Human Factors Integration for a Nuclear Waste Management Facility – a success story

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SUMMARY

This paper outlines the Human Factors (HF) integration work that was undertaken at a Sellafield Limited (SL) nuclear waste management facility in the north of the UK. The project consisted of the design and build of a new facility to store Intermediate Level Waste (ILW). The work was delivered by HF specialists at Risktec Solutions Ltd (Risktec) and involved multiple HF activities. A local operability review is presented as a case study that considered the environmental aspects of the new facility. This paper demonstrates the importance and impact of HF integration on a large-scale project.

KEYWORDS

Nuclear waste, Human Factors integration, Human Factors assessment, nuclear safety case

Introduction

The Sellafield site opened in 1947 and led the development of the UK's nuclear industry, from the production of plutonium for the nuclear deterrent programme, through to the development of nuclear power generation. Since 2003, electricity is no longer generated at the site, and the focus is now on the remediation and clean-up of the hundreds of nuclear and non-nuclear facilities across the site. The clean-up activities include the safe and secure storage of special nuclear materials, and retrieval of nuclear waste from the legacy ponds and silos, for storage in modern facilities (ONR, 2023). The site is regulated by the Office for Nuclear Regulation (ONR) and owned by the Nuclear Decommissioning Authority (NDA).

Risktec was approached by SL who were designing and building a new waste management facility to store ILW. The facility consists of concrete storage vaults, heavy mechanical handling equipment and high integrity building services and it connects to existing waste management facilities on the site. The ILW facility is important to SL as it contributes to both long term nuclear safety and strategic hazard remediation.

There had been continuous Suitably Qualified and Experienced Persons (SQEP) HF presence throughout this project since the commencement of its detailed design stage in 2016. Risktec HF specialists joined the SL SQEP HF team towards the end of 2020, with work starting in earnest in quarter one of 2021 and technical output was produced up until the middle of 2023. Risktec's work consisted of providing HF integration to the nuclear site safety case during the Pre-Active Commissioning Safety Report (PACSR) stage of the project for the ILW facility. Up to the plant entering early active operations at the end of 2023, Risktec provided oversight and input to the closure of HF issues raised during previous project stages.

This paper provides an overview of the HF integration achieved by Risktec and SL, and uses examples of HF analysis, review, and HF issue management to illustrate the achievements.

Facility Overview

The ILW is transported in packages on a road transporter through either the import facility or through an underground transfer tunnel from another on-site facility. The waste container held inside the package is then transferred into a concrete vault for long-term storage. The facility consists of several key areas, namely:

1. Road bay – where a transporter brings in the Waste Package (WP).
2. Import facility – a crane is used to lift the WP from the transporter in the road bay into the import facility.
3. Lid lift cell – the package lid is unbolted, and the WP is moved into a shielded room using a bogie, where the lid is removed.
4. Transfer cell – the operator then moves the bogie holding the WP through a second shield door into a room where the Waste Container (WC) is removed from the package using a crane.
5. Storage vault – This crane is then used to move the WC into a storage position in the vault to be stored safely.

Plant operations are a combination of local manual activities along with remote operations from a central control room. Maintenance and breakdown recovery activities are facilitated through controlled access into crane and bogie maintenance areas and workshops, as well as a restricted area within the import facility to provide access to the lid lift cell and transfer cell should that be required for routine or abnormal maintenance activities.

Human Factors Integration Process

The facility design aimed to avoid human activities which may result in significant safety consequences. The focus was on the avoidance of nuclear exposure. HF specialists developed a proportionate work scope to define, implement, and test the operator role, based on the potential consequences from certain operations and the reliance on the operator to achieve safety functions.

Prior to Risktec's involvement, a HF scope of work and strategy had been produced for the design, construction, installation, and commissioning phases of the project. They identified which areas of the facility required HF support, driven by the potential operator contribution to risk. They outlined a method of HF screening and categorisation that was used to develop the scope of the HF activities, proportionate to the risk, complexity, and consequences in accordance with internal SL guidance.

HF integration across the engineering design and safety case of the ILW facility ensured that:

- The design adhered to Sellafield Ltd Supporting Practices (SLSP) and Engineering Guidance (EG) to deliver a design that minimised the potential for human error and optimised human performance.
- The role of the operator was systematically defined, implemented, and tested to ensure that systems and equipment were operable and provided assurance that operational claims were reliably achieved.
- The design met the needs of operators and accommodated for human psychological and physical characteristics.

