

Designing for Constructability

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SUMMARY

UK nuclear licensed sites will have large construction programmes ongoing for at least the next decade. Design for constructability is essential to ensure programmes are achievable and to optimise project performance, safety and efficiency. Early assurance of constructability, for each construction phase, of potentially multiple interfacing projects, will minimise errors, delays and cost over runs. The current, regulatorily driven, approach to Human Factors (HF) in industry projects integrates HF activities through project design development stages, commissioning and into operations, ensuring human capabilities, limitations and behaviours are considered to support safety, operability and maintainability. This paper provides additional guidance on HF aspects to be considered throughout the design and delivery process to ensure HF specialists are making decisions that support effective and reliable construction activities.

KEYWORDS

Design, Construction, Constructability

Introduction

The current demand for significant construction works across UK nuclear sites, for at least the next decade, has driven consideration of how nuclear industry Human Factors Integration (HFI) ensures constructability in the Human Factors (HF) activities undertaken across a project lifecycle. A failure to consider constructability slows construction down, increases potential for design changes, rework and subsequently increases costs and programme timescales. Historically, HF construction aspects of a design have not been considered in as much detail as safety, operability and maintainability. A structured and consistent approach to HFI in developing the constructability argument is required to support the current, more established, engineering activities.

To ensure HF teams are considering construction, along with safety, operations, maintenance and emergency response, throughout the design lifecycle, construction specific guidance is required. Whilst HF principles apply in the same way for constructability, the provision of guidance is beneficial to ensure a consistent approach.

In this paper, the term constructability encompasses manufacturability (applying mostly to process plant and equipment and to constructability (applying mostly to buildings and services). The aim of constructability assurance is for detailed design submissions to evidence that we can:

1. Build the facility to meet its intended use, to the quality required in the planned timescale
2. Manufacture the equipment to meet its intended use, to the quality required in the planned timescale
3. Install the equipment as intended and to timescale
4. Commission and hand over to operations the facility and equipment to a strategy, approach and plan.

This paper provides supplementary HF guidance specifically targeted at designing for constructability. It is based on internal guidance and provides aspects for consideration from initial concept through to commissioning and handover.

Human Factors Aspects of Constructability

Examples of Human Factors aspects of constructability that should be considered in a construction programme, are as follows:

- People, plant and equipment access (permanent and temporary access)
- Plant layout for safe and effective construction, commissioning, operational readiness testing and bringing into operation
- Equipment selection to consider construction demands and limitations
- Materials and construction technique selection
- Dependencies and interfaces, as they change through the construction phases
- Modularisation & standardisation to support construction and commissioning strategies and programmes
- Error identification and mitigation, considering the changes in performance shaping factors at each of the construction phases

Construction activities on a project should be considered from two perspectives:

1. The construction project itself
2. The impact on adjacent site operational facilities

The following sections of this paper expand on these HF considerations, across key areas of constructability, for consideration during the project lifecycle.

People, Plant and Equipment Access

A construction project requires consideration of a target audience of organisations and users that includes people who are temporarily on site. The SQEP arrangements and assurance, and cultural behaviours, of this group are often quite different to nuclear site workers. This can impact on the reliability of arrangements put in place to maintain the site safety case and may need robust engineered or administrative controls to be in place for the duration of the activity. An example is driving / moving large heavy plant on routes, where impact with operational facilities could challenge the structure of a building and may require installation of bollards, vehicle speed limiters and vehicle e-stops accessible to an independent supervisor, etc.

People access should not be considered in isolation but in conjunction with the tasks being conducted which will define the equipment needed. Physical constraints and arrangements should be identified to prevent access issues during installation.

Anthropometric guidance should be used to consider spatial requirements for people accessing areas requiring particular postures, dependent on work requirements, e.g. standing, kneeling, squatting, etc.

Personal Protective Equipment (PPE) such as hard hats, gloves, boots, and coats / high visibility clothing will be standardised for the construction sites. There also may be a requirement for specialist PPE that will be required for certain jobs that may significantly impact dexterity and movement. Consideration needs to be given to the PPE the construction team will be wearing and the impact this will have on movement and access.

