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Submission of Revision 2 to X Energy, LLC (X-energy) Xe-100 Licensing Topical Report: Control Room Staffing Analysis Methodology and Associated Implementation Plans

REFERENCES:

1) **Letter dated August 16, 2021, from T. Chapman to U.S. Nuclear Regulatory Commission, "Submission of X Energy, LLC (X-energy) Xe-100 Topical Report: Control Room Staffing Analysis Methodology," X-energy Reference Number XE00-R-R1ZZ-RDZZ-L-000715 Rev. 1 (ADAMS Accession No. ML21228A011)**
2) **Letter dated November 5, 2021, from T. Chapman to U.S. Nuclear Regulatory Commission, "Withdrawal of X Energy, LLC (X-energy), Xe-100 Topical Report: Control Room Staffing Analysis Methodology," X-energy Reference Number 2021-XE-NRC-016 (ADAMS Accession No. ML21310A000)**

The purpose of this letter is to submit Revision 2 of the subject licensing topical report (LTR) to the U.S Nuclear Regulatory Commission (NRC) on behalf of X Energy, LLC ("X-energy"), as well as the associated X-energy Human Factors Engineering (HFE) Program Management and Implementation Plans. Specifically, the Xe-100 HFE program will incorporate the following elements from NUREG-0711 as part of the basis for its Control Room Staffing Analysis Methodology:

- HFE Program Management,
- Operating Experience Review,
- Functional Requirements Analysis and Function Allocation,
- Task Analysis,
- Staffing and Qualifications,
- Treatment of Important Human Actions,
- Human-System Interface Design,
- Human Factors Verification and Validation, and
- Design Implementation.

Additional HFE elements from NUREG-0711, Procedure and Training Program Development, are part of a separate development effort currently in progress and will be managed by separate Program Management Plans.

X-energy submitted Revision 1 of this report via Reference 1 and held a meeting with the NRC staff on October 14, 2021 to discuss clarifying questions on the scope of the review and the supporting

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implementation plans. During the subsequent X-energy review of the implementation plans as supporting material for the review, we determined that a revision to the topical report was warranted to improve alignment with the plans. This submission provides both the revised topical report and associated implementation plans for X-energy's approach to conduct Control Room Staffing analysis based on the guidance of NUREG-1791 and the NUREG-0711-based HFE Program for the Xe-100 design.

X-energy intends that this report facilitate on-going discussion with the NRC staff on the proposed approach. The specific review schedule will continue to be developed with X-energy's NRC project manager, but we request that a nominal review duration of 12 months be considered. This report and the implementation plans were reviewed for proprietary and export-controlled information and determined to be fully releasable.

This letter contains no commitments. If you have any questions or require additional information, please contact Ingrid Nordby at inordby@x-energy.com.

Sincerely,

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cc:
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Enclosures:

1) Xe-100 Licensing Topical Report: Control Room Staffing Analysis Methodology, Rev. 2
2) Human Factors Engineering Program Management Plan
3) Xe-100 Operating Experience Review Implementation Plan
4) Xe-100 Functional Requirements Analysis and Function Allocation Implementation Plan
5) Xe-100 Task Analysis Implementation Plan

6) Xe-100 Staffing and Qualifications Implementation Plan
7) Xe-100 Treatment of Important Human Actions Implementation Plan
8) Xe-100 Human-System Interface Design Implementation Plan
9) Xe-100 Human Factors Verification and Validation Implementation Plan
10) Xe-100 Design Implementation Implementation Plan

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Enclosure 1

X Energy, LLC Xe-100 Licensing Topical Report: Control Room Staffing Methodology, Revision 2

Xe-100 Licensing Topical Report

Control Room Staffing Analysis Methodology

Configuration Classification	:	**XE00-R-R1ZZ-ZZZ-X**
Revision	:	**2**
Status	:	**Approved**
Issue Date	:	**17-Dec-2021**
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E-SIGNATURES: DOCUMENT APPROVAL

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This document is the property of X Energy LLC (X-energy) and was prepared for review by the U.S. Nuclear Regulatory Commission (NRC) and use by X-energy, its contractors, its customers, and other stakeholders as part of regulatory engagements for the Xe-100 reactor plant design. Other than by the NRC and its contractors as part of such regulatory reviews, the content herein may not be reproduced, disclosed, or used without prior written approval of X-energy.

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This document was reviewed by X-energy and determined to not contain information designated as export-controlled per Title 10 of the Code of Federal Regulations (CFR) Part 810 or 10 CFR 110.

Department of Energy Acknowledgement and Disclaimer

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EXECUTIVE SUMMARY

The Xe-100 pebble-bed high-temperature gas-cooled reactor is an advanced reactor design offered in plant configurations from a single unit to multiple units in operation. Each plant has some shared facilities, in operation from the commissioning of the initial unit, that contribute to safe and efficient operations. The Xe-100 was designed for simplicity of operations and relies primarily on inherent safety characteristics as part of its safety design approach, leading to a design that requires fewer operator tasks and no credited operator actions to perform required safety functions.

This licensing topical report provides detail on the approach that X Energy, LLC (X-energy) is taking to establish a Human Factors Engineering (HFE) Program based on the guidance provided in NUREG-0711. This topical report also provides detail on the methodologies to conduct a systematic control room staffing analysis. This analysis will provide the technical basis for the number, roles, and qualifications of the control room operators at an Xe-100 plant across all modes and states, from commissioning the first unit through full power operation of multiple units.

The base case for the Xe-100 is to deploy four units at a site, managed by a 3-person control room staff in one central control room. Additional expansion capability, either by adding single units to an existing deployment or additional four-unit plants, requires consideration of options such as additional control rooms, expanding the footprint of a single control room, and changes to shift operations, as well as the associated HFE impacts. The approach described herein and in the associated Implementation Plans (IPs) is intended to be flexible enough to provide credible HFE activities to validate that control room operations will be safely managed and the number of control room operators, their tasking, their span of unit control (4 units), and the associated control room design all support a robust defense-in-depth capability.

The approach and methodologies described in this report are intended to initiate pre-application engagement with the U.S. Nuclear Regulatory Commission (NRC). Deliverables produced from the application of this methodology, such as the development of HFE element deliverables, operator training simulator observations and staffing validation activities, and a matrix of control room operators, roles and qualifications (and applicability across the number of units and modes/states) will be provided in future revisions to this topical report or through design and licensing bases information submitted for site or design-specific licensing applications under 10 CFR 50, 10 CFR 52, or future 10 CFR 53. Other interactions with the NRC Staff such as audits and observations of simulator exercises may take place to review the results of the staffing analyses.

Ultimately, the matrix of control room operators and the supporting staffing analyses will form the technical basis for prospective Xe-100 licensees to request exemptions from the staffing requirements of Title 10 of the Code of Federal Regulations (CFR), Part 50.54(m), or for X-energy to use as part of a 10 CFR 52 Design Certification application. X-energy requests that the NRC staff review and approve the approach and the methodologies as described in this report in Section 4.

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CONFIGURATION CONTROL

Document Change History

Rev.	Date	Preparer	Changes
A	6/25/2021	P Hippely	Initial document with implementation plan information
1	8/6/2021	P Hippely	For approval
1A	12/17/2021	P Hippely	Incorporated review comments and changes related to Rev 2 of Implementation Plans.
2	12/17/2021	P Hippely	Finalized all changes into new revision.

Document Approval

Action	Designation	Name	Signature	Date
Preparer	Human Factors Lead Engineer	Paul Hippely	DocuSigned by: Paul Hippely 1AAE19CE8E784BD...	12/17/2021 | 12:49 PM EST
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ABBREVIATIONS

This list contains the abbreviations used in this document.

Abbreviation or Acronym	Definition
BNL	Brookhaven National Laboratory
CNSC	Canadian Nuclear Safety Commission
COL	Combined (Construction and Operation) License
DC	Design Certification
FA	Function Allocation
FRA	Functional Requirements Analysis
FSAR	Final Safety Analysis Report
HFE	Human Factors Engineering
HSI	Human-System Interface
KSA	Knowledge, Skills and Abilities
LWR	Light-Water Reactor
NRC	(United States) Nuclear Regulatory Commission
OER	Operating Experience Review
PRA	Probabilistic Risk Assessment
SAT	Systematic Approach to Training
SMR	Small Modular Reactor
SPV	Staffing Plan Validation
S&Q	Staffing & Qualifications
TA	Task Analysis
TIHA	Treatment of Important Human Actions
V&V	(Human Factors) Verification & Validation

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DEFINITIONS

This list contains a glossary of terms used in this document.

Term	Definition
Element	From NUREG-0711 [2] the four general activities are separated into the following twelve elements: • HFE Program Management • Operating Experience Review • Functional Requirements Analysis and Function Allocation • Task Analysis • Staffing & Qualifications • Treatment of Important Human Actions • Human-System Interface Design • Procedure Development • Training Program Development • Human Factors Verification and Validation • Design Implementation • Human Performance Monitoring
Concept of Operations	The Concept of Operations describes how a Xe-100 plant intends to operate to achieve its goals and objectives. As part of the HFE Program, this document is a placeholder of conceptual information related to the operation of a Xe-100 plant useful for the development of further HFE activities.
Control personnel	Personnel are designated as control personnel, if that individual is responsible for controlling and monitoring plant or unit operations
Integrated system validation	An evaluation using performance-based tests to determine whether an integrated system design (i.e., hardware, software, and personnel elements) meets performance requirements and acceptably supports safe operation of the plant.
Job definitions	The responsibilities, authorities, skills, knowledge, and abilities that are required to perform the tasks and functions.
Shift composition	Refers to the different types of jobs that must be performed on each shift and the number of personnel required for each of the jobs on a shift.
Situation or situational awareness	An individual's mental model of what has happened, the current status of the system, and what will happen in the next brief time period.
Workload	The physical and cognitive demands placed on plant personnel.

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1. INTRODUCTION

1.1. PURPOSE

The purpose of this report is to:

- Describe the approach for the Xe-100 reactor plant control room staffing analysis. This analysis will form the basis for establishing the optimum number and qualifications of control room operator personnel required for safe and reliable Xe-100 plant operations in a multi-unit plant configuration across various modes, states, and operating conditions,
- Describe the planned X-energy methodologies for operator task analysis (TA) and validation testing of the staffing plan, and
- Initiate NRC review of the control room staffing plan analysis approach and methodologies and obtain NRC approval of the X-energy control room staffing approach.

1.2. SCOPE

This topical report describes the approach X-energy will employ to determine the optimum number and qualifications of control room operator personnel required for safe and reliable Xe-100 multi-unit operation. For the purposes of this report, control room operator personnel include reactor operators (ROs) and senior reactor operators (SROs) as defined by 10 CFR 55.4.

10 CFR 50.54(m) specifies minimum licensed operator staffing requirements for control rooms and responsibilities as a license condition of plant operating licenses. These requirements do not address a plant design with more than three units on a site or more than two units operated from a single control room. Further, licensee requirements regarding control room staffing, including the number, composition, and qualifications of personnel, are more appropriately based on features unique to the design rather than on the existing large, light water reactor-based staffing levels. Features unique to the Xe-100 include an safety design approach that relies on inherent safety features, increased use of automation technologies, and adopting innovative control station designs. The initial Xe-100 concept of operations establishes a shift crew of three control room operators who will oversee multi-unit operations from a single control room, optimized at the conceptual design phase for four units.

The application of HFE in the design of Xe-100 control rooms will establish the optimal staffing level for Xe-100 operators controlling multiple units and will meet the regulations promulgated in 10 CFR 50.34(f)(2)(iii) and guidance described in NUREG-0711, “Human Factors Engineering Review Model.” Specifically, the Xe-100 HFE program will incorporate the following twelve elements:

- HFE Program Management,
- Operating Experience Review,
- Functional Requirements Analysis and Function Allocation,
- Task Analysis,
- Staffing and Qualifications,
- Treatment of Important Human Actions,
- Human-System Interface Design,

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- Procedure Development,
- Training Program Development,
- Human Factors Verification and Validation,
- Design Implementation, and
- Human Performance Monitoring.

This topical report presents the approach to conducting the staffing optimization analysis through the Xe-100 Human Factors Engineering (HFE) Program and will follow the guidance from NUREG-0711 and NUREG-1791 [3] to develop and technically justify an alternative staffing model. Ultimately, the matrix of control room operators and the supporting staffing analyses will form the technical basis for prospective Xe-100 licensees to request exemptions from the staffing requirements of 10 CFR 50.54(m), or for X-energy to use as part of a Part 52 Design Certification application. X-energy will develop an HFE-focused Concept of Operations (ConOps) consistent with the requirements specified in 10 CFR 50.34(a)(6) as a part of future submittals.

1.3. RELATIONSHIP TO OTHER DOCUMENTS

Reviewers are advised to reference the “Xe-100 Technology Description Technical Report” [Braudt 2021] [4] for details on the Xe-100 design and unit and plant operations. NRC staff review of that report is not requested at this time. X-energy has a series of referenced Implementation Plans for specific elements of the Xe-100 HFE Program that will be made available through the review period.

1.4. DOCUMENT LAYOUT

This document presents the approach using the key tasks from the Xe-100 HFE Program. Section 2 provides relevant context to the Xe-100 plant design and safety features. Section 3 provides an overview of relevant regulatory requirements and guidance. Section 4 provides a detailed description of the Xe-100 HFE program methodology. Section 5 illustrates their compliance with the review criteria presented in NUREG-1791 [3], summarizing the overall process, the supporting data, and analysis approach to support future control room staffing exemption requests. Section 6 contains the conclusions of this topical report and Section 7 describes the request for NRC review and approval.

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2. OVERVIEW OF THE XE-100 PLANT DESIGN

An overview of the Xe-100 plant design and key safety features has been provided to the NRC Staff in the Xe-100 Technology Description Technical Report [Braudt 2021] [4]. The limited description provided in that document includes a description of safety features of the Xe-100 that warrant consideration in the control room staffing optimization analysis for an Xe-100 plant in various modes, states, and operating conditions.

NUREG-1791 provides examples of design features and concepts of operation for advanced reactors that could lead to acceptable bases for reduced control room operating personnel. Some of the design/technology attributes described that are applicable to the Xe-100 design include:

- safety design approach based on inherent safety features,
- high level of automation,
- extremely long grace periods during licensing basis events, and
- no risk-significant operator actions in the safety design approach.

2.1. XE-100 REACTOR DESIGN

The general HTGR concept evolved from early air-cooled and carbon dioxide (CO_2)-cooled reactors. The use of helium instead of air or CO_2 as the heat transport fluid in combination with ceramic fuel and a graphite moderator offered enhanced neutronic and thermal efficiencies and several advanced safety characteristics. The combination of helium and a ceramic core makes it possible to produce high temperature nuclear heat while maintaining a large safety margin to material limits. Two reactor core configurations, a pebble-bed core and a prismatic core, have been developed internationally for the commercial modular HTGR designs.

The Xe-100 reactor design is based on a pebble-bed core configuration. Pebble bed reactor technology dated back to the late 1960s, when the 46 MWt Arbeitsgemeinschaft Versuchsreaktor (AVR) was designed and operated in Germany. Later, advanced pebble bed reactor designs were developed in Germany, South Africa, and China. The Chinese have a modular HTGR pebble-bed reactor design, the HTR-PM, with two 250 MWt reactor units serving a single 200 MWe turbine/generator, that has started hot functional testing as of 2021. The Xe-100 reactor technology basis, design parameters, fueling scheme, pebble fuel, fuel handling and storage system, and safety characteristics are discussed in X-energy's core design reports and the Xe-100 Technology Description.

The Xe-100 reactor and steam generator systems are shown in Figure 1. The main reactor characteristics, including dimensions, thermal power, and major operating conditions are described further in the Technology Description Technical Report [4]**.** The active core volume is filled with approximately 224,000 spherical fuel elements, or pebbles[1], to form the pebble bed. Each pebble contains approximately 19,000 TRISO-coated particles. The fuel particles consist of a fissionable ceramic fuel kernel surrounded by three ceramic coating layers for retention of fission products. Fissions within the coated particles create the

[1] The Xe-100 spherical fuel elements are called pebbles in this report.

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nuclear heat which is conducted to the pebble's surface. A helium circulator transports the helium heat transport fluid through the pebble bed, transporting heat from the pebbles to the steam generator.

Fuel pebbles are loaded into the core while the reactor is operating through a central tube at the top of the reactor pressure vessel (RPV). A fuel discharge system at the bottom of the core removes spent pebbles through the bottom of the RPV for assessment by the Burn-up Measurement Systems (BUMS) that evaluates each pebble for physical damage and burn-up and can return them to the top of the RPV, where they are again loaded into the core, or send them to spent fuel storage. A typical pebble goes through this process six times before it is removed from the reactor before reaching burn-up limits. The spent fuel pebbles are inventoried and placed into spent fuel casks for storage. These processes are managed via automated control systems due to the frequency of pebble circulation (hundreds of time per day) that the control room staff monitor and can intervene if necessary.

