projects. For instance, it may be the entire design of the software and hardware for a given system, including the HMI, or only the supply of individual HMI elements such as push-buttons or valves. The vendor may also be requested to customize an existing design.

In many cases, it may not only be necessary for the HF Specialist to provide input to documents such as Technical Specifications, EQRs and POs, but to also become directly involved in the bid evaluation or component selection process. The presence of the HF Specialist during internal and external procurement-related meetings can potentially expedite the selection process since the HF Specialist is usually the best person to accurately communicate and explain HF concerns.

In some situations, it may be possible for HF to instruct the procurement department what the standard HF concerns are, such as those covering the bulk components for a particular project. A good example of this is the HF preferred HMIs on manually operated valves. By using HF concerns as an additional decision variable in the procurement process, the number of acceptable choices can be quickly narrowed down.

Another factor to consider with respect to procurement is that the HF regulatory requirements in the nuclear industry are more stringent than those commonly used in other industries, so it may be very difficult for the vendor's representative to demonstrate that their products comply with certain HF guidelines since they simply do not have the required technical information. This might be the case with the force required to activate a push-button, or with push/pull force limits for moving heavy equipment given a specific coefficient of friction. The Contractor must be prepared for such occurrences, but this is generally dealt with on a case by case basis by the HF Specialist using professional expertise and discretion to decide how to address or disposition the issue.

3.3 Communicating with other Design Engineers as the design evolves

Since many large projects in the nuclear industry require the simultaneous involvement of several different engineering disciplines and the HF analysis and design process is iterative in nature, this can lead to communication problems and scheduling conflicts with other disciplines. The following situations are likely to arise:

- HF may rely on the discipline engineer for information required to complete HF analysis but not necessary to complete some levels of his or her own design work. A difficulty arises when deliverable dates for HF and another discipline align but the time for processing acquired information needed to produce these deliverables does not. It is also possible that information needed for completing the HF analysis will only become available when some design work has already taken place.

- HF analysis usually results in design recommendations that are addressed through dispositions that are iteratively presented to system users. Including iterations of recommendations into design work can become quite complicated when coordinating with other engineering design deliverables.

Therefore, it is necessary to establish an effective way of communicating and exchanging information between HF and the other technical staff within an organization. This may take the form of file sharing, including HF on cc lists for other design-related correspondence, clearly identifying who has what type of expertise and decision-making authority, and organizing regular meetings to address HF issues.

Sharing files using a common and well organized data depository, and being part of Design Engineers' cc lists, are excellent ways for the HF personnel to have direct access to information gathered by the other engineers. These tactics give the HF Specialist an opportunity to use his or her expertise to search large amounts of information and decide what may have potential HF value without having to request it directly from the Design Engineer. Because of the analytical nature of the HF process, the HF specialist requires access to a broad range of design information before he or she can formulate useful design input or pose concise questions to other engineers.

Identifying who within the organization has what type of expertise, what is the HF Specialist's role and mandate, and who has the decision-making authority with respect to HF issues is

essential for addressing situations where a Design Engineer may not concur with a recommendation proposed by the HF Specialist. It is necessary to develop a clear methodology for resolving such disputes including, if necessary, a suitable escalation process.

Organizing regular HF meetings is a good way of allowing the HF personnel to communicate their needs to other engineers and to include them in the HF process. It also encourages the Design Engineers to address HF concerns that may arise between meetings and to prepare any questions they may have for the HF Specialist. It is a very practical way of ensuring that all affected personnel are kept up-to-date on all the relevant design developments resulting from the iterative review with end users and other stakeholders.

3.4 Coordinating the HF work with input from End Users and Vendor's representatives

In addition to internal communications with other Design Engineers, another challenge is the coordination of the work of the HF Specialist and Design Engineers with input received from end users, and then the communication of the resulting design information to the vendor.

The first task is usually to identify the correct end users who will be most knowledgeable in the system being modified and to request their participation in the design process. These end users are typically Operations and Maintenance staff who work on shift and it is not easy to relieve them from their normal duties at the plant. In some cases, input from Client System Engineers or other technical staff may also be required. Once the appropriate representatives of the end user population are made available, the design organization is under great pressure to make effective use of their time. This may be difficult in practice since their input and feedback is usually needed on an ongoing basis as the design evolves.

The second task is to develop an effective way of relaying user feedback to the vendor and then the vendor's response regarding the feasibility of certain design options back to the design organization. In doing so, one has to keep in mind several factors: the different locations of the three parties (the design organization, end users, and the vendor), security issues related to electronic exchange of information, the need to allow for travel time, if required, and all the associated commercial aspects.

It is important to streamline the activities involving end users and vendor's representatives as much as possible through proper planning. For instance, the HF Specialist may request the Client to schedule user interviews well in advance to ensure that there is enough time to make all the necessary arrangements. During all communications with end users, it is also important to keep in mind that some concerns or suggestions made during such reviews may be beyond the scope of work of a given project. The HF Specialist must always assess end user input against the established design intent of a particular modification.

3.5 Performing and documenting Function and Task Analysis

One of the essential elements of HF effort during a design project is the Function and Task Analysis.

On a project that involves a number of different companies and engineering disciplines, performing and documenting the Task Analysis can require a substantial amount of effort. It is often relatively easy to develop a preliminary task list, but it is much more difficult to perform the actual analysis.