Human Factors Route Map

Figure 1 shows the route map, developed by SL and Risktec HF specialists, which demonstrates the inputs and outputs to the HF activities required to deliver a comprehensive suite of design, safety and operational support activities that follows SL HF technical methods, and utilised SL EG.

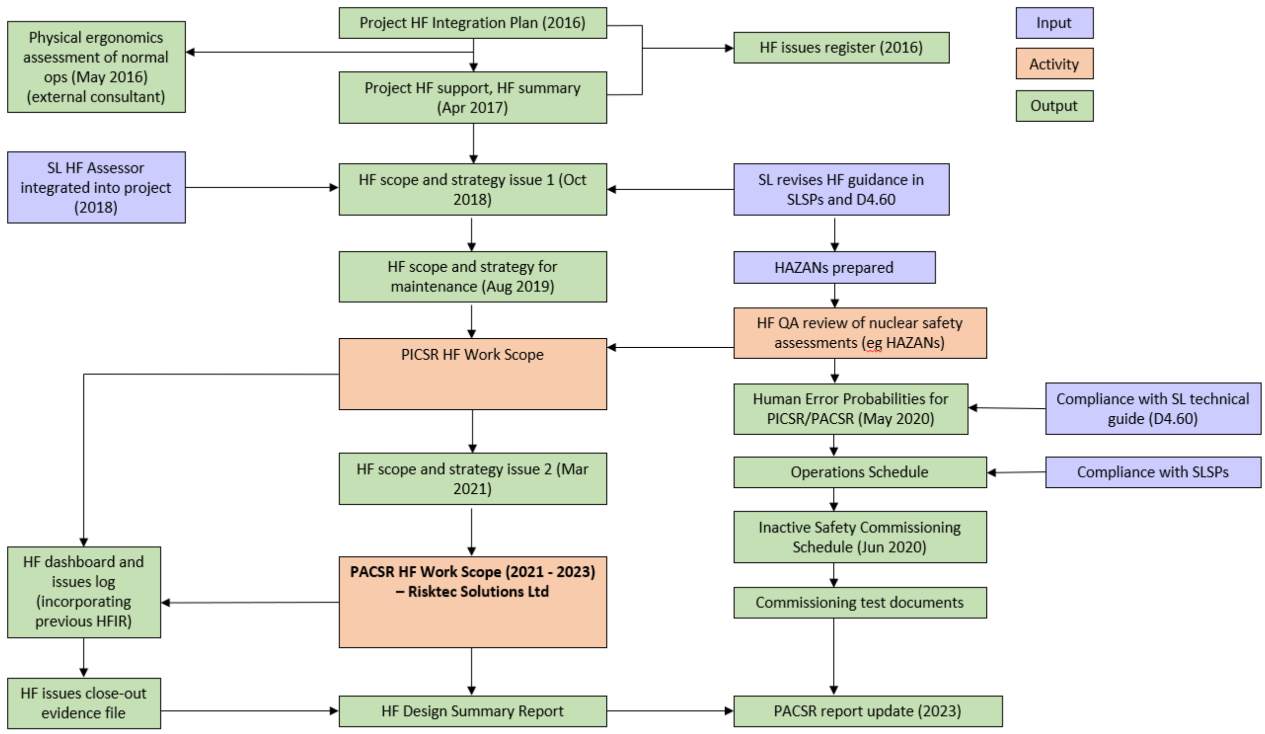

Figure 1: Human Factors Integration Route Map for ILW Facility Project

The route map shows where Risktec HF specialists became involved in the ILW facility project, with an associated scope of HF activities required for the PASCR project stage. Risktec's HF input included:

1. **HF design verification activities and deliverables** – to demonstrate how the role of the operator was systematically defined and implemented across the SL facility, and how the design of systems and equipment minimised the opportunity for human error by adhering to SL HF guidance (Sellafield Ltd, 2016).
2. **HF safety case verification activities and deliverables** – to demonstrate how the human actions performed in support of safety functions were appropriate, achievable and could be reliably completed, and how the potential for human error was minimised through design and operational controls, in accordance with SL safety case guidance (Sellafield Ltd, 2018).
3. **Validation testing of Operational Protection Measures during inactive safety commissioning** – to demonstrate how human actions important to safety were tested and validated.

Operational Protection Measures (OPMs) are required operating instructions and operating assumptions within the safety case that need to be satisfied by arguments and evidence to demonstrate the facility can be operated safety. Certain OPMs rely on input from a human operator (rather than an automated system) and where this occurred, HF activities were carried out to provide the evidence required to satisfy the OPM.