Plant Layout

The construction of new buildings will occur alongside the operation of existing facilities, and the activities on these adjacent sites will need to be planned in detail. The plant layout required during the construction process (commissioning, operational testing and bringing into operation), in the most efficient manner, should be considered along with plant access, e.g. movement of heavy equipment around site and within a facility (routes and access may change throughout the programme).

Construction site layout may only exist during the construction phase and can introduce multiple aspects of complexity to be considered. For example, separating construction traffic from pedestrian routes, providing lay down areas for deliveries (potentially separating construction materials and delivered equipment items that need careful handling or “clean” areas for sensitive equipment), site access controls and location, location of welfare facilities, location of temporary utilities (e.g. diesel generators, fire water storage tanks, pressurised bottled gases, etc).

The footprints of major items of construction equipment, e.g. mobile cranes and mechanical handling equipment, must be considered for floor space and overall space requirements in all directions. Space for unpacking large items, by appropriate lifting equipment or cranes, is to be considered (noting this is often three times the space of the item footprint – the package, the lid and the item).

Construction activities should be planned to allow easy installation of bulky items (e.g. delaying internal partitioning installation until large items have been moved into position.) For the permanent process plant and equipment (in place during and after the construction phase) space should be provided for temporary enclosures or lifting equipment for the installation, or future removal, of plant items (this includes the internal access routes to move equipment to the installed location). An example being internal corridors to allow fully intact ‘as built’ gloveboxes to be moved into their final location without having to strip down the tested modules.

As the construction process develops, there will be commissioning of equipment while other areas on the site are still being built. To support this phased commissioning, it may be that extraction and ventilation systems need to be configurable or separated, or additional equipment installed to complete the commissioning process, e.g. powered equipment requiring power, generators, cabling, etc. This additional equipment will have spatial requirements that should be planned for to ensure that there is sufficient space to import, export and use them.

Construction planning will need to consider provision, and maintenance of, protected spaces around installed equipment during construction and commissioning ongoing activity.

Case Study: The Trees are too Big!

While planning the decommissioning of a UK Facility, site layout, as well as plant layout, had to be considered as movement of key equipment required for decommissioning processes needed careful planning. Movement of large vehicles in an area that was not used to such heavy traffic was required. The structure of site roads was reviewed to ensure they could withstand the loading of a large transporter and the trimming of trees to allow a path through to the decommissioning site.

Key takeaway: Consideration of all aspects of available space needed for construction activities can prevent programme delays and rework.

Equipment Selection

During construction, HF good practice in construction equipment selection should be applied, such as selecting appropriate tools, anatomical considerations, strength, pressure exertion, and health and safety aspects such as noise and vibration. While this equipment is “temporary” they may be used for years. Consideration should be given to support aids and innovation, e.g. mechanical assistance.

Case Study: Innovation in Construction

Passive exoskeletons are wearable devices that are designed to augment a worker’s strength. In laboratory studies, passive exoskeletons may increase muscular endurance and field studies have shown the potential of passive exoskeletons to reduce bodily exertion and discomfort in construction work. Therefore, exoskeletons are perceived as a promising solution to reduce the risk of musculoskeletal disorders that are highly prevalent and costly.

Construction workers can use exoskeletons to reduce the effects of physically demanding work. A study examined the perceptions of construction workers who have used an exoskeleton for multiple work shifts to identify tasks that may benefit from exoskeletons and identify design improvements to facilitate their adoption. Those workers who used these exoskeletons believed they were beneficial for prolonged overhead work. A subsequent systematic review suggests quality and productivity impacts of exoskeletons depend on task characteristics.

From a study by Yazdani & Yung, 2025.

Key takeaway: Innovation in the selection of construction equipment has the potential to reduce injuries and improve productivity.

Materials and Construction Technique Selection

There are many opportunities for selecting materials that will be available, reliable in quality, easy to work with (usable) and support a flexible construction technique. The benefits of this selection are realised at build / installation, commissioning and handover. In addition, there is opportunity during material and construction method selection to design out risk and build in reliability.

The HF contribution can ensure ease of installation, commissioning, maintenance and replacement of facility elements. An example is the cladding on the facilities could be in manageable weighted / sized sections that can be installed with specified handling equipment. Potentially the size of cladding section could be standardised so that replacing cladding during operations will not challenge a facility safety case with regard to the maximum aperture tolerable in an operational facility (e.g. for water ingress).