The maximum fuel temperature during normal operation is well below 1000°C, which is significantly lower than many earlier HTGR designs and leaves large margins to the established TRISO performance envelope. The core excess reactivity is limited by on-line refueling since fuel can be loaded and unloaded as desired during full power operation. The Xe-100 has an overall negative temperature coefficient of reactivity due to Doppler broadening of the kernel uranium and the fuel pebble graphite and reflector graphite, ensuring stability during operations and negative reactivity insertion during core heat-up events. This inherent reactivity feedback is one of the required safety functions the fuel is credited with during transient and safety analyses and allows the Xe-100 to achieve a safe shutdown condition for certain Licensing Basis Events (LBEs).

Safe shutdown capability is also provided by two banks of control rods inserted into the side reflector. One control rod bank, the Reactivity Control System, is used in normal operation and can achieve hot shutdown if inserted. The second control rod bank, the Reactivity Shutdown System, credited as the diverse means of achieving the reactivity control function, is inserted by the safety-related Reactor Protection System and is used to establish long-term cold shutdown conditions. The relatively small core diameter allows safe shutdown by inserting control rods into the side reflectors only; no in-core control rods are needed. There is provision for initiating a manual trip from the control room as additional defense-in-depth, as well as provision for unloading pebbles as another means of removing excess reactivity and ensuring a subcritical state. While the control room operators monitor plant/unit responses and can provide such defense-in-depth support, these are not risk-significant actions and plant safety is assured without operator intervention.

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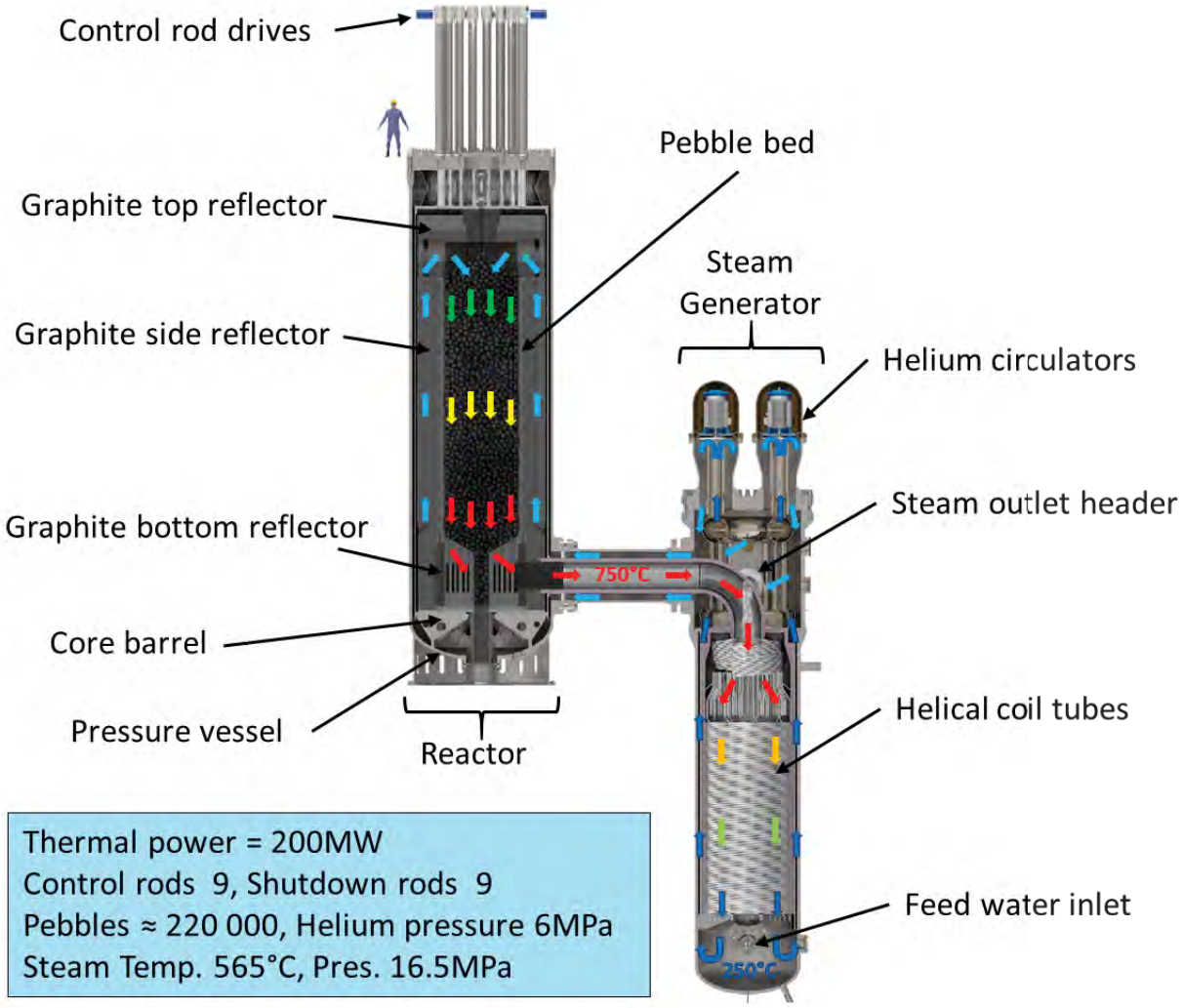

Figure 1: Xe-100 Section View

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If active cooling is lost, maximum fuel temperatures are limited by design, and decay heat is passively removed from the fuel through the core structures, core barrel, and RPV via conduction, natural convection, and radiation. Heat removed from the RPV to the reactor cavity is discharged to the ultimate heat sink by one of three methods: 1) to the atmosphere by two trains of tube curtains called the Reactor Cavity Cooling System (RCCS) in an active-cooling mode, 2) to the atmosphere by the RCCS in a passive boil-off mode, or 3) directly to ground by conduction, natural convection, and radiation from the reactor cavity through the RCCS tube curtain and into (and through) the reactor building concrete structures. Design features such as the low core power density, relatively large height-to-diameter ratio of the reactor, and the non-insulated RPV ensure effective heat removal if active cooling is lost. The core power density is nearly 20 times lower than most light water reactors (LWR) [4]. The combination of a low core power density and the large structural mass and heat capacity of the graphite ensures very slow thermal transients. Thermal transients in the Xe-100 typically occur in periods of hours or days, rather than in the seconds or minutes characteristic of LWR thermal transients. Further, the functions of moderation and thermal transport are fully separated in the case of the Xe-100 versus that of typical LWRs. Therefore, losing the thermal transport medium for any reason is of no safety consequence. The moderator (pebble graphite matrix) remains in-place. These long grace periods lead to a significant difference in how operator decision-making occurs, and safe conditions in the reactor are assured even without operator intervention.

2.2. THE XE-100 SAFETY DESIGN APPROACH

2.2.1. Objectives of the Safety Design Approach

The Xe-100 safety design approach[2] supports the objectives of designing, constructing, maintaining, and operating the plant to ensure the health and safety of the public and workers and protection of the environment throughout the spectrum of Licensing Basis Events (LBEs): normal operating conditions including Anticipated Operational Occurrences (AOOs), Design Basis Events (DBEs), Design Basis Accidents (DBAs) which are analyzed assuming only the safety-related SSCs are available, and Beyond Design Basis Events (BDBEs).

The Xe-100 safety design approach is different from that of the currently licensed LWRs, which focuses on preventing and mitigating core damage and a large early release of radionuclides in the event of core damage. The safety design approach of the Xe-100 precludes fuel degradation or failure sufficient to significantly affect radiological consequences and focuses on preventing and limiting the release of relatively small amounts of radionuclides during normal operation and off-normal event sequences. X-energy uses the guidance of NEI 18-04, as clarified by Regulatory Guide 1.233, as the basis for identifying and selecting LBEs for evaluation in the design and licensing bases for the Xe-100. The implementation of

[2] X-energy takes the definition of safety design approach from NEI 18-04, as "The strategies that are implemented in the design of a nuclear power plant that are intended to support safe operation of the plant and control the risks associated with unplanned releases of radioactive material and protection of the public and plant workers. These strategies normally include the use of robust barriers, multiple layers of defense, redundancy, and diversity, and the use of inherent and passive design features to perform safety functions."

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NEI 18-04 in the Xe-100 design is further described in X-energy's licensing topical report on the Risk-Informed, Performance-Based Licensing Basis Approach for the Xe-100 Reactor (ML21196A070).

2.2.2. Reactor Passive and Inherent Design Characteristics that Contribute to the Design Bases

Passive design features are defined as design features engineered to meet their required functional design criteria without (a) needing successful operation of active systems with mechanical components such as pumps; blowers; heating, ventilation, and air conditioning or sprays that require an external power source; (b) depending on alternating current electric power; or (c) relying on operator actions. Inherent design characteristics are those characteristics associated with the reactor concept and the properties of the materials selected for the basic reactor components. Of direct relevance here are those passive design features and inherent characteristics that serve to limit the fuel temperatures during normal operation and AOOs and LBEs such that the fuel integrity is not compromised.

In addition to the fuel, the specific characteristics of the Xe-100 design that contribute to safety include:

- A large solid graphite moderator/reflector structure with very high temperature capability. The graphite provides large heat capacity in the core that increases the time constants and reduces the magnitude of core thermal transients. Limiting transients occur over hours and days, not seconds. No fast-acting active safety systems are required to maintain the fuel within specified acceptable fuel design limits.
- A passive heat transfer path from the fuel to the ultimate heat sink, the external atmosphere or ground. This heat transfer path through graphite moderator/reflector and through the reactor vessel to the reactor cavity cooling system, and to the external atmosphere or ground has the capacity, without requiring any active systems, to limit fuel, reactor pressure vessel, and reactor cavity structural concrete temperatures. This ensures there is no degradation of the core geometry and that degradation of the fuel pebble barriers is limited to acceptable levels.
- A large negative temperature coefficient that inherently limits reactor power levels to relatively low levels under accident conditions without reactivity control system or reactivity shutdown system rod insertion of negative reactivity.
- A low core power density and high core surface-to-volume ratio that limits the fuel temperature rise during the most limiting conditions of loss-of-forced cooling and depressurization of the primary circuit.
- A single-phase, chemically inert, neutronically transparent, and high thermal conductivity helium heat transport fluid with low stored energy, minimizing the functional requirement for containment of energy in a postulated breach of the reactor helium pressure boundary.

The Xe-100 helium pressure boundary (HPB) is shown in Figure 1. The functional layout of a single Xe-100 unit is shown in Figure 2. The Xe-100 reactor building is a vented, low-pressure reactor building. Additional reactor design parameters can be found in the Xe-100 Technology Description Technical Report.

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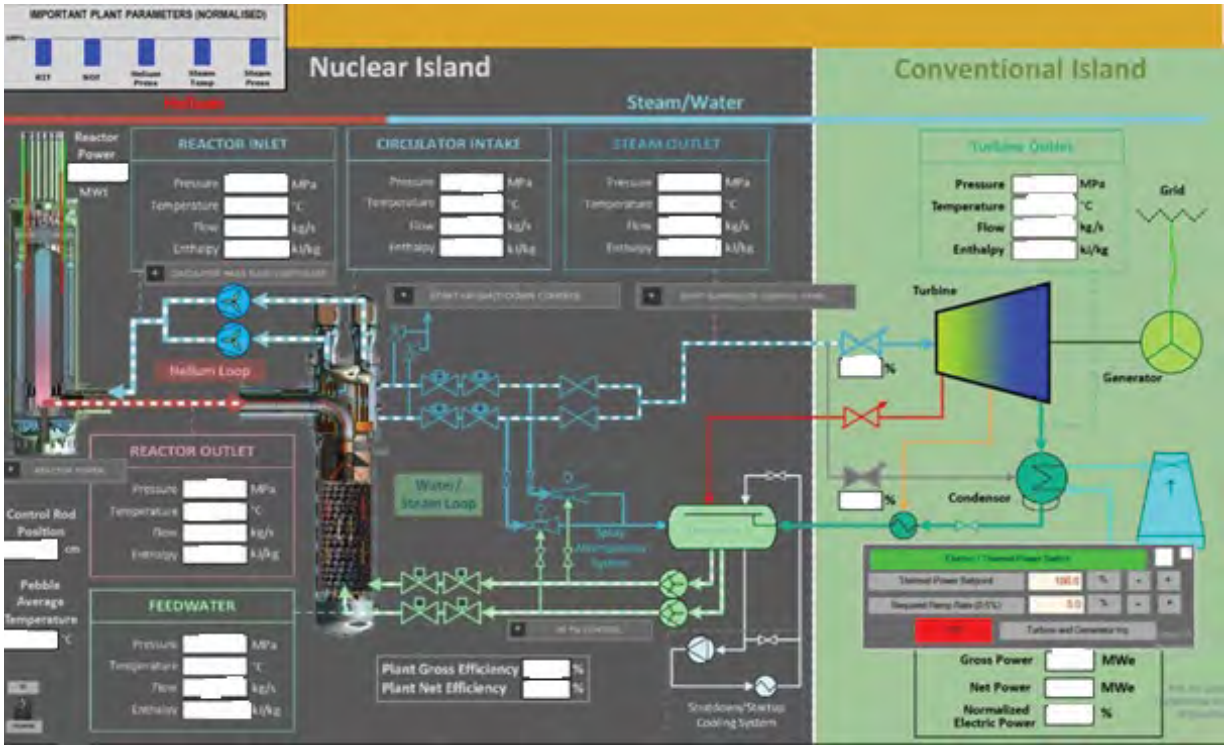

Figure 2: Functional layout of a single Xe-100 unit

3. OVERVIEW OF REGULATORY REQUIREMENTS AND GUIDANCE

10 CFR 50.54(m) specifies minimum licensed operator staffing requirements for control rooms and responsibilities as a license condition of plant operating licenses. These requirements do not address a plant design with more than three units on a site or more than two units operated from a single control room. Further, control room staffing, including the number, composition, and qualifications of personnel, are more appropriately based on features unique to the design rather than on the existing large, light water reactor-based staffing levels. Features unique to the Xe-100 include a safety design approach that relies on inherent and passive safety features, increased use of automation technologies, and adopting innovative control station designs. The initial Xe-100 concept of operations establishes a shift crew of three control room operators who will oversee multi-unit operations from a single control room, optimized at the conceptual design phase for four units.

The hierarchy of regulatory requirements and guidance followed in the development of the approach described in this topical report and to be followed in subsequent analysis activities is illustrated below. While X-energy does not intend to use NUREG-0800 guidance across all sections of a license application, the review acceptance criteria for HFE in Chapter 18 are relevant to this topical report and the Xe-100 staffing analysis approach.

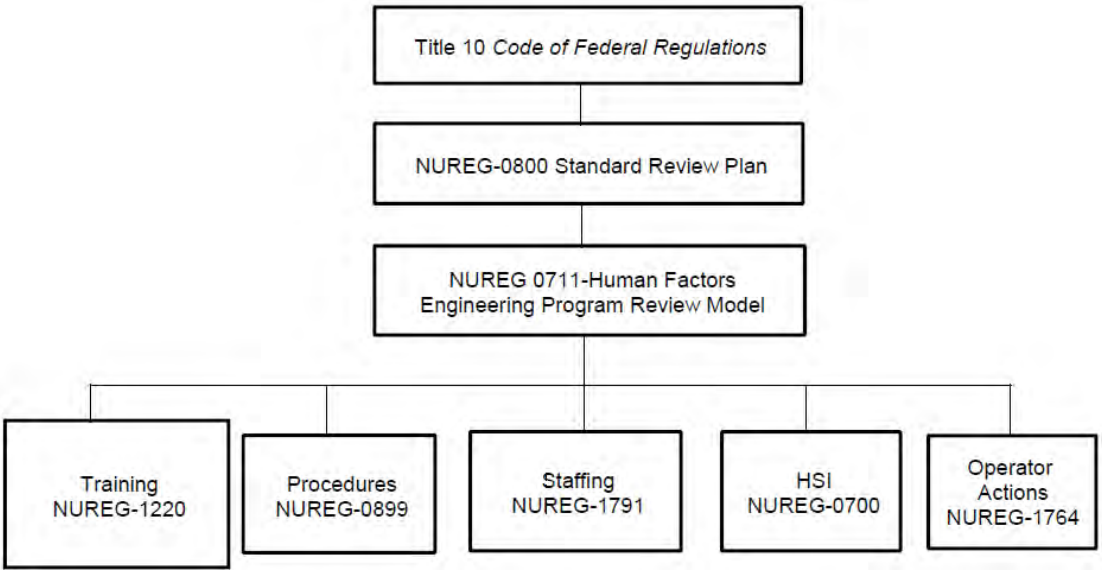

Figure 3: Relationship of NUREG-1791 and other regulation and related guidance

3.1 Code of Federal Regulations Requirements

3.1.1. 10 CFR 50.34(f)

Although consideration of this post-TMI regulation may not be specifically required for an Advanced Nuclear Reactor, X-energy will evaluate the requirements of 10CFR 50.34(f) for applicability and incorporate those requirements that should be included in the development of the Xe-100 HFE program.

