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Human Factors Considerations in the Transfer and Storage of Liquid Nuclear Waste at Chalk River Laboratories

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ABSTRACT

This paper describes Human Factors issues associated with the design and operation of waste management facilities with a focus on the design of Chalk River Laboratories Liquid Waste Transfer and Storage project. Although these issues pose challenges to the project, the paper briefly describes how some of the Human Factors engineering tools used successfully in the power plant domain may also be used in the effective analyses, design, and review of a waste management system.

1. INTRODUCTION

The Chalk River Laboratories (CRL) site has a number of aging radioactive waste storage systems that are approaching the end of their useful life. The CRL Liquid Waste Transfer and Storage (LWTS) project aims to consolidate liquid wastes presently in tanks constructed prior to 1980 into a new storage system that meets current standards for design, construction, and operations. In addition, some waste such as the high-level medical isotope production waste must be conditioned in order to reduce criticality constraints, monitoring requirements and to meet regulatory commitments. Finally, the consolidation of the waste into one facility helps reduce operating costs and future liabilities.

A Human Factors Engineering Program Plan (HFEPP) was developed to incorporate Human Factors design considerations throughout all aspects of the LWTS project. This paper describes this program model and identifies some of the key Human Factors considerations associated with the design of LWTS, which include:

1) Establishing the operational basis,
2) Designing for radiation protection limitations, and
3) Managing the complexity of multiple control interfaces.

2. DEVELOPMENT OF A HUMAN FACTORS PROGRAM

The Canadian Nuclear Safety Commission (CNSC) P-119[1], Policy on Human Factors, mandates the consideration of Human Factors issues into the design and operation of any nuclear related facilities or systems. The CNSC allows for some flexibility of how a project may deliver a comprehensive Human Factors program and provides guidance of such programs in G-276, Human Factors Engineering Program Plans[2]. The LWTS project adopted a strategy for applying Human Factors program plan based on the U.S. Nuclear Regulatory Commission Human Factors Program Review Model, NUREG-0711[3]. The elements of the model and how the project addresses the element are presented in Table 1.

Table 1 Map of NUREG –0711 HFE Elements to LWTS Activities

NUREG-0711 HFE Design Element	Design Component	LWTS Activity
Element 1: HFE Program Management	Planning	Developed a Human Factors Engineering Program Plan specifically for the LWTS project.
Element 2: Operating Experience Review (OER)	Information Gathering: Operations & Maintenance Systems Interface Experience	Performed an extensive review of the similar systems in North America and compiled the issues within several assessment and safety analysis documents.
Element 3: Function Requirement Analysis and Function Allocation	Analysis of plant/system control requirements and assignment of control/monitoring functions to various levels of automation.	Initiated a Functional Analysis for the entire project, which led to identification of information requirements in the operation of multiple interfacing work sites. The preliminary functional analysis will be an input to detailed design.
Element 4: Task Analysis	Review of operator/maintainer performance expectations and adequacy of Human System Interface design (e.g., layout and design of displays, controls, and annunciations). Review of any operational/maintenance occupational Health & Safety Concerns (e.g., radiation exposure, awkward motion, accessibility, lifting, etc.).	Established a requirement for Task Analysis that will be integrated with the CRL's job analysis protocol.
Element 5: Staffing	Review of staff requirements and assigned responsibilities to ensure system design is compatible with operations/maintenance model.	Established the lines of authority for operation and the staffing roles and responsibilities in the Operational Basis.
Element 6: Human Reliability Analysis (Safety Analysis and Risk Assessment)	The operational/maintenance design of the system will factor in the impact of design changes on the system safety analysis.	The project performed an extensive Hazards Analysis that compiled issues and concerns with respect to the safety of the design. The resolution of such issues will be an input to the detailed design.
Element 7: Interface Design	Covers three areas: HSI Displays & Controls Design (e.g., functionality, alternative device evaluation, labelling, mimics, layout design, scale range/type, etc.), Annunciation, and Design for Maintenance (e.g., design for accessibility of maintainer/tools, ease of maintenance tasks, adequate lighting).	Developed two design guides that outline the application of Human Factors principles to the design of control and display interfaces as well as spatial and anthropometric limitations.