Dependencies & Interfaces

Multiple facility build projects on a site can be ongoing simultaneously, understanding and managing the interfaces between construction projects, identifying dependencies and deconflicting conflicts is key to project delivery. Facilities themselves are complex systems consisting of processing plant, ventilation, utilities, specialist systems, and each system will exist alongside multiple systems and not be built or used in isolation. Commissioning of plant may start while the construction process is still underway and subsequently there could be maintenance of equipment, commissioning and construction all happening concurrently. The sites project programmes should manage these interfaces and dependencies, minimising delays. An example is having access for

importing new Gloveboxes onto and across site at the time of delivery from the manufacturer, with appropriate space envelopes for laydown, unboxing, assembly and installation. This may require deconfliction of other site works that could cause access problems (e.g. a mobile crane blocking the travel path).

Note that the levels of accuracy and tolerances defined as requirements in equipment design should be questioned as they may compound to make construction more onerous than necessary, and they also may change throughout design and build.

Separation of services should be considered if there are concerns around how these might interface or have the potential to damage or degrade equipment, e.g. potential leaks and what they may drip on. The siting of maintainable components should be considered to avoid obstruction by other services being installed over them.

Modularisation & Standardisation

Identifying opportunities for modularisation or construction of items away from site helps to deliver both consistency and simplicity. Inputting ready-built items and identifying areas that can be standardised should be encouraged during design development.

Standardisation of designs, within facilities or even across the nuclear industry, saves money based on the design and re-use principle. This standardisation also derisks the supply chain capability.

Case Study: The Adoption of an Industry Standard for Glovebox Design and Maintenance

The need for gloveboxes across the nuclear industry is significant. To make supply of these gloveboxes easier from a design and manufacturing perspective, the UK nuclear industry is working together.

Cross-sector collaboration has seen guidance developed for use across UK nuclear operations via the UK Alpha Resilience & Capability (ARC) Programme. ARC is a partnership between government, nuclear operating companies and the wider nuclear industry to ensure a consistency in glovebox design standards, helping the supply chain meet the industry's future demands.

As thousands of new gloveboxes are needed to support future work, the design guidance standardises the design approach across multiple site users to ensure quality, safety and efficiency of engineering design practices. This will limit design differences and provide a common understanding for the licence sites and supply chain. This includes HF design guidance.

The benefits:

- The supply chain will not need to deal with several different design guides. As such, gloveboxes will be easier to design and manufacture
- A reduction in the time and resource that was previously required to maintain the AWE documentation
- The resource pool of glovebox experts in the UK will be adding to the guides, as opposed to individuals creating their own internal guidance

Key takeaway: Standardisation can save money and should be considered during design developments.

Modularised design allows installation and commissioning programmes to be sped up. Skid based design is when items of process plant and equipment are designed as a module that can undergo factory acceptance testing and pre-commissioning before delivery to site. The benefit of a modularised design is that equipment can be delivered to site ready configured and simply plugged into place. One of the challenges of modularisation is that the dimensions of each skid must be suitable for road transport, HF must ensure that this constraint does not drive a congested design. Modular skid-based designs must meet the same access and plant layout good practice, for installation, operation and maintainability, as non-modularised design. Modular design must consider the interfaces with other 'on site' installed equipment and final state operation and maintenance activities, in addition to transport and installation requirements.

Error Identification & Mitigation

The phases of a construction project can introduce additional or novel hazards. The HF practitioner will collaborate with stakeholders in the hazard identification process throughout the construction phases and provide reliability assessments where required.

Any plant / equipment designated as important in terms of nuclear safety are defined as Structures, Systems and Components (SSCs) and are recorded in the safety case documentation suite. It is important that these items are correctly installed and fully commissioned within the system to ensure they are available to perform their functions as required by the safety case.

The installation and commissioning of safety important items that are claimed in safety cases should be subject to review in terms of potential errors that would make those systems not perform their design function. The constructability and commissioning of safety structures and components should be reviewed, prioritising them based on risk and claims within safety case. In addition, where construction activities that could impact on an operational or in construction SSC, potentially reducing its effectiveness, may require reliability assessment.