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3.1.2. 10 CFR 50.54(m)

The current requirements for main control room staffing are primarily found in 10 CFR 50.54(m). These requirements evolved over decades of operating experience with the large LWR fleet of designs and their concept of operations. The minimum staffing levels are often captured for convenience in Table 1 of NUREG-1791 (reproduced in Figure 4) for multi-unit sites in various modes of operation.

Number of Nuclear Power Units Operating[2]	Position	One Unit	Two Units		Three Units	
		One Control Room	One Control Room	Two Control Rooms	Two Control Rooms	Three Control Rooms
None	Senior Operator	1	1	1	1	1
	Operator	1	2	2	3	3
One	Senior Operator	2	2	2	2	2
	Operator	2	3	3	4	4
Two	Senior Operator		2	3	3[3]	3
	Operator		3	4	5[3]	5
Three	Senior Operator				3	4
	Operator				5	6

[1] Temporary deviations from the numbers required by this table shall be in accordance with criteria established in the unit's technical specifications.

[2] For the purpose of this table, a nuclear power unit is considered to be operating when it is in a mode other than cold shutdown or refueling, as defined by the unit's technical specifications.

[3] The number of required licensed personnel when the operating nuclear power units are controlled from a common control room is two senior operators and four operators.

Figure 4: Minimum Requirements Per Shift for On-Site Staffing of Nuclear Power Units by Operators and Senior Operators Licensed Under 10 CFR Part 55

- As described in NUREG-1791, there are implicit assumptions found in these requirements, and limitations on their scope, including:
  - there is a maximum of three units and three control rooms at a plant/station;
  - the number of control rooms does not exceed the number of units;
  - there are no more than two units controlled per control room;
  - there is always at least one operator at the controls for each unit (10 CFR 50.54(m)(2)(iii));
  - there is always at least one, and sometimes two additional operator(s) on site, for each unit in operation;
  - there is at least one senior operator on site at all times (10 CFR 50.54(m)(2)(ii));
  - there is one senior operator in the control room for each unit in operation (10 CFR 50.54(m)(2)(iii));
  - there is one more senior operator than the number of units operating when multiple units are in operation in more than one control room, except when three units are in operation in two control rooms; and

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- operator and senior operator are the only two job functions addressed by the Code of Federal Regulations, and their roles, responsibilities, and qualifications are as defined in 10 CFR Part 55.

Additionally, 10 CFR 50.54(m)(2)(iv) requires a person holding a senior operator license (or senior operator license limited to fuel handling) to directly supervise alterations of the core of a nuclear power unit during fuel handling without any other assigned duties. Due to the continuous refueling regime of a pebble-bed reactor, this requirement is not logical or practical for the Xe-100 operational staff. The basis for this consideration is moving bundles of fuel discretely to manage core load requirements. In comparison, the Xe-100 concept of refueling operation (i.e., automated, continuous recirculation and replenishment of pebbles representing extremely small fractions of the total excess reactivity, with the ability for operator intervention when necessary) does not warrant continuous SRO supervision. The Xe-100 approach to continuous fuel movement and resultant impact on operator workload will be addressed in the control room staffing analysis.

3.2. SUPPORTING REGULATIONS

3.2.1. Exemption Requests in Regulations and Regulatory Guidance

10 CFR 50.12 provides the authority for the Commission to grant specific exemptions from the regulations. The technical basis for assessing exemption requests from licensed operator staffing requirements specified in Part 50.54(m) are provided in NUREG/CR-6838. NUREG-1791 provides additional guidance for assessing control room staff exemption requests, and which special circumstances exist that provide justification for §50.12 exemptions.

3.3. NUREG-0711 HUMAN FACTORS ENGINEERING PROGRAM REVIEW MODEL

The Xe-100 Control Room Staffing methodology will use accepted HFE standards and guidelines, including the applicable guidance provided in Human Factors Engineering Program Review, NUREG-0711, Rev. 3. The planning and analysis portion of the HFE Program will include a staffing and qualifications analysis to establish the number and qualification of licensed operators required for safe and reliable operations

3.3.1. NUREG-1791 Guidance for Assessing Exemption Requests for the Nuclear Power Plant Licensed Operator Staffing Requirements Specified in 10 CFR 50.54(m)

NUREG-1791 provides the primary guidance for the NRC staff to evaluate exemption requests for the minimum staffing requirements of 10 CFR 50.54(m) and provides a systematic approach to determining the acceptability of such requests. It provides a review process that addresses the major elements, mostly related to a comprehensive HFE program, that will provide the technical bases for an exemption from regulatory requirements, which includes:

- Discussion of each review process step and the basis for inclusion,
- Data and information requirements to support NRC review of each step,
- Review criteria for evaluating an applicant's submittals, and
- Recommended additional information that may be useful in performing the review.

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It also provides checklists for each review step, some of which are described later in this topical report.

3.3.2. NUREG/CR-6838 Technical Basis for Regulatory Guidance for Assessing Exemption Requests from the Nuclear Power Plant Licensed Operator Staffing Requirements Specified in 10 CFR 50.54(m)

This contractor-developed NUREG provides the technical bases for NUREG-1791 and the systematic approach to reviewing exemption requests for 10 CFR 50.54(m). The control room staffing analysis methodology described herein applies to the HFE elements that provide a technical basis for determining the number and qualification of licensed operator personnel as defined in 10 CFR 55 “Operators’ Licenses”. This topical report does not provide a methodology for analysis of non-licensed operators, maintenance or craft personnel, or other plant support staff (i.e., health physics, engineering, security, emergency operations, etc.) numbers or qualifications. As part of the HFE elements described herein, the task analysis and job description activities (among others) may identify impacts on licensed operator workload for further analysis in the area of non-licensed operator personnel, which will be provided in future licensing submittals when necessary.

3.3.3. NUREG-0700 Human-System Interface Design Review Guidelines, Revision 3

This guidance, co-authored with Brookhaven National Laboratory, provides guidelines to evaluate the interfaces between plant personnel and plant systems as part of the overall HFE program review. Since task analysis and functional requirement analysis and function allocation play a significant role in establishing the bases for licensed operator personnel numbers and qualifications, and these activities are dependent on some amount of human-system interface development, X-energy uses NUREG-0700 as a key reference to develop the human-system interfaces for the control room.

3.4. COMMISSION POLICIES

X-energy reviewed the following Commission policies considered relevant to the analysis methodology described in this topical report.

3.4.1. Policy Statement on the Regulation of Advanced Reactors, 73 FR 60612 (NRC-2008-0237)

This policy statement, an affirmation of the Commission’s earlier Advanced Reactor Policy of 1984 with further clarifications, the Commission provides its expectation that advanced reactors “will provide enhanced margins to safety and/or use simplified, inherent, passive or other innovative means to accomplish their safety and security functions”. Two specific attributes related to this topical report are:

> *Simplified safety systems that, where possible, reduce required operator actions, equipment subjected to severe environmental conditions, and components needed for maintaining safe shutdown conditions. Such simplified systems should facilitate operator comprehension, reliable system function, and more straightforward engineering analysis.*
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Designs that include considerations for safety and security requirements together in the design process such that security issues (e.g., newly identified threats of terrorist attacks) can be effectively resolved through facility design and engineered security features, and formulation of mitigation measures, with reduced reliance on human actions.

The Xe-100 safety design approach included consideration of safety and security requirements early in development to produce a multi-unit plant that, by design, requires fewer human actions during normal operation and across the spectrum of LBEs. The use of inherent system characteristics to manage heat generation and removal, protect the multiple barriers providing radionuclide retention, and maintain the overall system geometry to assure the required safety functions are provided for meets the expectation of simplified safety systems. This safety design approach supports a control room staffing analysis approach with expected results that will differ from the large LWR designs.

3.4.2. Policy Statement on Engineering Expertise on Shift, 50 FR 43621

This policy statement provides the Commission's expectations regarding educational experience and combining certain roles within the licensed operator personnel on shift during nuclear power plant operations. It provides the Commission's expectation that engineering and accident assessment expertise be provided on shift to provide for immediate actions that may become necessary during off-normal conditions. In evaluating the roles and responsibilities of the Xe-100 control room operator personnel, including necessary qualifications, the HFE Program will address the adequacy of such technical expertise available for normal operations and the spectrum of LBEs. This will include consideration of the most recent industry guidance, operating experience, and related Commission Policies (i.e., Education for Senior Reactor Operators and Shift Supervisors at Nuclear Power Plants 54 FR 33639).

3.4.3. Policy Statement on the Conduct of Nuclear Power Plant Operations, 54 FR 3424

This policy statement provides the Commission's expectations with respect to a professional, controlled environment in a nuclear power plant's main control room, emphasis on licensed operators' conduct and attentiveness, and other direction to enhance the safety of plant operations. The systematic methodology described in this report will enable X-energy to provide a sound basis for future licensees to conduct operations in a professional and safe manner and meet the Commission's previously established expectations. Areas analyzed in the HFE process include:

- the control room design and layout,
- operator tasks and job descriptions,
- operator knowledge, skills, abilities, and
- the identification of the number of licensed operators.

3.5. SECY PAPER PRECEDENTS

The NRC has released Commission SECY papers relevant to development and use of a control room staffing analysis and HFE Program. X-energy reviewed these documents as part of the developing the control room staffing analysis methodology described in this topical report.

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3.5.1. SECY-93-092 Issues Pertaining to the Advanced Reactor (PRISM, MHTGR, and PIUS) and Candu 3 Designs and Their relationship to Current Regulatory Requirements

Section F "OPERATOR STAFFING AND FUNCTION" of this SECY paper provided considerations for advanced reactor designs (of the time period) regarding Operator Staffing and Function. These considerations are similar to issues identified for LW-SMRs developed in later years. In SECY-93-092, the NRC staff provided the following specific recommendations:

Staff Recommendation

The staff believes that operator staffing may be design dependent and intends to review the justification for a smaller crew size for the advanced reactor designs by evaluating the function and task analyses for normal operation and accident management. The function and task analyses must demonstrate and confirm the following through test and evaluation:

- *Smaller operating crews can respond effectively to a worst-case array of power maneuvers, refueling and maintenance activities, and accident conditions.*
- *An accident at a single unit can be mitigated with the proposed number of licensed operators, less one, while all other units could be taken to a cold-shutdown condition from a variety of potential operating conditions, including a fire in one unit.*
- *The units can be safely shut down with eventual progression to a safe shutdown condition under each of the following conditions: (1) a complete loss of computer control capability, (2) a complete station blackout, or (3) a design-basis seismic event.*
- *The adequacy of these analyses shall be tested and demonstrated. The staff is currently recommending that an "actual control room prototype" be used for test and demonstration purposes.*

These considerations will be addressed in the Xe-100 design through implementation of the Control Room Staff Analysis methodology.

3.5.2. SECY-11-0098 Operator Staffing for Small or Multi-Module Nuclear Power Plant Facilities

This Commission paper provided the NRC staff's assessment of approaches to resolve the issue of control room staff compliment determinations for multi-unit facilities and exemptions to the minimum staff requirements of 10 CFR 50.54(m). The proposed approach was to process a limited number of applications using exemption requests before considering rulemaking to codify any changes to the regulation. The NRC staff reference earlier work on the subject (e.g. SECY-10-0034) and on-going efforts to understand various stakeholder positions on the subject. The staff provide a path to develop exemptions via the guidance provided in NUREG-1791, described in this report in a later section.

Of particular interest from this SECY, the NRC staff observes the following significant differences between existing large LWR designs and the SMRs under consideration:

- *The SMRs may require different operator tasks. The task requirements will include operating multiple units in different modes of operation. A major challenge will be to identify tasks that may be omitted and those that could substantially affect operator workload.*

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- *Very limited operational experience will be available to use as a resource, as these designs are first of a kind. The use and observation of simulator activities will be important to the verification of the task analyses and staffing plans. Parallels in other industries may be useful, if they exist.*
- *Integration challenges exist in defining not only tasks required for operating the unit but also for interacting with other on-site maintenance and support organizations for multiple units.*
- *The skill set for control room operators may require a different distribution of qualifications (e.g., more senior reactor operators, fewer reactor operators).*
- *For some SMR designs, operators will face the challenge of managing the operation of additional units as they are placed online. As the number of modules increases, the demands on the operators will change, and potentially the number of operators required for safe operation (i.e., multiple staffing plans may be needed to address the addition of up to 11 more units during the construction period or subsequent operating period).*

These considerations will be addressed in the Xe-100 design through implementation of the Control Room Staff Analysis methodology.

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4. CONTROL ROOM STAFFING ANALYSIS METHODOLOGY

The X-energy Control Room Staffing Analysis Methodology will be based on the guidance provided in NUREG-0711 on developing an HFE program and will include the 12 elements required to analyze and describe the results of an acceptable HFE program as delineated in that guidance.

4.1. CONCEPT OF OPERATIONS

The Xe-100 Concept of Operations [8] provides an understanding of how the initial staffing fits into the overall plant design and operation. The document introduces the staffing, qualifications and operation assumptions that will be subsequently consolidated, modified, or dismissed during the implementation of the HFE Program.

The concept of operations, degree of automation, and the Xe-100 plant design is different than existing LWR operations during normal, abnormal, and emergency situations.

The Concept of Operations includes the starting premises for:

- primary design and operating characteristics of the plant,
- specific staffing goals and assumptions necessary to implement the concept of operations,
- number of personnel who will have plant monitoring and operational control responsibilities on each shift,
- roles and responsibilities of everyone designated as control room personnel, if that individual is responsible for controlling and monitoring plant or unit operations,
- overall operating environment and primary HSIs to be used by control personnel,
- interactions of control personnel with each other and with people not directly responsible for the control and safe operation of the plant,
- interaction of control personnel with automated support systems and the role of these systems in the overall management and control of the plant,
- changes in the responsibilities or qualifications of the control personnel, such as combining the responsibilities for operations and fuel handling,
- aspects related to multi-unit operations during construction of additional units (as applicable),
- interaction of control personnel with automated systems, including responsibilities for monitoring, operating, and overriding automated systems, and
- other mechanisms that enable or support control personnel responsibilities for monitoring, disturbance detection, situation assessment, response planning, response execution, and the management of transitions between automatic and manual control.

The Concept of Operations provides a staffing baseline for the beginning of the HFE Program. The staffing configuration and the above listed aspects might evolve during the execution of HFE activities, especially during the S&Q element. During execution the following items will be assessed:

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- staffing levels for personnel across shifts, and
- training and qualifications required for control personnel.

4.2. OPERATIONAL CONDITIONS CONSIDERED IN THE HFE PROGRAM

For the purposes of the HFE Program, it is necessary to select the operational conditions based on the results from various sources of event sequences, which will provide a robust sample to be further analyzed and tested. The selection will compile those conditions that present the greatest challenges to human performance and those critical for plant safety.

Subsequent analysis activities of the HFE Program focus on the operational conditions chosen. The scope of the analysis will include:

- a description of the operational conditions selected for analysis, and
- the rationale for selecting the operational conditions analyzed and for excluding others that could have been analyzed.

The following activities may provide sources to identify the operational conditions:

- PRA, Probabilistic Risk Assessment,
- HRA, Human Reliability Analysis,
- OER, Operating Experience Review,
- TIHA, Treatment of Important Human Actions, and
- TA, Task Analysis.

The selected operational conditions will be turned into a sample of prioritized interfaces and operational scenarios to be verified and tested (validated). This task is carried out in the HFE Program in the HF V&V element prior to performing the following activities:

- HSI Task Support Verification,
- HSI Design Verification, and
- Integrated System Validation.