NUREG-0711 HFE Design Element	Design Component	LWTS Activity
Elements 8 & 9: Procedure and Training Program Development	Development of Operating Procedures and Training Program	Established a requirement to develop operating procedures and training programs using the Systematic Approach to Training methodology employed throughout the CRL site.
Element 10a: Design Verification	Confirmation that Human Factors aspects of the design (e.g., display/control/annunciation interface, accessibility, lighting, function allocation, layout, etc.) meet design requirements/ guidelines to the extent practical and assurance that any Human Factors Engineering design aspects with potential operations, maintenance, or safety implications are justified and appropriately documented.	Established a requirement to verify the final design to the Human Factors design practices outlined by the guidance documents. A requirement was also established to integrate Human Factors validation into the final testing and acceptance of the final design.
Element 10b: Design Validation	Confirmation that the sub-systems design and the LWTS system design as an integrated whole, meets the overall performance objectives of the system.	

3. ESTABLISHING THE OPERATIONAL BASIS

The field of Human Factors is often dominated by issues and human errors associated with Human System Interface (HSI) design, but as described in P-119, Human Factors encompasses a broader scope, which includes establishing organizational and management structures, policies and programs, and staffing provisions. The LWTS project addresses these factors early in the design phase through the development of an operational basis. The operational basis outlines the operational principles and practices governing the operation of LWTS systems. Outlining the operational strategies and identifying the responsible groups on site proved to be a challenge for a number of reasons. Firstly, the historic waste is generated from different processes and therefore under the responsibility of different Facility Authorizations. The Facility Authorization sets out the key requirements, conditions, and limits for the safe operation of the facility, in accordance with the site license. As the various types of waste are consolidated in the new Waste Storage System (WSS), the boundary between different presiding authorities becomes obscure. This was particularly the case in the transfer of fissile material from the Molybdenum 99 Production Facility (MPF) to the new storage system. The new storage system is under the supervision of the existing Waste Treatment Centre (WTC) Facility Authorization. The operating basis must outline the safe conditions (based on he expertise and knowledge of the waste properties and management) for the MPF to relinquish responsibility of this waste to the WTC Facility Authority.

Secondly, the operational basis helped to identify that the methods for transferring the waste to the WSS, also highlights some organizational concerns. Figure 1 illustrates the different transfer methods for the various wastes. While waste is in transit outside the tanks and outside of the existing Facility Authorizations, the operational basis development helped define what operational body is responsible during unplanned events. In the case of the pipeline transfers, the responsibility of the waste rests on the organization that governs the facility from which waste originated. With the exception of the fissile material, all the historic waste transferred by pipeline is under the WTC Facility Authorization. The WTC Facility Authority must collaborate with the Nuclear Materials Management Team (NMMT), the Safety, Environment, and Radiological Protection (SERP) group, and the Emergency Preparedness group at site to address unplanned events associated with waste that must be transported by a cask and liner from a location that is 3 km away from the WSS. Dotted boxes in Figure 1 identify the areas where the WTC does not govern the handling and storage of the waste.

Finally, the different properties of the waste require different operating principles during various phases of LWTS operation. Operations surrounding LWTS can be characterized by four main operations: waste retrieval, transfer, storage and on-going monitoring. At various points during these operations, different external bodies must be involved to witness a crucial operation.

Identifying the various operational and organizational bodies through the operational basis highlights a need for a well-managed communication scheme in order to exchange important information during normal, abnormal, and emergency LWTS operations. Once the operational framework is established, the facility and equipment physical design should dovetail with the planned operation of the waste management systems. Major considerations in the physical design include the radiation protection limitations imposed and the complexity resulting from multiple control interfaces.