Human Factors Dashboard and Issues Log

HF specialists used a HF Dashboard and Issues Log to capture and manage HF issues and recommendations raised during HF activities. The log was owned by the ILW facility safety case team and safety case manager, who reviewed and progressed the issues in close collaboration with the HF specialists and relevant stakeholders. Project ownership ensured that HF issues were allocated appropriate personnel to be responsible for closing out the issues. The safety case manager determined the timeline for addressing each issue in relation to the overarching project programme.

Figure 2 shows an excerpt from the original project HF dashboard and issues log. It was managed in a spreadsheet, capturing pertinent information about the issue including its origin and screening to determine the importance of resolving the issue raised.

REF	Date	Issue	Recommendation	Source document	Issue Owner	Responsible department	Screened	Plant availability / interface dependency for closure	Target close out	Actual close out	Progress*	Comments	Evidence of Close-out
185	Jan-23	*"Action in the Event of Total Loss of Vault Ventilation"* is not a routine operation and therefore the operators will be unfamiliar with instruction steps, including the location and method of operating the equipment.	The Commissioning Team shall perform on-plant procedural validation for the alignment of temporary forced ventilation to ensure the procedure accurately and clearly describes the required actions. The Training Team shall include scenario-based training for the operator actions in the event of a total loss of ventilation within the facility training programme.	HF Assessment of Facility Emergency Arrangements	SB/RS/CW	Commissioning/ Training	Issue to be addressed following implementation of new plant design.	Issue to be addressed following implementation of new plant design.	May-23			16/03/2023 – solution is currently being redesigned so that this is all in situ. Issue ongoing. 21/07/23 – SB and/or RS will raise a training request form with CW to further investigate any potential training requirements.	

Figure 2: HF Dashboard and Issues Log Illustration

Breadth of HF Integration

The breadth of activities varied widely across the HF discipline, with HF activities on the training approach, software and interface design, procedure validation, assessment of emergency arrangements, a cross-facility interface review, and testing specification development. This was in addition to any HF input required to address HF issues and outstanding actions on the HF dashboard and issues log.

The work scope also included liaison and meetings with the ONR (the nuclear regulator) to ensure that the nuclear site licence conditions set by the ONR are met by the ILW facility design and operation. Specific licence conditions need to be met by sites that handle nuclear materials, and HF integration, input, and output is required to meet some of these conditions.

Case Study: Local Operability Review

Introduction

One of the activities in the HF scope and strategy was to undertake a local operability review of key plant areas that operators and maintainers would interface with, specifically focusing on environmental ergonomics, ensuring that environmental conditions (including lighting, noise, temperature) and access arrangements complied with existing SL ergonomic and HF guidance, as well as relevant HF good practice.

As the facility was still in the PACSR stage of the project, some of the plant conditions were not fully representative of the finalised working conditions, therefore the review was to consider the environmental conditions at the PACSR stage. It was appropriate to carry out the review at this stage so that any identified issues could be addressed for improvement alongside ongoing plant development.

Purpose and Scope

The purpose of the review was to check the suitability of the environmental conditions and access arrangements in the plant areas that operators and/or maintainers would be located and performing their tasks. The plant areas were identified through the review of procedures, floor plans, and training documentation, as well as through conversations with the safety case manager, conventional health and safety specialists, and plant operators.

The level of review for each area of the plant was based on a screening process which assessed: the safety significance of the tasks undertaken in the area, the frequency of use of each area, and areas that have a high personnel occupancy during normal operations. This screening process was used to ensure a proportionate approach to the assessment so that the level of detail of each review was commensurate with the level of importance. Six main areas of the plant were identified for detailed review, and three areas for a high-level review.

Method

Requirements relating to lighting, noise, temperature, and access arrangements were developed to form the basis of the local operability review. These requirements were extracted from existing SL guidance and requirements documentation, including SL EG on ergonomics for the design of control rooms, human-machine interfaces, and the working environment (Sellafield Ltd, 2016). The SL conventional health and safety team had also conducted their own lighting and noise assessments against industry standards (HSE, 2005) so requirements could be derived from the outcome of this assessment as well as the existing SL guidance.

Requirements were divided into two groups – mandatory requirements (to comply with SL guidance) and desirable requirements that were developed from relevant good practice sources such as HSE Workplace Regulations 1992 (HSE, 1992) and a British Standard for Lighting at Work (BSI, 2011).

Four site walkdowns were completed, and the outputs of each were used to generate the local operability review recommendations. The walkdowns were carried out by SQEP HF specialists, a conventional health and safety advisor, and a commissioning manager. During the walkdowns, the operator tasks carried out in each location were discussed with operators and with other SMEs (e.g. safety case experts and conventional health and safety advisors) to gain an understanding of the context of the activities performed.