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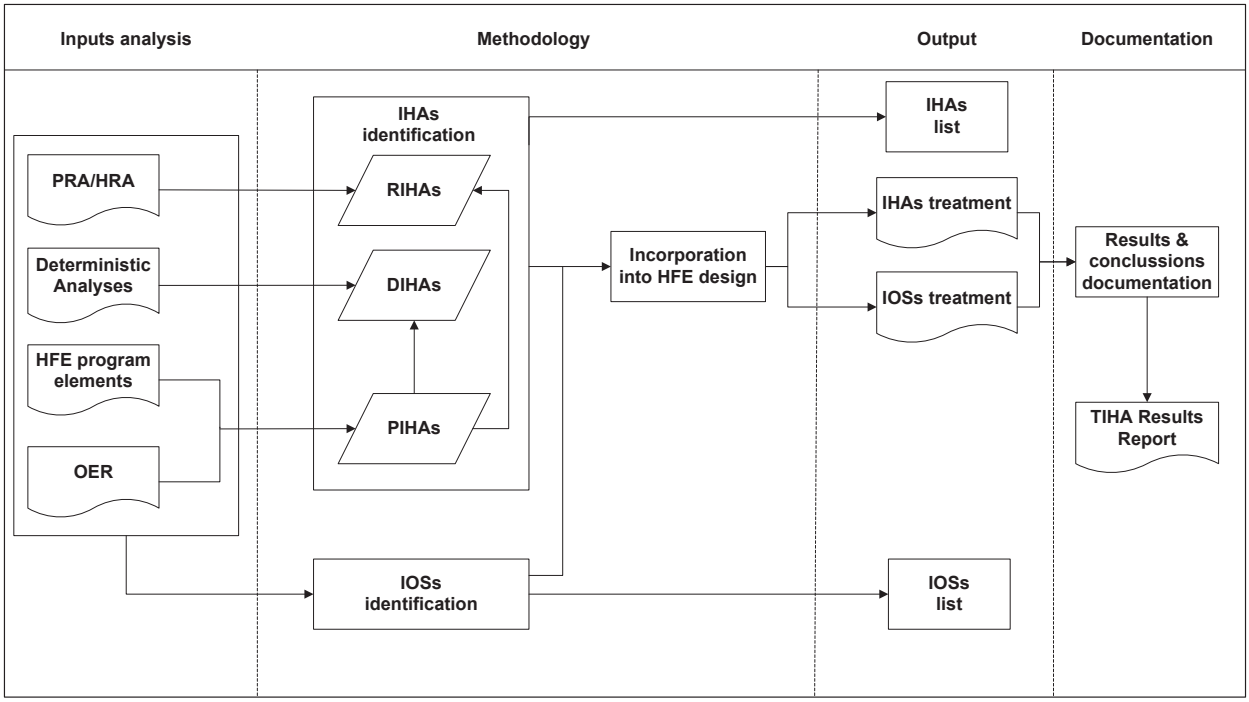

Figure 5: TIHA activities flowchart

Within the Xe-100 HFE Program, the TIHA analysis, as described in its implementation plan [10], envelops the above concept of operational conditions. As shown in Figure 5, the TIHA identifies: the actions (or IHAs) and the operating sequences, or IOS. Each IHA has a detailed description, including the context in which the IHA was identified. It may refer to specific plant conditions and/or events. The IOS is defined in the same manner. The IHAs and IOS are later incorporated, with a specific resolution (called treatment in the flowchart above), into the rest of the HFE program elements.

4.3. OPERATING EXPERIENCE

The Xe-100 shares similarities with several existing reactor types and precedents. While the majority of operating HTGRs were developed and operated outside of the U.S., several mature designs have progressed through the U.S. licensing framework to varying degrees, and these designs share operating characteristics with the Xe-100 design. The international experience with pebble-bed HTGRs was principally established in Germany and is now growing with the Chinese demonstration plants.

X-energy has conducted an initial search for operating experience (OPEX) from domestic and international HTGR plants to inform the plant design. Multi-unit operational considerations were not applicable to those plants, so alternative sources of OPEX will be explored for these considerations. Specific insights from the number and qualifications of control room operators and their contributions to safe plant operation will be developed in accordance with the HFE program.

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The operating experience review of the HFE Program should identify staffing issues to be avoided. Also, it should identify staffing practices that have proven to be effective and therefore be incorporated into the operation environment.

Since the operating experience from new reactor designs is limited, research will be oriented to past high-temperature gas-cooled reactor designs, prototype reactors and recent modular designs. Multi-unit operation experiences can be found in other industries giving valuable insights for the Xe-100 plant operation.

Research sources for potential Operating Experiences are:

- NRC Database;
- IAEA Database;
- INPO Database;
- NEA Scientific and technical publications;
- CANDU Database; and
- Sources from non-nuclear industries:
  - Non-nuclear Electric Generating Stations,
  - Chemical industry,
  - National Transportation Safety Board,
  - Aviation Safety Network, and
  - Natural Gas Generating Stations.

Finally, the operating experience review provides useful input to the rest of the HFE Program elements and activities, especially Task Analysis, in which the issues found related to the impact of staffing shortfalls may be useful. The operating experience review can also be a source for identifying operational conditions relevant to the control room staffing analysis.

The methodology for conducting the Operating Experience Review for the Xe-100 consists of three steps, illustrated in Figure 6, and it is fully described in the OER Implementation Plan [9].

Figure 6: OER methodology process

4.4. FUNCTIONAL REQUIREMENTS ANALYSIS AND FUNCTION ALLOCATION

As explained in the HFE PMP [7], the Functional Requirements Analysis aims to identify the functions that must be performed to achieve Xe-100 plant goals. The analysis will define and assess the aspects of the control room staffing analysis on the functions, especially those allocated to the operator.

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Performance of the function allocation analysis assigns the functions to personnel, system elements or combination of both. The results from this analysis provide a concept of the level of plant automation necessary to achieve the functions not being performed by the personnel.

This analysis is linked to the staffing requirements, as the workload of the operators is closely related to the level of plant automation. A reduction of workload and staff necessary to monitor and control the reactor units is linked to the levels of automation and their reliability and should support a reduction in the number of operators in charge of plant operations due to the increased level of reliable automation.

The HFE Program will ensure that the allocation of functions enables the plant's goals to be accomplished, specifically for functions under the operational conditions relevant for the staffing exemption. This fact can only be satisfied if Task Analysis, Staffing and Qualifications, and Design Verification and Validation tests further validate the outputs from the Function Allocation.

If, during the validation tests of the operational conditions, the shift crew compliment is not proven to be sufficient to achieve a safe operation of the plant, then a review of the functional analysis will be conducted and a reallocation of the functions may be required.

The HFE Program activities, such as Function Allocation, will be iterated until the final staffing meets the operational needs.

Functional Requirements Analysis will be conducted to ensure that the functions necessary to accomplish plant goals are identified and sufficiently defined. The analysis will consist of a functional breakdown, where plant goals are in the top level and plant component statuses are in the lowest level. A plant goal is met if the related plant components are operating in their specified status. Hence, the functional requirements to accomplish the plant goals are the plant components properly operating.

Function Allocation will be performed to assign the functions to personnel and/or automation, considering their relative capabilities, strengths, and weaknesses. Therefore, the allocation methodology is based on HFE criteria. The objective is to avoid operation mistakes and maximize efficiency and reliability of the plant by maintaining the operator's awareness of plant status.

The results of the FA will provide the aggregate of human actions needed to perform the functions. These human actions will be further analyzed in the Task Analysis (Section 4.5). The overall process is shown in Figure 7.

The methodology to conduct Functional Requirements Analysis and Function Allocation is described fully in the Xe-100 FRA & FA Implementation Plan [11].

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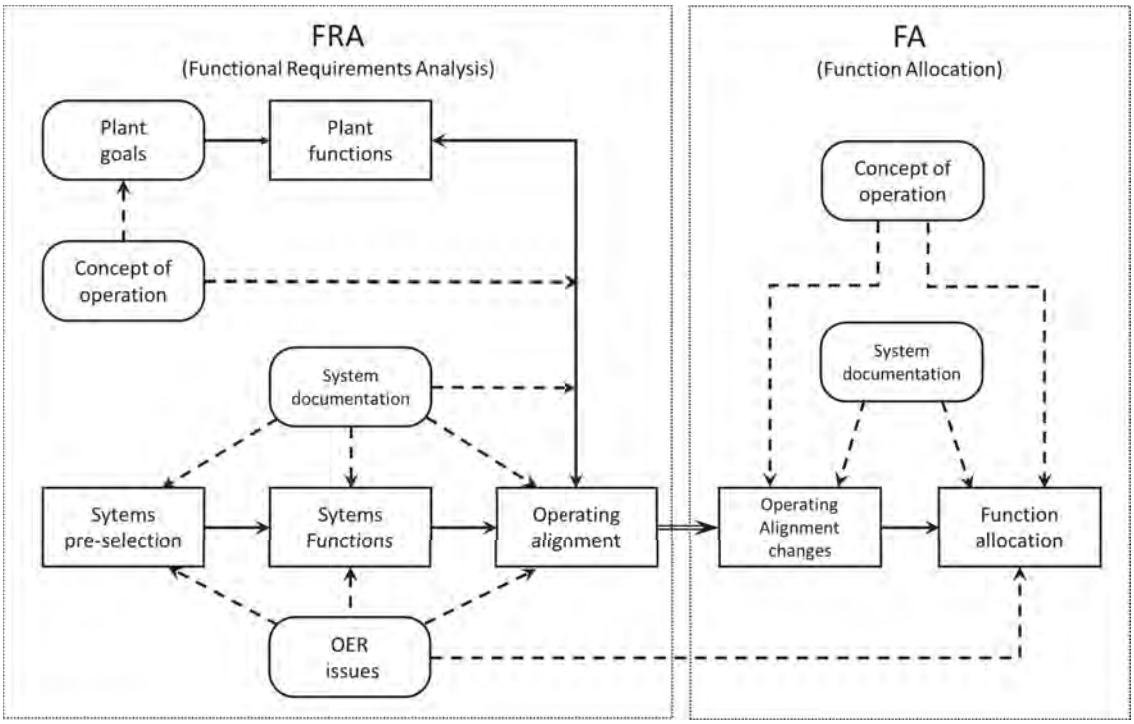

Figure 7: FRA & FA overall process

4.5. TASK ANALYSIS

Similar to the Functional Requirements Analysis and the Function Allocation, the Xe-100 Task Analysis addresses the operational conditions relevant to demonstrate changes in the shift crew make up. Human actions are needed to accomplish functions, and human actions can be further divided into smaller elements called *activities*. An individual activity is defined as a single action performed by the operator contributing to the completion of a task. For each activity, the information, control, and support requirements will be addressed as applicable.

Performance of the TA is rarely a "one-step" process, usually requiring one or more iterations as more detailed information about the plant or its systems becomes established, and the roles of various personnel become clearer. As the design matures, the TA becomes more detailed. TA and system design (including interface design) initially consider the types of information personnel need to understand the current system status, and requirements for information processing and display. In parallel, the types of controls necessary for response to presented information are also identified. After information and response requirements (e.g., displays, controls, procedures, etc.) are identified, ways the requirements are to be satisfied are specified. The importance of this formal and systematic approach becomes evident when considering the complexity of some human operations within system operations, and the coordination required to integrate various design decisions affecting human tasks at different stages during the design process.

The objective of an initial TA is collection and organization of information (data), facilitating subsequent use of the information for a variety of purposes (e.g., development of training requirements and training content, input to HFE design and design review, etc.). Specifically, the purpose of TA is appropriate HFE

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design, so the information is managed and structured toward definition of the optimum human-system interface based on the requirements made evident by the inherent predictive nature of TA.

The information compiled and analysis conducted are predictive, attempting to determine requirements for definition of an optimum human-system interface based on the information derived from the system design bases and experience of the industry. Information is also sought concerning the training requirements of operations and maintenance personnel and requirements for plant procedures.

The task analysis provides information to identify task timing and workload issues, giving potential information to determine conflicts that would affect the staffing configuration. Detailed task descriptions are developed for operating sequences which affect plant safety, applying a graded approach to the TA. Therefore, tasks required to fulfill *important operating sequences* identified in the Treatment of Important Human Action process (those performed under the chosen Operation Conditions, see Section 4.2) will be more thoroughly described.

Detailed task descriptions provide:

- Information required (parameters, units, precision, accuracy),
- Information source (alarms, displays, verbal communication, etc.),
- Actions to be taken,
- Overlap of task requirements (serial vs. parallel tasks),
- Frequency,
- Time available for operator response based on the plant response characteristics,
- Temporal constraints (task ordering),
- Tolerance and accuracy,
- Operational limits of personnel performance, and of machine and software,
- Feedback required to indicate adequacy of the actions taken,
- Cognitive and physical workload,
- Tools and equipment required,
- Computer processing support aids,
- Workspace location,
- Number of personnel, their technical specialty, and their specific skills,
- Communication required, including type,
- Personnel interaction when more than one person is involved, and
- Job aids or reference materials required.

The steps for compiling and organizing information in TA methodology are structured as follows:

1) Converting functions to operating sequences,

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2) Developing narrative task descriptions, and
3) Developing detailed task descriptions.

The full methodology to conduct the Task Analysis is described in the Xe-100 TA Implementation Plan [12].

4.6. JOB DEFINITIONS

A job is a group of tasks and functions that are assigned to a specific operational position.

As the Xe-100 job definition may vary from traditional jobs in the control room, it is necessary to precisely define the qualifications (knowledge, skills, and abilities) with the tasks that an individual must perform. The job definition will be addressed after the HFE Task Analysis by the Systematic Approach to Training (SAT) process.

By following the SAT process for the training material development, matching between the KSAs (Knowledge, Skills, and Abilities) list, job definition, and Staffing & Qualification is ensured, as all the activities are connected and take the same Task Analysis as input. The Staffing & Qualifications (S&Q) activities describe and define the scope and impacts on the roles, responsibilities, and qualifications of control room personnel.

4.7. STAFFING PLAN

The next step is to analyze the number of personnel necessary to perform each job. The staffing plan is supported by the results of the preceding analyses and it provides information about the operational staff shift composition and shift scheduling. In the case of operations that take place outside the main control room, the location and personnel will be specified.

The S&Q element of the HFE Program involves a theoretical assessment of the staffing plan under the operational conditions selected in terms of response time. It is characterized by a systematic approach, namely the different stages of the methodology that are intended to be followed in the order in which they are presented.

Figure 8 presents a high-level representation of the S&Q process to be followed during the S&Q analysis development.

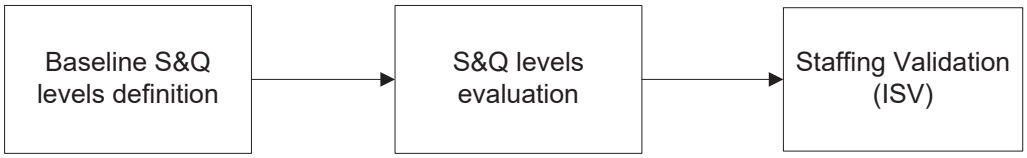

Figure 8: S&Q overall process

The analysis is iterative; that is, the initial staffing goals are defined for the personnel in the control room and then will be re-evaluated as information from other HFE elements becomes available, until the ISV is completed and the staffing level is validated.

The methodology to conduct the S&Q analysis is described in the Xe-100 S&Q Implementation Plan [13].

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4.8. ADDITIONAL DATA AND ANALYSES

Other data and analysis may be provided:

- Human reliability analysis, used to demonstrate how risk-important human actions affect staffing levels.
- Data from the HSI development and verification, to demonstrate that the design supports the previous HFE analysis, which is ensured because the HFE Program follows NUREG-0711 [2].
  - The Xe-100 will be a predominately software-controlled installation; the operation tasks are accomplished through interaction using a human-software interfaces.
  - The goal of the HFE program elements is to provide an analysis that supports the software based HSI and provide alternative HSI options if the use of software HSI is not a viable option for specific applications.

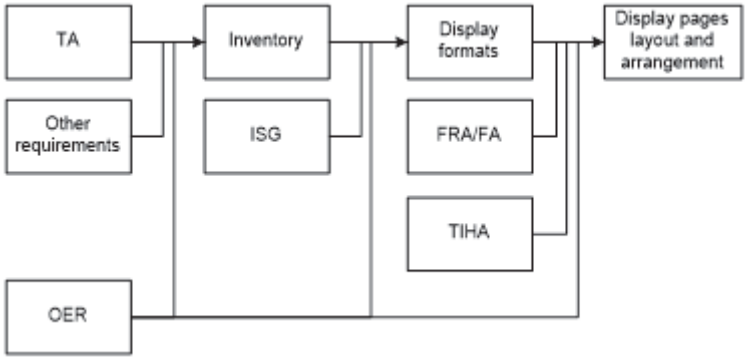

Figure 9: HSI design process

  - The HSI will also address the the allocation of displays and controls for manual system-level actuation of critical safety functions, and for monitoring those parameters that support them.
  - The HSI design methodology is described in the HSI Design Implementation Plan [14]. A representation of the HSI design path is provided in Figure 9.
- KSA analysis and list to support task analysis and job definitions.
- Procedures and Training Program documentation demonstrating the implementation of concepts from the HFE Program that support the staffing exemption.