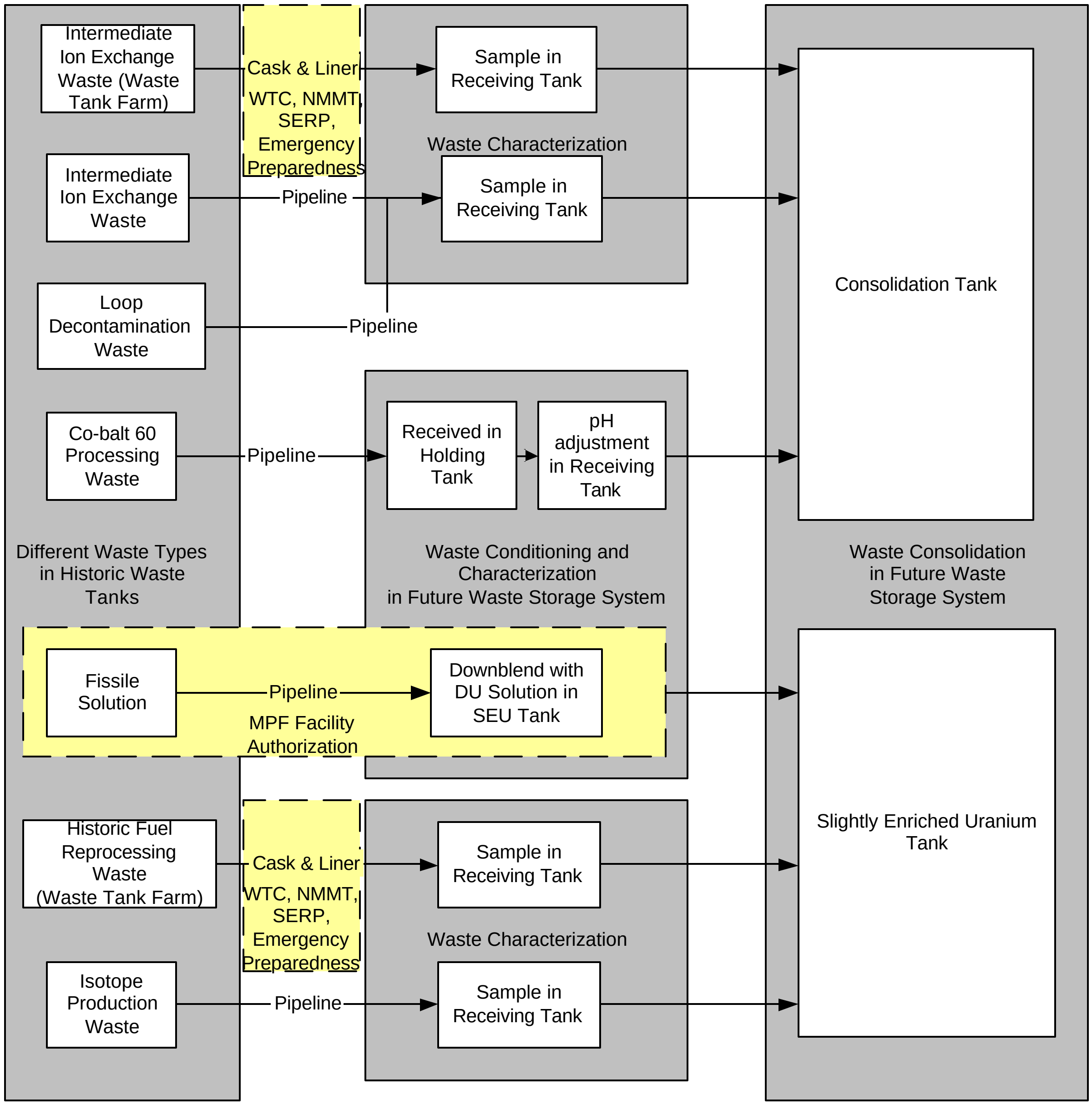

Figure 1 Waste Transfer, Conditioning, Characterization and Consolidation

4. DESIGNING FOR RADIATION PROTECTION LIMITATIONS

As with work done at the face of a nuclear reactor, the design of the WSS building must accommodate workers in radiation protection equipment by taking into account increased spatial, visual, auditory, and instrument handling constraints. Unlike work in a Reactor Building vault where work done on a platform is in a very open environment, the new storage building is characterized by smaller spaces around process tanks and above storage tanks, pumps, and other permanent and temporary structures. To mitigate hazards associated with loose contamination, the confined spaces must be sized for manoeuvrability with protective gear, breathing air apparatus, and all the tools that may be required to perform operations or maintenance work. The minimum accessibility recommendations were developed through the adaptation of U.S. military standards for artic clothing to fit the current work situation. Structural barriers must also be incorporated into the design to ensure sufficient shielding for the workers, and ventilated confinement of radioactive contamination.

The radiation protection requirements are not limited to indoor environments where the conditions are usually consistent, but also apply to outdoor field-work involving access to tanks during retrieval and transfer of the waste. In such work environments, the fluctuating temperature and humidity (particularly in the summer months) can have a negative effect on human performance. Therefore, guidance on these work constraints must be identified upfront and either designed out or procedurally controlled through minimizing the time outdoors. CRL has adopted American Conference of Governmental Industrial Hygienists (ACGIH) TLV (Threshold Limit Values) WBGT (wet bulb globe temperature[1]) as a guideline for evaluating and controlling heat stress situations.

The radiation protection requirements also have an impact on the interface design. Primarily, displays must be designed to take into account the difficulties associated with viewing items through a plexiglass front. Important information must have appropriate visual resolution and must be salient (through the use of colour, movement, size, and shape) to minimize the time required to perform the work and thereby decrease potential radiation dose. Controls must be designed to accommodate gloved hands and preclude accidental operation. An example of where all these factors come into play would be the ergonomic design of the glove box used for acquiring samples of the waste from process and storage tanks at the WSS.

5. MANAGING THE COMPLEXITY OF MULTIPLE CONTROL INTERFACES