The HF dashboard and issues log was also reviewed prior to conducting the site walkdowns to ascertain whether there were any existing issues relevant to the scope of the review. Six open issues were identified, and the local operability review aimed to close out as many as possible, as well as review the facility against the bespoke set of HF requirements.

Findings

Each area of the plant was assessed for compliance against the HF requirements and relevant good practice requirements. HF issues and their corresponding recommendations were raised where improvements were required to bring the ILW facility in line with HF good practice and SL ergonomic guidance, and to improve operator performance and reliability. Outstanding actions were raised when the areas reviewed were not sufficiently developed or in a suitable state of readiness at the time of the HF review.

An initial finding was that due to the status of the facility and equipment at the time of the walkdowns, alarms across the facility were not fully operational and therefore could not be included in the assessment and this was identified as an outstanding action.

For each of the six plant areas designated for a detailed assessment and for the three designated for a high-level assessment, an overview was produced to capture the function of that area and the tasks that would be undertaken, including staffing levels, roles and responsibility, and level of supervision present during task completion, where this information was available.

OPMs directly related to the plant areas were highlighted in the output of the local operability review to demonstrate the link between the HF output and the safety case, and to provide evidence that the OPMs were satisfied by the facility design.

A key area of the ILW facility is the Central Control Room. Most of the normal operations within the facility will be controlled and monitored from this workspace using several complex control and monitoring systems. It was identified that the control room will be staffed 24 hours a day, seven days a week, with at least one operator and one supervisor present during operations.

Lighting measurements in the control room were taken during a walkdown. It was confirmed that lighting levels could be altered at each desk in line with the user's preferences and needs. Noise readings were not taken, as previous observations by health and safety professionals did not yield any concerns. There was no equipment that emitted sounds at an excessively high decibel level, with the exception of alarms where high decibel levels are required. Temperature is controlled by an integrated system that allows operators to adjust the temperature of the room to suit their needs. No issues with access to the control room were identified, as entry is controlled via swipe access for essential and approved personnel only and is centrally controlled by SL security.

For the control room, there were no HF concerns around the environmental conditions of lighting, noise, and temperature, or around the access arrangements at the time of the assessment.

Case Study Conclusions

As well as the control room, the road bay, the import area, the lid lift and transfer cells, and crane and bogie maintenance areas were all subjected to a detailed assessment. Additionally, a high-level assessment was carried out for several auxiliary areas and plant rooms across the facility.

Table 1 provides an example of one HF issue that was identified during review of the road bay area. Care was taken over the wording of each recommendation to ensure they were specific, measurable, achievable, realistic and with a time-based element (or, SMART).

Table 1: Example of HF Issue and Recommendation

ID	HF Issue	Recommendation	Owner
1	The road bay is not temperature-controlled therefore extreme temperatures could impact an operator's ability to complete tasks safely and efficiently.	The effects of discomfort caused by the thermal environment in the road bay shall be managed using pre-job risk assessments on a case-by-case basis and appropriate control measures shall be implemented to reduce the effect of working temperatures that negatively impact operator performance (e.g. personal protective equipment, frequent rest breaks, portable task heating/cooling, access to water).	Facility Safety Case Manager

Lessons Learned

One of the most challenging aspects of this project for the Risktec HF specialists was to understand the scope required for each of the HF activities listed in the HF scope and strategy. Whilst the need for certain outputs was identified relatively early in the project, the means for completing these activities was not defined. Generating suitable methods for discharging the HF analysis became one of the most labour-intensive and demanding tasks. Even with the existence of SL HF guidance, which importantly provided a baseline for each assessment, the HF specialists had to develop the method and process for obtaining the required evidence to satisfy the safety case requirements and OPMs. This included identifying relevant stakeholders for each discreet activity and maintaining regular contact with them once a connection was established.

Maintaining regular contact with senior project staff and the SL HF Intelligent Customer was one the keys to the success of HF integration. The Intelligent Customer ensured that the client's interests and requirements were being met by the work being carried out by the HF team. The HF specialists also set up weekly progress meetings with the project which provided a conduit for obtaining answers to project, facility, and site-related questions. The HF specialists actively sought out contact with other HF practitioners on the Sellafield site to further integration and to participate in knowledge sharing and learning from experience, for example by participating in the regular HF community sessions run by SL. These tasks were collectively time demanding but were necessary to maintain contact, facilitate communication with the client and make progress with HF activities.