4.9. STAFFING PLAN VALIDATION

Staffing baseline resulting from the S&Q analysis is tested in the HFE Program during the Verification and Validation activities.

The staffing plan validation (SPV) refers to an assessment using performance-based tests to determine whether the staffing plan meets performance requirements and acceptably supports safe operation of the plant.

The validation tests of the HFE Program will be performed during different phases of the design. In the beginning, this is done by early partial validations with portions of the HSI design. Finally, when the complete simulation environment is ready, the Integrated System Validation (ISV) is performed. In this

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way, the HFE Program ensures operator's gradual adaptation to the HSI and control room environment from the beginning of the design.

The assessment should demonstrate that the proposed Xe-100 plant shift crew, three operators in one control room operating multiple reactor units, can satisfy the plant and human performance requirements identified in the functional requirements analysis, function allocation, and task analyses. This assessment should include the range of operational conditions identified as relevant.

Therefore, the demonstration is done through simulations that involve the operators and operating experience contribution. The following detailed test objectives and considerations will be addressed to provide evidence that the integrated system adequately supports plant personnel in safely operating the plant:

- Validate the acceptability of the shift staffing level(s), the assignment of tasks to crew members, and crew coordination within the control room, between the control room and local control stations and support centers, and with individuals performing tasks locally.
- Validate that the design has adequate capability for alerting, informing, controlling, and providing feedback such that personnel tasks selected are successfully completed during normal plant evolutions, transients, design-basis accidents, and a range of licensing basis events, including risk-significant beyond-design basis events, as defined by sampling operational conditions.
- Validate that specific personnel tasks can be accomplished within the time and performance criteria, with effective situational awareness and acceptable workload levels that balance vigilance and personnel burden.
- Validate that the HSIs minimize personnel error and assure error detection and recovery capability when errors occur.
- Validate the assumptions about performance on identified important human actions.

The fundamental characteristics for the SPV are introduced below:

1. V&V sampling. Using the operational conditions as input, a sample of interfaces and scenarios are selected. The sampling dimensions to identify the conditions to be addressed are:
    - Plant Conditions:
        - Normal operations,
        - I&C and HSI failures,
        - Off-normal conditions and emergencies,
        - Transients (abnormal operational events) and accidents (emergency operational events),
        - Maintenance;
    - Personnel Tasks;
    - Error forcing contexts;
2. Testbed conditions. A description of the validation environment, providing:
    - the scenarios to be tested,

- a representative number of crews and scenario repetition,
- the state of the simulator,
- the simulation conditions, and
- the number and duties of the HFE observers.

3. Human Performance Measurements. Data will be collected during the tests, through observation, questionnaires, and other techniques. The measurements can be typically classified according to a human cognitive model in the following fields:
   - Monitoring and detection,
   - Situation assessment,
   - Response planning,
   - Response implementation,
   - Situation awareness
   - Workload, and
   - Communication and teamwork

The data are analyzed and processed by considering a set of performance measurements that are established prior to the validation, for example:

- time to complete actions,
- timeliness of actions,
- accuracy and completeness of actions, and
- omitted actions.

The methods for data analysis and assessment will be described in a Validation Procedure and documented in the Validation Result Summary Report.

4. Validation criteria. Applicable criteria are identified in advance to determine the acceptability of the results. Examples of acceptability criteria are:
   - Main plant parameters were kept inside normal operational range,
   - The scenario finished with the plant stable,
   - Plant mode X was reached,
   - Nominal task performance times have not been exceeded by more than 10 percent,
   - No more than 60 seconds have been required to begin Task X after Event Y, and
   - No actions have been omitted.

The process and methodology for the human-in-the-loop simulations are described further in the Xe-100 Verification & Validation Implementation Plan [15]. The specific details for each validation test will be

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provided for in a Validation Procedure and documented in a Validation Result Summary Report. A summary of the V&V process activities is shown in Figure 10.

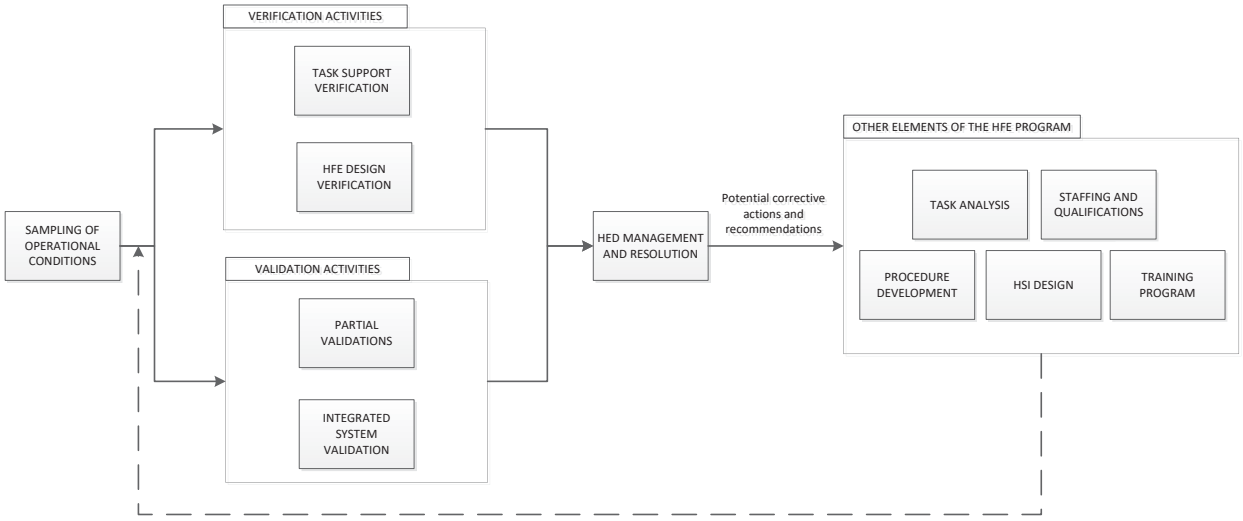

Figure 10: V&V overall process

4.10. EXEMPTION REQUEST PROCESS

NUREG-1791 provides the NRC's review guidance for exemption requests and, by extension, an approach to develop the technical basis for an exemption request for license applicants to the regulatory requirements of 10 CFR 50.54(m). This approach has also been recently applied to develop similar technical bases for a Part 52 Design Certification application. The specific approach to licensing will be made on a project-specific basis, but the control room staffing analysis methodology described herein will support a variety of options. During the development of the Xe-100 Implementation Plans of the NUREG-0711 [2] elements, additional requirements from NUREG-1791 [3] were added to ensure completeness of the methodology. For a license application. the exemption review is guided by the path shown on Figure 11, which is excerpted from NUREG-1791 [3]. NUREG/CR-6838 [5] comprises the basis for these eleven steps, which are further explained in NUREG-1791 [3].

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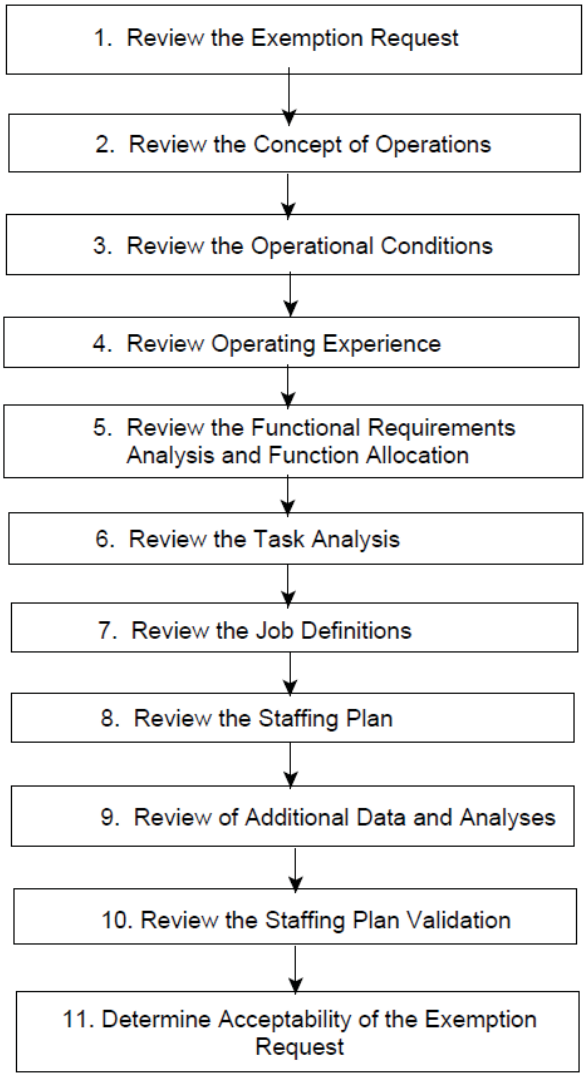

Figure 11: Exemption Request Review Process

The following tasks provide support to the exemption request and will be reviewed together:

- Operating experience review (OER),
- Functional requirements analysis and function allocation (FRA & FA),
- Task analysis (TA),
- Human Factors Verification & Validation (HF V&V).

Specifically, the HF V&V element contains performance-based tests to determine whether the Staffing & Qualifications support a safe operation of the plant.

Additional analyses and studies may also support the exemption request and review process. Figure 12 shows the importance of each NUREG-0711 [2] element in the strategy, from darkest blue, most important, to lightest blue, least importance.

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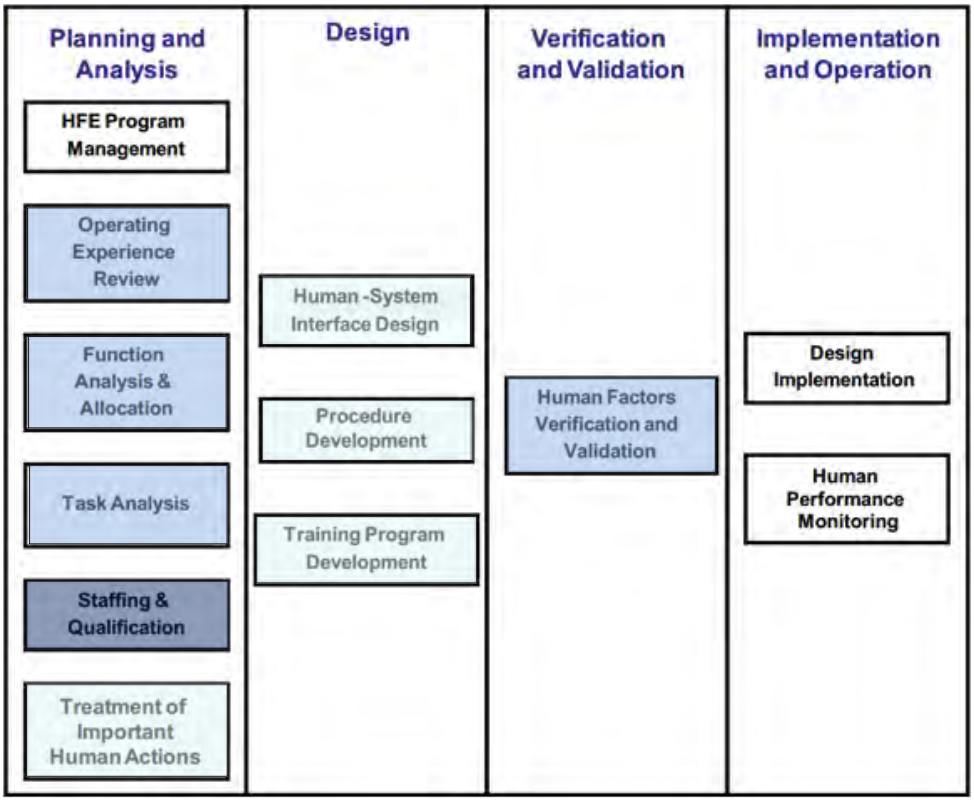

Figure 12: NUREG-0711 elements relevance in the NUREG-1791 approach

5. DEVELOPING THE CONTROL ROOM STAFFING ANALYSIS

Figure 13 shows the process to be followed by the Xe-100 HFE Program to develop the control room staffing analysis based on NUREG-1791 [3].

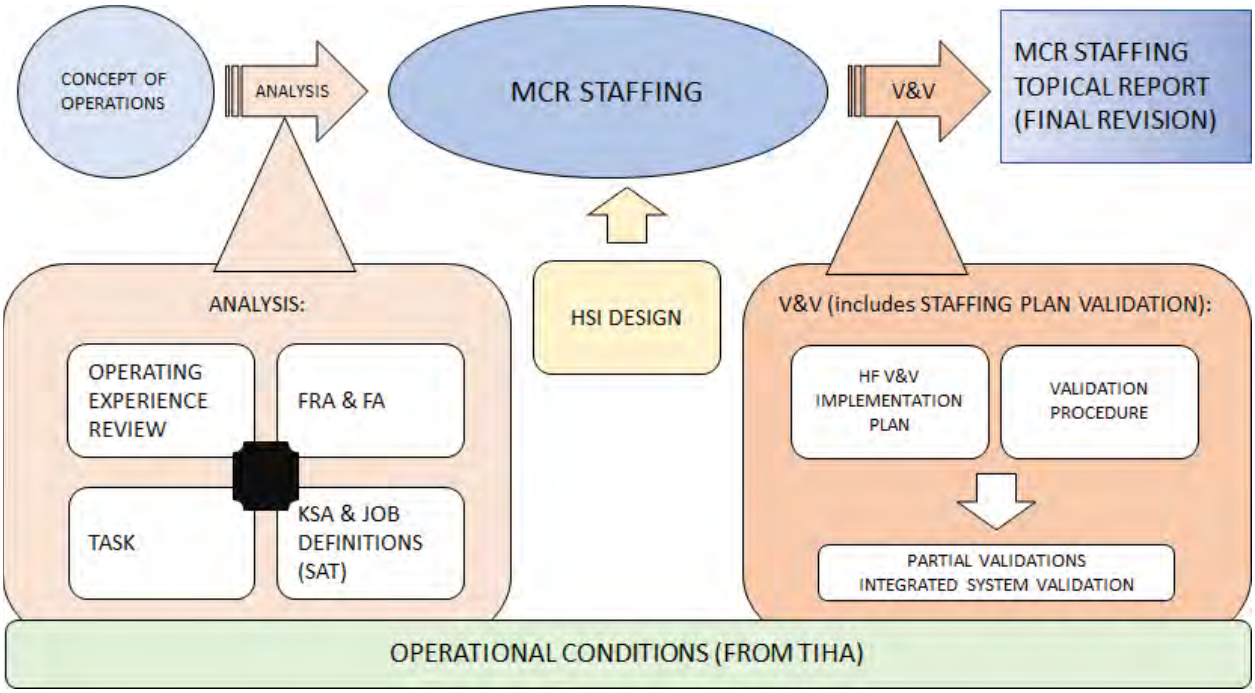

Figure 13: Xe-100 HFE Program Staffing Exemption Request Process

The concept of operations provides the staffing plan premises for the plant. The Staffing Plan is developed during the Xe-100 HFE Program. After several analysis steps (i.e. OER, FRA & FA, TA, and KSA and Job Definitions from Systematic Approach to Training), the S&Q will be established and assessed. Following the validation plan and tests, this topical report will be updated to include the results and conclusions of each element to provide the comprehensive technical basis and control room staff plan.

The HFE elements will be supplemented with the criteria listed in NUREG-1791 [3] during their development. The elements which should be provided to support the technical basis include:

- Operating Experience Review,
- Treatment of Important Human Actions,
- Functional Requirements Analysis and Function Allocation,
- Task Analysis,
- Staffing & Qualifications, and
- Human Factors V&V.

An HFE software database tool that contains the information and data resulting from the development of each element activities will be utilized to generate the following outputs:

1. OER Results Summary Report;

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2. TIHA Results Summary Report;
3. FRA & FA Results Summary Report;
4. TA Results Summary Report;
5. S&Q Results Summary Report;
6. V&V:
   i. Task Support Verification Report(s),
   ii. HFE Design Verification Report(s),
   iii. ISV Procedure (if applicable, as it could be part of the ISV report), and
   iv. ISV Report;

Additional:

- Treatment of Important Human Actions,
- Human System Interface Design,
- KSA analysis (Non-HFE Program),
- Training material & Procedures (Non-HFE Program), and
- PRA (Non-HFE Program).