The ideal approach is to derive feedback from live analyses of tasks in conjunction with engineering input, after the preliminary step of investigating procedural documentation. However, this is rarely feasible in an operating Power Plant or on a system that has not yet been built.

In practice, it is usually necessary for the HF Specialist to:

- understand the various engineering design aspects of the system being modified
- obtain and review operating and maintenance manuals and user guides for the existing and new system, if available
- analyze the above in detail with input from end users
- based on input from end users, understand the existing practices related to the particular system, keeping in mind that they may deviate from written manuals and guides
- identify the required procedural or design changes and translate them into specific recommendations
- discuss the feasibility of specific recommendations with other Design Engineers and in some cases vendor's representatives

These activities rely on the analysis of procedures and manuals available either at the power plant or from the vendor in the case of new components. Early review of this material allows the HF Specialist to understand the system and formulate the questions for the users. The best way to expedite this process is for the Client to provide HF with the required documents at the beginning of the project.

It is important for the HF Specialist performing the Function and Task Analysis to know the difference between what is in documentation vs. what is carried out in practice in the field. Hence, it is best for the operating documentation to come directly from the actual users rather than from other groups outside Operations. The end users will be able to provide the latest marked-up manuals including changes that are legitimate but not yet formalized. The actual users are also better able to specify what sections are applicable to a given system or design.

In addition to documentation, the Contractor may also require feedback from users, Design Engineers and Client System Engineers to ensure that the task analysis is comprehensive. While end users have a practical, experience-based understanding of the system operation, the Engineers have the required knowledge of its internal logic and structure. It is the HF Specialist's role to lead everyone through the process and to bridge the gap between the two groups while

ensuring that HF concerns are addressed. This is best done in an open discussion during a meeting with all the attendees.

3.6 Addressing scope and schedule changes arising from HF analysis

During the design process, HF analysis or feedback received from end users may indicate that the original design based on the contract agreement must be enhanced in order to address specific HF requirements. This usually occurs as a result of operating experience reviews, Task Analysis and detailed HMI development, user interviews, and formal validation exercises. Such changes may have important commercial and schedule implications that have to be reconciled through scope change requests. Therefore, throughout the HF analysis process, the HF Specialist must keep track of all the HF-related deviations from the original contract document, and must be able to explain the HF requirements using common engineering terminology.

A question can arise as to whose responsibility should it be to pay for such changes: is it the Contractor's since that company is ultimately responsible for providing a design that is sound from both the technical and HF point of view, or is it the Client's since the design description provided in the contract did not include all the features required to accommodate the end users needs. It is very important to develop an effective method of addressing such situations and distinguishing between the cost of performing the HF analysis and the cost of scope changes introduced as a result of this analysis. It is advisable to resolve this at the beginning of the project when preparing the Human Factors Engineering Program Plan.

For small changes from the original scope, such as an extra display or instrument on a control panel, it may be possible to discuss with the client each individual change separately. But for more complex designs, a different approach is needed. One possible solution is for the Contractor to develop several different design options, one reflecting only the contractual obligations and the other(s) addressing the additional HF requirements. The different designs, together with a summary of the advantages and disadvantages of each option, are then presented to the Client, and it is the Client's role to make the final decision on which option to implement.

4. Summary

Figure 2 is a graphical overview of the most important HF considerations and challenges described in this paper, shown in relation to the main stages of the overall design process. It provides an outline of a realistic approach to streamlining the HF activities within the constraints of a typical design project.

STAGES OF A DESIGN PROJECT		PRACTICAL HF CONSIDERATIONS AND CHALLENGES
Contract Award / Scope Review Walkdown / Kick-off Meeting	**Planning**	Determine the amount of HF effort - clarify Client's expectations / screen as Minor or Major - organize training to educate others about the HF process - prepare an HF program plan and integrate HF activities into the overall project schedule - establish a method of addressing potential scope / schedule changes due to HF requirements
Engineering Plan		Prepare for detailed design by establishing effective communications with other technical staff: - file/information sharing - clarification of HF mandate and decision-making authority - regular meetings to address HF issues Conduct Operating Experience Review
Conceptual Design Technical Specification / Engineering Quotation Request Bid Evaluation Process Purchase Order	**Preliminary Analysis and Procurement**	Ideally, complete all remaining HF analysis, design, verification and validation before issuing the Purchase Order In practice: ensure that Procurement / Purchase Order account for HF by: - including in the Technical Specification relevant HF guidelines / requirements - requesting in the Purchase Order vendor's assistance during detailed HF analysis and design - involving the HF Specialist in the bid evaluation / component selection process
Detailed Design Internal Review External Review Final Submission to the Client	**Detailed Design**	Coordinate the HF design work with input from end users and vendor - identify the correct end users - streamline the exchange of information between end users, designers, and vendor Perform Function and Task Analysis - obtain operating and maintenance manuals - consider all practical aspects, including actual field practices Perform Verification and Validation of the HMI design Document all HF work
Installation Commissioning	**Implementation**	Ensure that "as-built" HMI conforms to documented and validated design

Figure 2 Overview of the HF Considerations and Challenges

Most of the practical considerations of incorporating HF requirements into design changes relate to the iterative nature of HF analyses, the complexity of administrative arrangements on many large projects, and the need to better educate other industry stakeholders about the HF discipline and its significance for the safe and effective operation of power plants.

It is hoped that sharing the recent experiences of one Company during several nuclear design projects and offering insight into the HF processes within a Contractor’s organization will promote more proactive participation of other industry members in expediting the HF process in the future.