Performance Adaptations from Safety Rules

The increased construction activity on nuclear sites will lead to people working on nuclear sites who are general construction workers not used to working with the standards and processes in the nuclear industry.

A study on adaptive safety on the construction frontline found that frontline construction workers deviate from / adapt their working practices away from the safety rules and the prescribed safe work method statements (SWMS) due to their learned experiences, production pressures and a constantly changing work environment

Key findings from the study show that:

- Participants acknowledged the value of safety rules, but compliance with them varied
- Three primary drivers for performance adaptations (deviation from SWMS) were identified: production pressures, constantly changing work environment, and social dynamics and the relationship between labourers and their supervisors
- Participants' attitude towards risk / rule-breaking was linked to how comfortable they were deviating from the rules

Construction workers develop preferred ways of working which are linked to their desire to perform tasks safely and efficiently. These ways of working constantly evolve as their learned experience of the tasks evolves. Because of this, workers with less experience may have fewer references to draw on when adapting their performance, increasing the likelihood of negative

schema transfers. These different levels of experience either contribute to organisational safety and resilience or compromise it.

HF integration into the design of construction tasks where safety features are under construction ensures that critical steps in the task are highlighted as specific control measures. These control measures are subject to an appropriate level of scrutiny by qualified and experienced Quality Inspectors at the point of installation, ensuring appropriately qualified operators undertake key activities to the specified standard.

From a study by Horn, Waterson & Jun, 2025.

Key takeaway: Consideration of how to ensure safety rules and methods of working are complied with needs to be a HF focus during construction.

Checklist

A checklist has been developed to help HF practitioners during the design phase. This checklist is designed as a prompt for review of aspects of the design of potential issues to consider with the Engineering Manager and the design team.

Table 1: HF Checklist for Constructability

Category	Checklist Questions
People Access – Construction	<ul style="list-style-type: none"> • What physical access is required for construction tasks (considering equipment, tooling and the number of people involved)? • Are posture constraints relevant (standing, kneeling, squatting)? • Implications of PPE on reach/movement/dexterity? • Are temporary access systems needed (platforms, scaffolds, MEWPs)?
People Access – Commissioning	<ul style="list-style-type: none"> • What access is required for commissioning? • Will access routes/space envelopes change? • Need for temporary power, lighting, ventilation?
Plant Layout	<ul style="list-style-type: none"> • Laydown areas for large items/modules/sensitive equipment/packaging? • Need for clean/protected zones? • Movement routes and lifting/movement envelopes? • How is equipment powered during construction/commissioning?
Equipment Selection	<ul style="list-style-type: none"> • Mechanical aids required? • Powered or non-powered tools? • Innovative aids (exoskeletons, handling devices)? • Errors introduced by equipment selection?
Dependencies & Interfaces	<ul style="list-style-type: none"> • Additional equipment needed before all services available? • Adjacent construction impacts? • Are tolerances realistic? • Could services obstruct/degrade each other? • Are space envelopes available when needed?
Modularisation & Standardisation	<ul style="list-style-type: none"> • Can assemblies/modules be built off-site? • Can design be standardised within facility/site/industry? • Does standardisation reduce design differences?

Error Identification & Mitigation – Installation	<ul style="list-style-type: none"> • Ease of SSC installation? • Potential installation errors (alignment/orientation/torque/sequence) that could compromise SSC function? • Are critical steps identified and controlled?
Error Identification & Mitigation – Commissioning	<ul style="list-style-type: none"> • What commissioning errors could compromise SSC function? • Are SQEP personnel available at the right stages? • Are reliability assessments needed when construction affects operational SSCs?
Error Mitigation Controls	<ul style="list-style-type: none"> • Engineered or administrative controls? • Which tasks require enhanced inspection/verification?

Conclusion

Integrating HF into constructability from concept through commissioning enhances programme certainty, reduces potential for redesign, and supports safe, reliable construction delivery.

A failure to consider constructability during design development could lead to increased requests for design changes and rework as well as delays in construction and increased costs. Aspects of HF in constructability have been presented in this paper for HF specialists to consider during the design phase to improve the constructability of a project.

References

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