The HFE Program's support to the control room staffing approach is summarized in the following actions:

- Follow the process shown in Section 5 and provide the submittals from Section 6;
- Develop the Implementation Plans including the methodology of the NUREG-0711 [2] elements, but also considering NUREG-1791 [3] guidance;
- Develop NUREG-0711 [2] elements incorporating the guidance from NUREG-1791 [3]; particularly, ensure that the submittals fulfill the review criteria from NUREG-1791 [3] Appendix A, "Review Checklists;"
- Address as context for each NUREG-0711 [2] element the most challenging operational conditions for human performance and plant safety;
- Perform a complete Task Analysis, which is of key importance to supporting the staffing reduction, describing each task in terms of operation performance requirements (see Section 4.5);
- Ensure proper correspondence between the Training Program development and the HFE Program, by following the SAT process and using the Task Analysis as input for KSA list and Job Definition;
- Perform a staggered SPV through human-in-the-loop simulations from the initial partial validations until the final integrated system validation to ensure end-user and human-oriented HSI design.
- Include simultaneous abnormal and emergency events on multiple units in the control room simulator in the SPV. Those scenarios produce likely challenging and high workload conditions which are needed to assess the proposed staffing reduction to ensure plant operational and safety goals are achieved.

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6. CONCLUSION

X-energy will continue to pursue development of the Xe-100 HFE Program described herein. Implementation Plans for each of the subject elements provide guidance for developing the information necessary to demonstrate execution of a successful NUREG-0711-based program and control room staffing analysis, and developing the technical bases described here.

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7. NRC TOPICAL REPORT REVIEW OBJECTIVES

X-energy's objective is to license the Xe-100 modular high temperature gas reactor design for construction and operation. This requires the development of a control room staffing approach that meets regulatory requirements and provides an optimal staffing model for control room operations of multiple units from a single control room. This report has been prepared to provide the proposed methodology for the Xe-100 HFE Program, which will be used as the basis for developing the technical basis for control room staffing in accordance with the guidance in NUREG-1791, or in support of a future 10 CFR 52 Design Certification application. X-energy is requesting NRC review and acceptance of this approach as a means to conduct the HFE program methodologies to support approval of the Xe-100 control room staffing and develop a valid basis for licensees requesting exemptions from 10 CFR 50.54(m) or X-energy to use in support of a future Design Certification application.

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8. REFERENCES

The following documents are referenced within this topical report.

	Document Title	Preparer/ Author	Document Number	Revision or Date of Issue	Classification	Applicable[3] (Yes/No)
[1]	NUREG-0800, Standard Review Plan for the Review of Safety Analysis Reports for Nuclear Power Plants: LWR Edition, Chapter 18, "Human Factors Engineering"	NRC	N/A	2016	N/A	Yes
[2]	NUREG-0711, Human Factors Engineering Program Review Model	NRC	N/A	Rev 3	N/A	Yes
[3]	NUREG-1791, Guidance for Assessing Exemption Requests from the Nuclear Power Plant Licensed Operator Staffing Requirements Specified in 10CFR50.54(m)	NRC	N/A	2005	N/A	Yes
[4]	Xe-100 Technology Description Technical Report	X-Energy	001118	1	XE00-P-G1ZZ-RDZZ-D	
[5]	NUREG/CR-6838, Technical Basis for Regulatory Guidance for Assessing Exemption Requests from the Nuclear Power Plant Licensed Operator Staffing Requirements Specified in 10 CFR 50.54(m)	NRC	N/A	2004	N/A	Yes
[6]	SECY-11-0098, Operator Staffing for Small or Multi-Module Nuclear Power Plant Facilities	NRC	N/A	2011	N/A	Yes
[7]	Human Factors Engineering Program Management Plan	Tecnatom	001247	Rev 2	N/A	Yes
[8]	TEC-XE100-HFE-COO, Concept of Operations	Tecnatom	N/A	Rev 0	N/A	Yes
[9]	Operating Experience Review Implementation Plan	Tecnatom	000982	Rev 2	XE00-R-R1ZZ-RDZZ-X	Yes
[10]	Treatment of Important Human Actions Implementation Plan	Tecnatom	000984	Rev 2	XE00-R-R1ZZ-RDZZ-X	Yes

3 Applicable documents are applicable to the extent specified within this document and thus deemed to form part of this document.

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Document Title	Preparer/ Author	Document Number	Revision or Date of Issue	Classification	Applicable[3] (Yes/No)
[11] Functional Requirements Analysis and Function Allocation Implementation Plan	Tecnatom	000985	Rev 2	XE00-R-R1ZZ-RDZZ-X	Yes
[12] Task Analysis Implementation Plan	Tecnatom	000986	Rev 2	XE00-R-R1ZZ-RDZZ-X	Yes
[13] Staffing & Qualifications Implementation Plan	Tecnatom	000987	Rev 2	XE00-R-R1ZZ-RDZZ-X	Yes
[14] Human-System Interface Design Implementation Plan	Tecnatom	000988	Rev 2	XE00-R-R1ZZ-RDZZ-X	Yes
[15] Human Factors Verification and Validation Implementation Plan	Tecnatom	000989	Rev 2	XE00-R-R1ZZ-RDZZ-X	Yes
[16] Plant Staffing Report	X-Energy	000077	Rev 3	XE01-P-X-Z-D	Yes

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Enclosure 2

Human Factors Engineering Program Management Plan

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Human Factors Engineering

Program Management Plan

Configuration Classification	:	**XE00-B-G1ZZ-GLZZ-E**
Revision	:	**2**
Status	:	**Approved**
Issue Date	:	**10-Dec-2021**
Project	:	**Xe-100**
Project Phase	:	**Concept**

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E-SIGNATURES: DOCUMENT APPROVAL

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SYNOPSIS

The Human Factors Engineering Program Management Plan is related to Element 1 of NUREG-0711 [1], HFE Program Management Plan (HFE PMP), which guides the team to properly develop, execute, oversee, and document the HFE Program.

Consistent with the guidance of NUREG-0711 [1], the document addresses the following points:

1. HFE Program goals and scope
2. HFE Team and organization
3. HFE Process and procedures
4. HFE Issue tracking system
5. HFE Technical Program

The Xe-100 HFE Program will be developed under the structure provided by NUREG-0711 [1]. However, the HFE Program also conforms with Canadian regulation (REGDOC 2.5.1 [8]) due to the equivalence between NUREG and REGDOC technical elements.

Appendix I includes compliance checklists for both NUREG-0711 [1] and REGDOC 2.5.1 [8], for licensing process in the United States (US) and Canada, respectively.

CONFIGURATION CONTROL

Document Change History

Rev.	Date	Preparer	Changes
0	16-Oct-2020	Nuria Bernal	First issue as TEC-XE100-HFE-PMP.
0A	03-Aug-2021	Hector Martinez-Pinna	Update to current information. First issue as XE00-R-R1ZZ-RDZZ-X-001247.
1	09-Aug-2021	Hector Martinez-Pinna	Update according to X-energy comments on rev 0A.
1A	02-Dec-2021	Richard Gutierrez	Extensive revision to address new comments.
1B	02-Dec-2021	Richard Gutierrez	Incorporated final review comments.
2	10-Dec-2021	Richard Gutierrez	Incorporated review comments into new revision.

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Document Approval

Action	Designation	Name
Preparer	Tecnatom, Human Factors Principal Engineer	Richard Gutierrez
Reviewer	Tecnatom, Project QA Engineer	Santiago Lucas
Reviewer	Senior Human Factors Lead	Paul Hippely
Reviewer	Senior Licensing Engineer	Thomas Braudt
Approver	Operator Training Simulator Manager	Yvotte Brits

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ABBREVIATIONS

This list contains the abbreviations used in this document.

Abbreviation or Acronym	Definition
CNSC	Canadian Nuclear Safety Commission
CSA	Canadian Standards Association
D3	Defense in Depth and Diversity
DI	Design Implementation
DV	Design Verification
EOF	Emergency Operations Facility
FA	Function Allocation
FRA	Functional Requirements Analysis
HED	Human Engineering Discrepancy
HFE	Human Factors Engineering
HFEITS	Human Factors Engineering Issue Tracking System
HPM	Human Performance Monitoring
HRA	Human Reliability Analysis
HSI	Human-System Interface (Design)
HTGR	High Temperature Gas Cooled Reactor
IAEA	International Atomic Energy Agency
IHA	Important Human Action
IEC	International Electrotechnical Commission
IP	Implementation Plan
ISG	Integrated Style Guide
ISV	Integrated System Validation
LCS	Local Control Station
LWR	Light Water Reactor
MCR	Main Control Room
NRC	(United States) Nuclear Regulatory Commission
OER	Operating Experience Review
PMP	Program Management Plan
PRA	Probabilistic Risk Assessment
RSR	Result Summary Report

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Abbreviation or Acronym	Definition
S&Q	Staffing & Qualifications
SAR	Safety Analysis Report
SMR	Small Modular Reactor
TA	Task Analysis
TIHA	Treatment of Important Human Actions
TSC	Technical Support Center
TSV	Task Support Verification
US	United States (of America)
V&V	(Human Factors) Verification & Validation

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DEFINITIONS

This list contains the terms of glossary used in this document.

Term	Definition
Element	From NUREG-0711 [1] the four general activities are separated into the following twelve elements: 1. HFE Program Management Plan 2. Operating Experience Review 3. Functional Requirements Analysis and Function Allocation 4. Task Analysis 5. Staffing & Qualification 6. Treatment of Important Human Actions 7. Human-System Interface Design 8. Procedure Development 9. Training Program Development 10. Human Factors Verification and Validation 11. Design Implementation 12. Human Performance Monitoring
Human Factors Engineering	The application of methods and knowledge about human capabilities and limitations in designing the plant, its systems, and equipment, to reasonably assure that the implemented design is compatible with the attributes of the personnel who operate, maintain, and support them.
Human-System Interface	Part of the system through which personnel interact to perform their functions and tasks.
Implementation Plan	Document that describes the proposed methodology for conducting an HFE element.
Results Summary Report	Document that summarizes the results of a completed HFE element and cites documents or files that contain the complete results.
Simulator	A facility that physically represents the HSI configuration and dynamically represents the operating characteristics and responses of the plant in real time. In this document, simulator refers to the full-scope simulator that simulates plant processes and recreates the control room to scale. A full-scope simulator can serve as a virtual plant to verify and validate HFE designs. After a certification process, it can be used for operator training.
Testbed	The environment or facility in which human performance is measured, that typically includes a representation of the human-system interface and may include a process model that can be used in testing human and integrated human-system performance.

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Term	Definition
Topical Report	Stand-alone report containing technical information about a reactor, structure, system or component, or safety topic that can be submitted to the NRC for its review and approval.
Validation	The set of activities to verify that a system was designed correctly to accomplish its intended use, goals, and objectives in the particular operational environment.
Verification	The process by which the design is evaluated to determine whether it provides the information, controls, and task-support needed to accomplish tasks; and conforms to the HFE design requirements.

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1. INTRODUCTION

X-Energy is developing an innovative nuclear power plant, namely the Xe-100, consisting of four 200 MWt pebble bed reactors coupled to four steam turbines. Due to its relatively low power, the Xe-100 reactor is classified as a Small Modular Reactor (SMR), and from a technological point of view, it is a High-Temperature Gas-cooled Reactor (HTGR) cooled by helium and moderated by graphite, implementing features that make the reactor inherently safe. This plant design is under licensing processes in the United States and Canada.

As required for licensing, a Human Factors Engineering (HFE) Program, with proven systematic analysis techniques to address human factors issues within the design process, shall be developed. The HFE Program and its products reflect state-of-the-art human factors principles[1].

Besides the generic HFE Program goals, the Xe-100 HFE Program is conducted to prove that three operators in the control room can operate, at a minimum, the four reactors and four turbines of the Xe-100 plant.

The Xe-100 HFE Program will be developed under the structure provided by NUREG-0711 [1]. However, the HFE Program also conforms with Canadian regulation (REGDOC 2.5.1 [8]) due to the equivalence between NUREG and REGDOC technical elements, as discussed in section 3. Additionally, NUREG-0711 guidance envelops other international standards, such as IEC 60964 [11] and its supporting standards, being IEC 61839 [12] for an example.

1.1. PURPOSE

The purpose of this HFE PMP is to document the first element of NUREG-0711 [1], whose objective is to verify that X-energy has a qualified HFE design team with the responsibility, authority, placement within the organization, and composition to reasonably assure that the design meets the commitment to HFE.

1.2. SCOPE

The scope of this HFE PMP is established in sections 4.2 to 4.8. These sections address the technical scope, the program duration, and the places, devices, and personnel object of the HFE Program.

1.3. RELATIONSHIP TO OTHER DOCUMENTS

This document is placed in the top level of the HFE documentation structure.

[1] Refer to 10 CFR 50.34 (f)(2)(ii), 10 CFR 50.34 (f)(2)(iii) [5], and REGDOC-2.2.1 [6].

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2. REFERENCES

The following documents are referenced within this document.

	Document Title	Preparer/ Author	Document Number	Revision or Date of Issue	Classification
[1]	NUREG-0711, Human Factors Engineering Program Review Model	NRC	N/A	Rev 3	N/A
[2]	NUREG-1791, Guidance for Assessing Exemption Requests from the Nuclear Power Plant Licensed Operator Staffing Requirements Specified in 10CFR50.54(m)	NRC	N/A	Jul 2005	N/A
[3]	NUREG-0700, Human-System Interface Design Review Guidelines	NRC	N/A	Rev 3	N/A
[4]	NUREG/CR-6838, Technical Basis for Regulatory Guidance for Assessing Exemption. Requests from Nuclear Power Plant Licensed Operator Staffing Requirements Specified in 10 CFR 50.54(m)	NRC	N/A	Feb 2004	N/A
[5]	10 CFR 50, Domestic Licensing of Production and Utilization Facilities, 50.34, “Contents of applications; technical information”.	NRC	N/A	Nov 2021	N/A
[6]	REGDOC-2.2.1, Human Performance Management - Human Factors	CNSC	N/A	Mar 2019	N/A
[7]	REGDOC-2.5.2, Design of Reactor Facilities: Nuclear Power Plants	CNSC	N/A	Apr 2019	N/A
[8]	REGDOC-2.5.1, Physical Design - General Design Considerations: Human Factors	CNSC	N/A	Mar 2019	N/A
[9]	REGDOC-2.2.5, Human Performance Management - Minimum Staff Complement	CNSC	N/A	Apr 2019	N/A
[10]	N290.14-14, Human Factors in Design for Nuclear Power Plants	CSA	N/A	Dec 2014	N/A
[11]	IEC 60964, Nuclear power plants – Control rooms – Design	IEC	N/A	2009	N/A
[12]	IEC 61839, Nuclear power plants – Design of control rooms – Functional analysis and assignment	IEC	N/A	2000	N/A
[13]	X-energy Quality Assurance Manual	X-energy	XEQAM 1.0	Rev 4	
[14]	TEC-XE100-HFE-COO, Concept of Operations	Tecnatom	N/A	Rev 0	N/A

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Document Title	Preparer/ Author	Document Number	Revision or Date of Issue	Classification
[15] TEC-XE100-HFE-ISG, Human-System Interface Integration Style Guide for Xe-100 Reactor	Tecnatom	N/A	Rev 0	N/A

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3. HFE REGULATORY FRAMEWORK

The HFE Program described in this HFE PMP is aimed at supporting the licensing process of the Xe-100 plant in the US and Canada. Therefore, the HFE Program meets the requirements established by both regulatory bodies, namely US Nuclear Regulatory Commission (NRC) and Canadian Nuclear Safety Commission (CNSC).

NUREG-0711 [1] is the most important reference in the development of an HFE Program of a new nuclear plant in the US. It defines a model where the HFE effort consisting of four major activities are divided into twelve elements to assist in the integration of HFE into the development, design, and evaluation of the plant:

1. HFE Program Management Plan
2. Operating Experience Review
3. Functional Requirements Analysis and Function Allocation
4. Task Analysis
5. Staffing & Qualification
6. Treatment of Important Human Actions
7. Human-System Interface Design
8. Procedure Development
9. Training Program Development
10. Human Factors Verification and Validation
11. Design Implementation
12. Human Performance Monitoring

In Canada, the HFE regulatory framework is described in REGDOC-2.5.2 [7] (section 7.21), REGDOC-2.5.1 [8] and N290.12-14 [10]. These documents provide guidance for license applicants in developing HFE programs that demonstrate how human factors are incorporated into activities licensed by the CNSC. The following sub-sections attempt to identify the equivalence between NUREG and REGDOC technical elements.

3.1. REGDOC-2.5.2, SECTION 7.21

REGDOC-2.5.2 sets out requirements and guidance for new license applications for water-cooled nuclear power plants. It establishes a set of comprehensive design requirements and guidance that are risk-informed and align with accepted international codes and practices. Human Factors is addressed in section 7.21.