The multiple control interfaces for different transfer and storage locations increases the complexity of design. The LWTS operations involves the following different control and instrumentation interfaces:

1) Five different waste retrieval sites
2) The retrieval and transfer equipment in the field
3) The Waste Storage System Control Room
4) Potential field panels in the Waste Storage System Building
5) Potential LWTS alarms in the Waste Treatment Centre Building[2]

[1] WBGT value is a measure of the environmental heat stress factors and is quite different from the dry air temperature as measured by a thermometer.
[2] The expectation is that the Waste Storage System building will only be periodically patrolled during long-term storage of the waste.

During the retrieval and transfer process, which will be the most complex in terms of operational organization the interlocks and handshaking signals must be in place at both the retrieval site and in the WSS control room to protect the interfacing systems and subsystems from potential damage, to protect personnel and to ensure the integrity of waste confinement. In some cases, the need to duplicate certain controls or indications at multiple locations was highlighted as desirable but still to be determined during detailed design. Such information and control requirements were determined through the development of a preliminary Functional Analysis of the entire LWTS system, which will be provided to contractors as input to completing detailed design.

From a design perspective, trying to maintain consistency on the various interfaces proved challenging as some of the control systems were developed in different eras of technology using design standards and for the new equipment coming from different contractors. The LWTS project addresses the design of new equipment by developing design guides that encompass the best practices used throughout the site or in industry standards and best incorporates established Human Factors principles and practices.

6. CONCLUSION

The LWTS project is moving towards detailed design and will require further Human Factors analysis and assessment. It has been shown that the Human Factors program plans used in the power plant industry can be successfully adapted to address the unique issues in waste management facilities. In particular, managing the difficulties associated with the project can be minimized when the designers recognize the importance of establishing an operational framework upfront, the constraints imposed by radiation protection requirements, and the issues associated with multiple control interfaces.

ACKNOWLEDGEMENT

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REFERENCES

[1] Canadian Nuclear Safety Commission, "Policy on Human Factors", P-119. October (2000)

[2] Canadian Nuclear Safety Commission, "Human Factors Engineering Program Plans", G-276. June (2003)

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