The management of the HF dashboard and issues log was paramount to the success HF integration. The list of issues reached over 200 at one point, and keeping a clear and concise log of progress against each issue was necessary to see it through to closure. The HF specialists at Risktec devised a method of gathering information from the safety and engineering project team members on HF issue progress, through "HF Issues Surgeries". The surgeries ran with one HF specialist and one SL project team member present for the meeting duration, where stakeholders were given time slots to join the meeting to discuss the progress and problems with closing out their particular HF issues. This was a time (and cost) efficient way of updating the HF issues and providing the stakeholder with a direct line of communication with the HF specialists to progress the issue under review.

Improvements around HF issue screening were identified. When discharging HF activities, proportionate assessments were identified and completed, however it proved challenging to apply this process to the HF issues. Despite the issues being screened, sometimes there was little differentiation between those issues and recommendations that could have a significant impact on facility safety or operation, and those issues where some deviation from HF best practice would not result in a shortfall in safety delivery. Hierarchical categorisation of the HF issues would likely have supported the SL project team to identify where to focus their efforts when progressing HF recommendations for issue closure.

Reflections can also be made surrounding the acceptance of evidence for HF issue closure. It was observed by both the SL project team and the Risktec HF specialists that there was often a mismatch between what was deemed as acceptable evidence to close out an issue, with the HF specialists tending to approach issue closure more conservatively. This occurred where certain aspects of SL guidance were not completely satisfied by the evidence provided, or where HF specialists felt that simple changes could have increased the operator's opportunity to complete their task more easily and with reduction in error – even if the task in question did not directly relate to the satisfaction of OPMs. For example, HF specialists recommended the provision of permanent etched labels and colour coding on task equipment in place of existing temporary or hand-written labels. A change of this type would have supported operators in completing their task and limited the possibility of labelling degrading and becoming unusable over time. The SL project team felt that given there were no time pressures or nuclear safety consequences due to the operator either taking a long time or making an error, that the label change was not justified on a cost-benefit basis.

Striking the balance between necessary change and desirable change is a challenge faced by many HF practitioners. Upon reflection, pragmatic management of this challenge for this project could have been achieved through several options. Firstly, at the point of recording the issue, reaching an agreement regarding the acceptable level of evidence required to close out the issue would have removed ambiguity later in the project. This method was used for some issues, but not all of them. Secondly, the HF issue screening process could have been more rigorously applied and therefore contributing to the decision HF specialists make regarding acceptable evidence for issue closure. The impact of the issue resolution on facility and operator would therefore have been better understood.

Thirdly, an HF specialist's role is to ensure they have exhausted all opportunities for task, equipment, and process improvement to minimise the likelihood of human error. Not all human errors are created equal, with some having the potential to negatively impact personnel or facility safety and others being limited to individual frustration or length of time to complete a task. Sometimes an HF specialist's desire to make something as 'good as possible' is at odds with a client's desire for something to be 'good enough'. Both views have their place and are equally valid positions to hold. Developing pragmatism to support 'good enough' is something continuously learned throughout an HF specialist's career and varies from project to project. In the case of the ILW facility project, a method for managing this disparity between HF specialist and client would have allowed for more timely progress of issue closure. For example, issues could have been marked appropriately in the HF dashboard and issues log to signify that, from the client's perspective, the issue had been addressed as far as was reasonably practicable and SL considered it closed, thus allowing for opposing views, but moving forward on an agreed basis.

Conclusion

The ILW facility project integrated HF as part of the engineering design of the facility and demonstrated this through the delivery of multiple HF activities completed for PACSR. The HF outputs supported the ILW facility design and safety case verification up to the PACSR stage of the project by describing the HF activities undertaken and summarising where HF issues had been identified, managed, and closed out. The HF activities provided confidence in the breadth of HF integration across the project, where screening activities ensured that the depth of analysis was proportionate to the risk and consequence to the operator.

The facility successfully entered active operations in mid Dec 2023, receiving its first box of nuclear waste and storing the ILW safely and securely above ground for the next hundred years. The facility will store the waste until its ready for permanent disposal underground in a geological disposal facility (NIA, 2023).

This paper highlights the importance and impact of HF integration on a large-scale nuclear project. The local operability review formed one part of a much larger HF effort, and the practitioners involved were able to identify areas for improvement across multiple aspects of the facility.

HF integration is of paramount importance to nuclear safety projects, where HF activities, advice, and guidance all contribute to developing robust HF arguments and evidence to minimise the opportunity for, and impact of, human error. Having tools and management strategies in place allows the HF specialist to perform their tasks effectively deliver high-quality HF integration to the client.

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