The introduction in section 7.21 refers to the requirement to include an HFE program in the design. In addition, it mentions three considerations that are equivalent to the HFE Program goals: 1) reduce the likelihood of human error as far as reasonably achievable; 2) provide means for identifying the occurrence

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of human error, and methods by which to recover from such an error; and 3) mitigate the consequences of error. The introduction also references requirements and guidance covered in NUREG-0711 elements.

“Guidance” in the sub-section refers to the need to apply Human Factors to most plant systems, and also identifies some areas that interface with the HFE Program, also identified in the NUREG-0711 model:

1. engineering design of specific SSCs
2. procedure development
3. training development
4. consideration of human actions in safety analysis
5. specifications of staffing and minimum shift complement
6. as a part of staffing, centralized shift-work schedules to meet the requirements of the plant or a specific process

“Planning” sub-section specifically refers to NUREG-0711, and describes the need for an HFE PMP, which is addressed by NUREG-0711 element #1. For specific guidance, this sub-section of section 7.21 also refers to other regulatory documents, which are outdated and superseded by REGDOC-2.5.1 (see section 3.2).

“Analysis” sub-section specifies some high-level requirements for the HFE analyses that are generally covered by NUREG-0711, either at a high-level approach in element #1 or in deeper detail in other elements. Also, this sub-section lists HFE analyses that could be part of the HFE Program. Table 1 illustrates each of these HFE analyses and their equivalent NUREG-0711 element.

Table 1. HFE Analyses in REGDOC-2.5.2 and NUREG-0711

REGDOC-2.5.2	NUREG-0711 elements
Function analysis	Functional Requirements Analysis
Task analysis	Task Analysis
Human reliability analysis	Data exchange from and to Treatment of Important Human Actions
Hazard analysis	Data exchange from and to Treatment of Important Human Actions
Link analysis	Task Analysis and Human-System Interface Design
Information requirements analysis	Task Analysis and Human-System Interface Design
Staffing analysis	Staffing and Qualifications
Usability analysis	Human-System Interface Design and Human Factors Verification and Validation
Operability and maintainability analysis	Human-System Interface Design and Human Factors Verification and Validation

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"Design" sub-section describes some criteria for the design, such as developing a systematic process and covering the operating experience of similar systems, which are both covered by NUREG-0711 elements. Also, the design shall demonstrate that the operators are provided with the necessary requirements and appropriate information to perform their duties, which is strongly related to Task Analysis. Besides, this sub-section refers to NUREG-0700 [3] as guidance for the design.

"Operating personnel" sub-section can be related to the organization of the HFE team that develops the HFE Program, which is addressed by NUREG-0711 element #1.

"Verification and Validation" sub-section is addressed fully by NUREG-0711 element #10, Human Factors Verification and Validation.

3.2. REGDOC-2.5.1

Part A of REGDOC-2.5.1 [8] sets out guidance for license applicants in developing HFE program planning documentation that demonstrates how human factors considerations are incorporated into activities licensed by the CNSC. Part B sets out guidance in planning for human factors verification and validation activities.

Both Parts are fully covered by the elements of NUREG-0711. REGDOC-2.5.1 divides the HFE effort into *technical elements*, the same as NUREG-0711, the only difference between them being the terminology used, as illustrated in Table 2.

Table 2: REGDOC-2.5.1 and NUREG-0711 technical elements equivalence

REGDOC-2.5.1		**NUREG-0711**
Element	**Description**	**Element**
Human-Machine Interface System	Any region or point at which a person interacts with a machine	Human-System Interface Design
Human-Machine Allocation of Function	Assigning system functions to human and machine agents (i.e., processes that are automated versus those that are manual).	Functional Requirements Analysis and Function Allocation
Human Reliability	Addressing issues pertaining to the probability that an individual or group will adequately perform a given task at the appropriate time.	Treatment of Important Human Actions Human Factors Verification and Validation
Job Design:	Determining how tasks will be grouped together and how work will be coordinated. This will include consideration of the operating states of the facility (i.e., shutdown, start-up, operation, etc.).	Task Analysis Staffing and Qualifications

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REGDOC-2.5.1		NUREG-0711
Element	**Description**	**Element**
Operating Experience Review	The review and use of knowledge gained from nuclear industry operating experience to improve future performance.	Operating Experience Review
Physical Working Environment	The total physical environment within which a worker performs his or her tasks.	Human-System Interface Design
Activities with potentially hazardous human interactions	-	Treatment of Important Human Actions
Procedures Development	The systematic process for the development of work instructions or instruction sets used to accomplish a given task.	Procedure Development
Shift-work systems	All the schedules implemented in a given workplace to meet the requirements of a given plant or process.	Staffing and Qualifications
Staffing	The process for determining numbers and placement of appropriate personnel for a given job.	Staffing and Qualifications
Validation	The process of determining the degree to which the human-machine system design and supporting mechanisms facilitate the achievement of overall safety and operational goals.	Human Factors Verification and Validation
Verification	The process of demonstrating that equipment and systems have been designed as specified and that adherence to human factors guidelines has been maintained.	Human Factors Verification and Validation

3.3. N290.12-14

N290.12-14 [10] is a standard which is referred in REGDOC-2.5.1 [8] as a requirement for nuclear power plants. It is a very high-level document that references NUREG-0711 and identifies some of the NUREG-0711 elements. However, it is not as specific as the US guidance. NUREG-0711 envelopes N290.12-14 and is more prescriptive in what is expected of the licensee.

At the end of the standard, four annexes are provided, but these are not mandatory, as clearly stated at the top of each annex.

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3.4. CONCLUSION

NUREG-0711 [1] is more restrictive than Canadian regulatory documents in what the licensee or license applicant must provide for review. For each of the twelve elements in NUREG-0711, the NRC provides a description of what they expect the licensee to provide, which N290.12-14 does not.

Therefore, following an HFE Program based on NUREG-0711 [1] provides compliance with the intent of REGDOC-2.5.2 [7], REGDOC-2.5.1 [8] and N290.12-14 [10].

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4. HFE PROGRAM GOALS AND SCOPE

4.1. GOALS

The Xe-100 HFE Program is implemented to provide a “human-centered” approach to human-machine interactions, to confirm that:

- Personnel tasks can be accomplished within time and performance criteria.
- Human-System Interfaces (HSI), procedures, staffing and qualifications, training, and management and organizational arrangements support personnel situation awareness.
- Design will support personnel in maintaining vigilance over plant operations and provide acceptable workload levels, i.e., minimize periods of under- and over-load.
- HSIs will minimize personnel error and will support error detection and recovery capability.

As the HFE Program is developed, these goals are further defined and used for HFE tests and evaluations.

4.2. TECHNICAL SCOPE

The HFE Program, as proposed by NUREG-0711 [1], is divided into twelve elements arranged in four general activities: Planning and Analysis, Design, Verification and Validation, and Implementation and Operation. The elements described in NUREG-0711 [1] contain the criteria for reviewing an applicant’s submittal, describing their HFE process and the resulting design. The same information can also be used as primary guidance for developing and conducting the HFE Program tasks.

1. HFE Program Management Plan (HFE PMP). The aim of this element is to provides that the HFE Program will be implemented by a qualified HFE design team for the design under consideration, with the responsibility, authority, placement within the organization, and composition to reasonably provide that the design meets the commitment to HFE.
2. Operating Experience Review (OER). The purpose of performing an operating experience review is to identify HFE-related issues from similar designs and to provide a basis to improve the plant design through the rest of elements.
3. Functional Requirements Analysis (FRA) and Function Allocation (FA). The Functional Requirements Analysis identifies the plant functions that need to be fulfilled to satisfy plant goals; the Function Allocation assigns levels of automation to those plant functions in a way that takes advantage of human strengths and avoids its limitations.
4. Task Analysis (TA). Functions allocated to plant personnel are accomplished through human actions, which are detailed in this element; including those alarms, indications, controls, and task-support items required to complete such actions.
5. Staffing and Qualifications (S&Q). The number of personnel and their qualifications are systematically analyzed to make sure that plant personnel can perform and understand the assigned tasks.

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6. Treatment of Important Human Actions (TIHA). The purpose of this element is to make sure that those human actions most important to safety, identified through a combination of probabilistic and deterministic analyses, are appropriately considered in the design of HFE aspects of the plant.
7. Human-System Interface (HSI) Design. This element translates the requirements from FRA, FA and TA to HSI design requirements and to the detailed design of alarms, controls, information and other aspects of the HSI, including the use of a style guide to define the design-specific conventions.
8. Procedure Development. This element provides HFE principles and criteria to incorporate into the development of the procedures used by plant personnel.
9. Training Program Development. This element provides HFE principles and criteria to incorporate into the development of the training program for plant personnel.
10. Human Factors Verification and Validation (V&V). HFE verification and validation are comprised of several evaluations that determine that the final HFE design conforms to design criteria and that the defined personnel tasks can be successfully completed.
11. Design Implementation (DI). This element addresses the implementation of the HFE aspects, verifying that the as-built design conforms to the verified and validated one, which comes from the HFE design process.
12. Human Performance Monitoring (HPM). A human performance monitoring program must maintain that the conclusions drawn from the integrated system validation remain valid with time and confirm that no significant safety degradation occurs because of any changes made in the plant.

The elements described above are applicable during the licensing process, but the applicability of HPM extends though plant operations.

Details regarding the development of these elements are provided in section 8 in the context of the HFE Program.

4.3. QUALITY SCOPE

The HFE Program is developed under the X-energy Quality Assurance requirements and follow the requirements of the X-energy Quality Assurance Manual [13] including implementing procedures, processes, and forms.

Quality requirements shall be determined for X-energy suppliers who deliver items and services under this Program. The quality requirements shall flow down to suppliers and potential sub-suppliers via procurement documents as required by X-energy. And like the quality requirements, the applicable criteria of the HFE PMP shall also flow down to suppliers and potential sub-suppliers via procurement documents.

Oversight of suppliers and potential sub-suppliers shall be performed in accordance with the X-energy Quality Assurance requirements.

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4.4. ASSUMPTIONS AND CONSTRAINTS

4.4.1. HTGR Technology

Most nuclear power plants are based on LWR (Light Water Reactor) technology. Therefore, most existing references and guidance for the development of an HFE Program reference this technology.

However, the Xe-100 plant design is an SMR based on HGTR technology. The reactor is inherently safe, based on the TRISO-particle in the pebble fuel that act as a container, containing 99.999% of all the radionuclides and fission products. Moreover, the Xe-100 reactor is meltdown proof.

Therefore, differences between the Xe-100 reactor and an LWR may affect the development of the HFE Program, and some outputs may differ from those of a standard analysis.

As this design can be considered first-of-a-kind, the operational experience from existing plants is limited, which affects the development of the OER in terms of inputs availability. Other activities such as TIHA and V&V, that use experience from similar plants for identification of Important Human Actions and scenarios for validation respectively, shall be affected as well. Limited availability of experienced operators in this technology shall affect the execution of scenarios during the validations as well. Section 8 describes these mentioned HFE Program elements.

Since the critical scenarios differs from the LWR technology, the list of scenarios for validation shall be conservative, including the abnormal and emergency paths that challenge plant safety functions.

4.4.2. Modular Design

Modularity affects the HFE analyses as new operational challenges might appear. Multi-reactor operation implies simultaneous tasks and requires a wide and accurate situation awareness of each reactor module and the plant as a whole.

The set of critical scenarios for HFE design validation (refer to V&V activities, section 8.12) shall combine transients and different operational states in several reactor modules, rather than to select scenarios related to system failures. Scenarios that combine operations in several reactor modules will challenge operators with new demands that need to be evaluated.

4.4.3. Passive Safety Features and High Automation Level

Xe-100 design incorporates passive safety features and automated action that reduces operator's workload in terms of control and actions. Thus, the operator will focus on the monitoring and management of automated actions by using messages, alarms, and acknowledgments in the HSIs.

Most operating tasks are automated (for example, online refueling, power increase/decrease, reactor mode change, etc.), allowing the multi-reactor operation without workload increase. The evaluation and testing of these assumptions are part of the HFE Program.

For example, as the reactor modules are refueled online, integrating related tasks within the operation of the rest of reactor modules introduces a change from a single-unit TA that only evaluates tasks from one reactor.

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4.4.4. Main Control Room Operators

Because of the reactor inherent safe design (see section 4.4.1), its passive safety features and the high automation level (see section 4.4.3), a design goal is to allow the control and supervision of the Xe-100 plant from one main control room with a staff composition of three operators. Considering that a standard Xe-100 plant comprises four reactor modules, such a goal does not meet 10 CFR 50.54 requirements.

Indeed, as shown in Figure 1, the nearest case considered in 10 CFR 50.54 is to operate three reactor units from two control rooms, requiring a minimum crew of three senior operators and five operators. Since the control philosophy of the Xe-100 plant is to operate four reactor modules from one control room by a shift of three operators, which is out of the bounds of the chart, the Xe-100 HFE Program shall target the exemption to this requirement.

Number of nuclear power units operating[2]	Position	One Unit	Two units		Three units	
		One control room	One control room	Two control rooms	Two control rooms	Three control rooms
None	Senior Operator	1	1	1	1	1
	Operator	1	2	2	3	3
One	Senior Operator	2	2	2	2	2
	Operator	2	3	3	4	4
Two	Senior Operator		2	3	[3]3	3
	Operator		3	4	[3]5	5
Three	Senior Operator				3	4
	Operator				5	6

Figure 1: 10 CFR 50.54 (m)(2)(i) Minimum staff requirement table

The advanced reactor design and the increased use of advanced automated control systems affect the TA, which is the main input for the S&Q. Therefore, these advanced features affect the roles, responsibilities, composition, and size of the crew required to control and supervise the Xe-100 plant. Once the initial staffing level is established, it shall be tested through the V&V activities. When finished, the final S&Q is set.

The consistent development of the NUREG-0711 [1] elements provide justification from the HFE perspective for elaborating the Topical Report for Staffing Exemption (to NRC) and the Minimum Staff Complement Procedure (to CNSC). Additional guidance is found in NUREG-1791 [2] and REGDOC-2.2.5 [9].

4.5. HFE PROGRAM DURATION

The Xe-100 HFE Program applies from the start of conceptual design through completion of plant startup testing. Once the plant is in operation, the plant HPM program shall keep Xe-100 HFE Program data valid and up to date.

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HFE activities are iterative and, as explained in section 8, feedback information between NUREG-0711 elements implies task iteration and result reports revisions.

4.6. FACILITIES

The HFE Program applies to the Xe-100 plant Main Control Room (MCR) and Reserve Shutdown Room(s), including the applicable controls, indications, alarms, and procedures.

The applicability of the program to other control rooms and stations, such as the Technical Support Center (TSC), Emergency Operations Facility (EOF), and Local Control Stations (LCSs), is dependent on the HSIs planned to be assigned to them. If the HSIs used in these facilities are derivates from the ones in the MCR, the HFE Program is implicitly applicable. If the HSIs are different, the HFE Program shall be applied following a graded approach considering the facility functionality and nuclear safety. Details on the graded applicability of the HFE Program shall be provided when design of TSC, EOF and LCSs is mature enough.

4.7. HSIS, PROCEDURES AND TRAINING

The HFE Program applies to the HSIs and related procedures implemented in the MCR and Reserve Shutdown Room(s) and used by MCR crew. The HFE Program also applies to the training program related to the MCR crew.

The degree of applicability of the HFE Program to the HSIs, procedures, and training implemented in other facilities for MCR crew shall be evaluated. Depending on the type of interfaces and their intended use (i.e., control, monitoring or emergency operation), a graded approach shall be used for the analysis, which implies that different HFE tasks and activities might be applicable.

The HFE Program supports HSI design, procedure development and training program development for normal operating, abnormal operating, emergency operating, alarm response, and accident management activities performed or supervised by MCR crew. The HFE Program also covers maintenance, test, inspections, and surveillance tasks that MCR crew perform or supervise in the MCR.

4.8. PERSONNEL

The HFE Program applies to the MCR crew, including operators, shift supervisor, and shift technical advisor, as these roles are deemed necessary. The staffing and qualifications for the MCR operators defined in 10 CFR 55, shift supervisor and shift technical advisor are set in the S&Q element.

Those persons subject to the training program identified in 10 CFR 50.120 (production field technicians, instrumentation and control technicians, electrical maintenance personnel, mechanical maintenance personnel, radiological protection technicians, chemistry technicians, and engineering support personnel), including the personnel who performs tasks related to plant safety, such as maintenance and troubleshooting information technologies technicians, are not within the scope of the HFE Program.

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5. HFE TEAM AND ORGANIZATION

5.1. RESPONSIBILITY

The Xe-100 HFE team is the primary organization responsible for the overall HFE program, including:

- developing HFE Implementation Plans (IP), procedures, and Results Summary Reports (RSR), and performing HFE activities' in compliance with the HFE plans and procedures;
- scheduling and overseeing HFE activities in HFE design, development, test, and evaluation;
- verifying that the team's recommendations are implemented;
- reviewing of documents produced by other engineering disciplines; and
- initiating, evaluating, resolving, or confirming resolution of, and maintaining tracking records for HFE issues noted during design activities.

5.2. ORGANIZATIONAL PLACEMENT AND AUTHORITY

Figure 2 shows a simplified organizational structure for developing the Xe-100 project. Considering this organization, the HFE team is under the Operator Training Simulator Manager and interfaces with the Design Manager, to verify that the design incorporates the HFE Program results into the design, and with the Licensing Manager, to align the HFE Program with the licensing process. Refer to section 6.4 for more details in integrating of the HFE activities in the design.

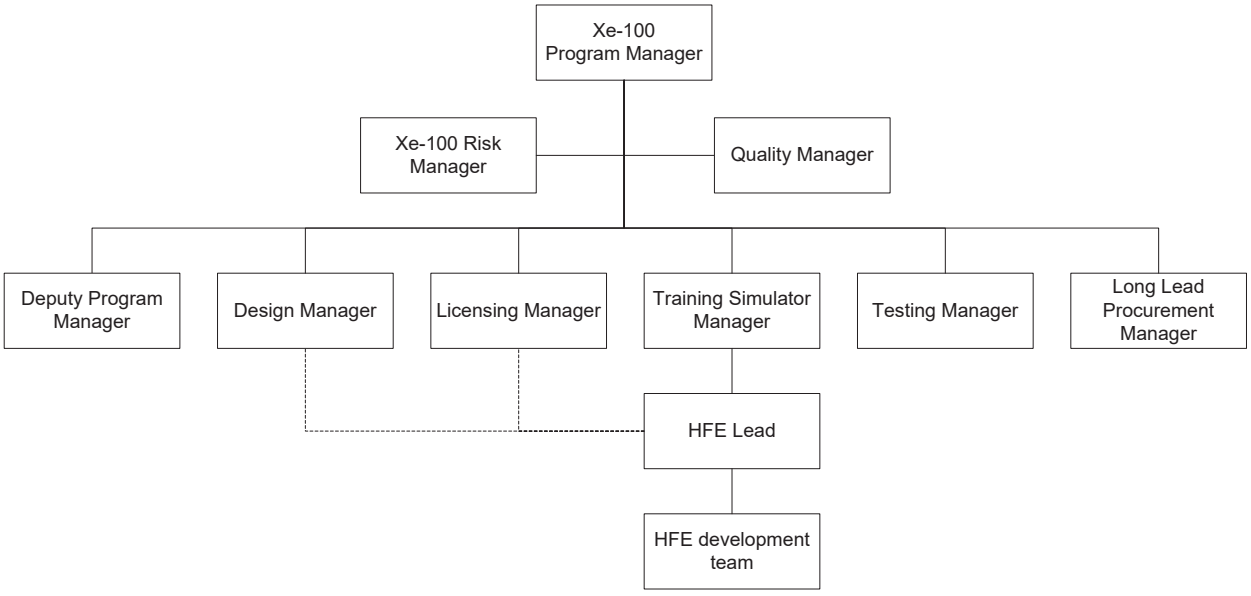

Figure 2: Xe-100 Project team organizational placement

In the development of the Xe-100 HFE Program, an HFE Leader is selected to be the main responsible and authority of the HFE efforts in the Xe-100 design. The HFE development team prepares project deliverables, takes part in technical meetings to provide clarifications regarding the work performed (if

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required) and assists the HFE Leader to resolve any inconsistence or deviation as detected during the project.

5.3. HFE TEAM COMPOSITION AND STAFFING

The HFE team comprises several roles for providing a multi-disciplinary perspective of the HFE Program. HFE team members are grouped as described in section 5.2. The HFE team can be augmented to include specific knowledge for developing needed tasks. HFE team core members meet the requirements as set in section 5.3.2, while augmentation personnel provide the team with additional knowledge to cover requirements needed for specific tasks within the HFE Program.

Responsibilities of the team members and their corresponding expertise are described below.

5.3.1. HFE Leader

The HFE Leader is responsible for the general management of the HFE Program, including the coordination of the HFE team members, making HFE decisions (including design decisions and reviewing of HFE products) and coordination with the general Xe-100 project control management.

The HFE Leader shall be a holder of a post-college degree, or equivalent experience, in any technical field. Additional requirements are:

- experience of at least eight years developing HFE projects,
- project management knowledge, and
- deep operation and HFE knowledge (NRC standards).

5.3.2. HFE Development Team Engineers

Responsibilities of the HFE development team are:

- Development of the HFE tasks and
- preparation of the corresponding RSR(s).

Team members involved in the development of the V&V tasks and preparation of the corresponding RSR(s) shall not be directly related in developing the design elements being verified or validated to verify independence.

Team members in the HFE development team shall hold a college degree, or equivalent or greater, in any technical field. Additional requirements are:

- knowledge of nuclear reactor fundamentals and nuclear power plant operation,
- knowledge of HFE NRC standards, and
- experience of at least one year developing similar or equivalent activities to those described in this HFE PMP.

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Team members not meeting these requirements may develop project activities; however, their work shall be reviewed and countersigned by another member who does meet the requirements.

The HFE Leader assigns HFE team members to HFE activities with the needed expertise in performing those activities. Specific expertise required for developing each element in the HFE Program is described below as a minimum requirement:

- OER
  - new plant design
  - operating experience international databases (NRC, IAEA, etc.)
  - capacity of coordination with the corresponding teams affected by the operating experiences identified
  - HFE principles
- FRA & FA and TA
  - nuclear engineering (plant operation processes)
  - general plant engineering (design characteristics and restrictions, components configuration, etc.)
  - plant operation
  - systems engineering
  - HFE principles
- S&Q
  - Plant operation and training
  - Nuclear safety (safety analysis (PSA), HRA, etc.) – supporting role
  - HFE principles
- TIHA
  - Plant operation and training
  - Nuclear safety (probabilistic and deterministic analysis) – supporting role for identification of important human actions
  - HFE principles
- HSI Design
  - I&C principles
  - Hardware equipment (functionality and installation)
  - Digital interfaces (selection of controls and displays)
  - Plant operation

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  - Equipment maintenance/inspections – supporting role
  - HFE principles
- Procedure development
  - Plant operation
  - Operation procedures writing principles
  - HFE principles
- Training program development
  - Licensing nuclear operator training basics
  - HFE principles
- V&V
  - HFE V&V principles and guidelines
  - I&C, digital systems, and maintenance – supporting role
- DI
  - HFE principles
  - Operation interfaces
- HPM
  - HFE principles
  - Operation interfaces
  - Procedures
  - Training program

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6. HFE PROCESS AND PROCEDURES

6.1. GENERAL PROCESS PROCEDURES

The HFE leader holds the main responsibility for implementation of procedures for HFE general processes:

- HFE team assignment to each HFE activity is decided by the HFE Leader considering the required expertise needed per activity, as established in section 5.3; internal management and overall supervision during the activities executions is likewise performed by the HFE Leader.
- The HFE Leader has the ultimate responsibility in the decision making on the HFE Program management. The HFE activities planning shall be in coordination with the other Xe-100 design activities and groups (see sections 5.2 and 6.4).
- Any member of the HFE team may identify problems and propose solutions using the HFE Issue Tracking System (HFEITS) described in section 7. As explained there, the HFE Leader is responsible for the final approval and resolution of HFEITS items, and responsible for HFE decision making. This also includes the review of the HFE products, in which the HFE Leader keeps the approval authority for identified HFE team products.
- Design changes to HSI and other equipment that have major input from HFE are governed through a design change process, in which the HFE team engineers are involved.

6.2. PROCESS MANAGEMENT TOOLS

HFE program tools and techniques used to fulfill responsibilities are also available to support the HFE elements. Specific tools and techniques used in HFE Program are presented in the Technical Program (section 8) and further described in the respective IP and/or RSRs, if applicable.

6.3. HFE PROGRAM MILESTONES

The HFE Program includes a set of tasks grouped into six areas of development. Table 3 presents the areas and tasks breakdown and the corresponding HFE Program deliverables. These tasks and deliverables will be further updated as the HFE Program is developed.

Table 3: Xe-100 HFE Program tasks breakdown and program milestones

Area	Task	HFE Program Deliverables
Area 1: HFE Basis	Task 1. HFE Program Management Plan	IP
	Task 2. Concept of Operations	Report

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Area	Task	HFE Program Deliverables
	Task 3. Control Room Staffing Analysis Methodology Description[2]	Report
Area 2: Plans	Task 1. Implementation Plans	IP
Area 3: Analysis	Task 1. Operating Experience Review	RSR
	Task 2. Treatment of Important Human Actions	RSR
	Task 3. Functional Requirements Analysis and Function Allocation	RSR
	Task 4. Task Analysis	RSR
	Task 5. Staffing and Qualifications	RSR
Area 4: Design	Task 0. Integrated Style Guide	Report
	Task 1. Human-system Interface Design	RSR
Area 5: V&V	Task 1. Human Factors Verification and Validation	RSR
Area 6	Task 1. Control Room Staffing Analysis Methodology Description (last revision) [2]	Report
	Task 2. Minimum Staff Component Procedure[3]	Report

Figure 3 shows a representative schedule, which assumes that the inputs required for the starting of the HFE activities are available. Since the HFE Program shall be integrated with the rest of Xe-100 design activities, the actual schedule dates for those activities in the HFE program are provided and updated separately (see section 6.4).

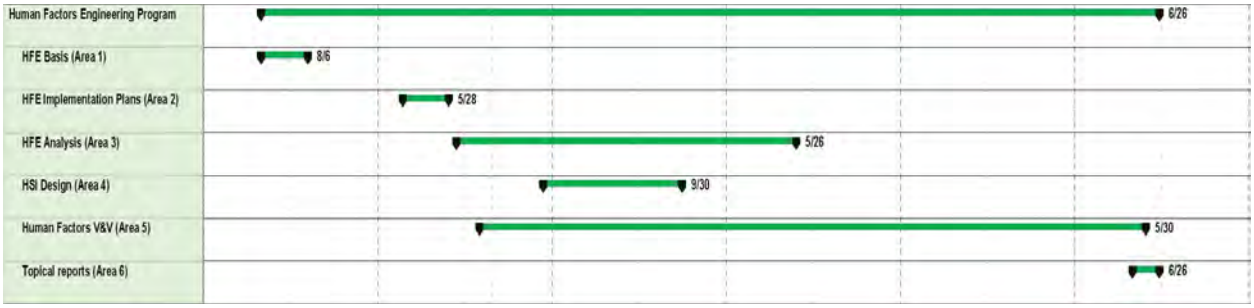

Figure 3: Tentative schedule for the Xe-100 HFE Program

[2] Only for the US.

[3] Only for Canada.

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6.4. INTEGRATION OF HFE AND OTHER PLANT DESIGN ACTIVITIES

The HFE Program activities are integrated in the Training Simulator & Operator Training phase established in the master schedule for the Xe-100 project. The development of the HFE Program highly depends on the Design phase of the Xe-100, since plant system information resulted from those activities is one of the main inputs to the HFE Program

Details regarding these relationships of the HFE Program areas and other design activities within the Xe-100 project are listed below:

- Before starting the HFE Analysis activities (Area 3), plant system information (system descriptions, P&IDs, etc.), should be available, at least in a preliminary version. As plant systems information is updated, HFE Analysis activities shall be evaluated for updating.
- Results from the FA (part of Area 3) may affect the automation levels defined. Hence, these results should be an input to re-evaluate the automation strategy, if appropriate.
- Results from the HFE analyses (Area 3) can be incorporated into the design in the Detail Design phase.
- Results from the TA (part of Area 3) should be an input to the operating procedures development.
- Results from the TA and from the S&Q (part of Area 3) should be an input to the operator training program development.
- HSI Design activities (Area 4) should be finished prior to implementing the HSI in the simulator.
- The HSI implementation in the simulator must be finished prior to starting validation activities (part of Area 5).
- The Integrated System Validation (part of Area 5) requires that the simulator shall be fully operational, and the operating procedures shall be drafted.

As noted in the list above, the HFE Program shall be understood as an iterative process, whose implementation requires performing the HFE activities several times, using each time updated inputs, which come from the design process or the HFE Program itself.

6.5. HFE DOCUMENTATION

HFE documents that support the design are quality records and retained under the X-energy Quality Assurance Manual [13]. That such documentation is available for review upon request. HFE documentation includes design verification checklists, HFEITS records and documentation identified in the HFE element technical reports (e.g., IPs and RSRs).

Table 4 provides a tabulation of the IPs and RSRs submitted for the elements that make up the technical scope of the HFE Program (see section 4.2). Unless otherwise noted, the contents of the RSRs are in accordance with the applicable guidance of NUREG-0711 [1].

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Table 4: HFE elements documentation

HFE element	IP	RSR	Notes
Operating Experience Review	X	X	
Functional Requirements Analysis and Function Allocation	X	X	
Task Analysis	X	X	
Staffing and Qualifications	X	X	
Treatment of Important Human Actions	X	X	
Human-System Interface Design	X	X	
Procedure Development			Note 1
Training Program Development			Note 1
Human Factors Verification and Validation	X	X	
Design Implementation	X		Note 2
Human Performance Monitoring	X		Note 3

Note 1 - This material should conform to the acceptance criteria specified in Standard Review Plan, NUREG-0800 Chapter 13, and should be submitted by the applicant in accordance with the guidance in Chapter 13.

Note 2 – An RSR is not required for this element since conformance of the as-built design to the verified and validated design and as-shipped design is confirmed at the plant. If it is determined that an RSR is required, it can be prepared, referencing the applicable plant documentation.

Note 3 - Submittal of an RSR is not expected because a problem identification and resolution program will be established as part of normal plant operations and so will be subject to routine regulator inspections.

Description of the IPs content is presented in the corresponding section of the Technical Program (see section 8.4). Description of the main results that shall be documented per HFE element is presented in the section 8 (refer to the elements corresponding subsections).

6.6. SUBCONTRACTOR HFE EFFORTS

HFE activities for the Xe-100 project can be performed by a subcontractor. As a part of the Quality Assurance (QA) audit team, the Xe-100 HFE Lead or designee shall verify that the subcontractor is properly

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trained and correctly applying the HFE criteria as defined in their contract. Planned audits will be performed in accordance with the X-energy QA Manual [13] and subordinate plans and procedures.

The HFE Team shall work in coordination with the rest of the Xe-100 groups as presented in sections 5.2 and 6.4.

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7. HFE ISSUE TRACKING SYSTEM

7.1. AVAILABILITY

The HFE Issue Tracking System (HFEITS) is used to address human factors issues during the life cycle of the HFE Program. The HFEITS enables the documentation and tracking of issues that need to be addressed at some later date, providing assurance that detected HFE issues are identified, tracked, evaluated, and corrected, until potential negative effects on human performance have been reduced to an acceptable level.

The kinds of issues to be addressed include:

- Recognized industry HFE issues (refer to OER).
- HFE issues identified during the development of the elements of the HFE Program.
- Human Engineering Discrepancies (refer to V&V).

The HFEITS is established during the planning phase, and it is used during the complete life cycle of the HFE Program.

The HFEITS administrator or designee, under the guidance of the HFE Leader, is responsible for entering an issue into the database. Any member of the HFE Team can identify an issue but only the administrator or designee can modify the database. The administrator or designee can provide reports as requested by team members.

A report of open and closed HFEITS issues will be provided to team members on a predetermined schedule.

7.2. METHODOLOGY AND DOCUMENTATION

The method selected to track the HFE issues identified is based on the creation of a HFEITS database which is used to store the relevant information associated to each issue. The process verifies that:

1. Problems, issues, and discrepancies are identified and entered into the HFEITS database with a unique tracking number.
2. Administrative responsibility is assigned for maintaining the tracking system and logs.
3. Issues are clearly documented with proposed resolutions and their effects.
4. Responsibilities are assigned to HFE team members regarding issue identification, resolution, and closeout.

Specific formats generated by the HFEITS database for each of the identified issues can be used by the appropriate HFE team members (as applicable).

The process is illustrated in Figure 4. The method to be followed is described. This process is one method of implementing corrective actions. Typically, operating plants use their existing corrective action programs, including established priorities of when the issue will be implemented.

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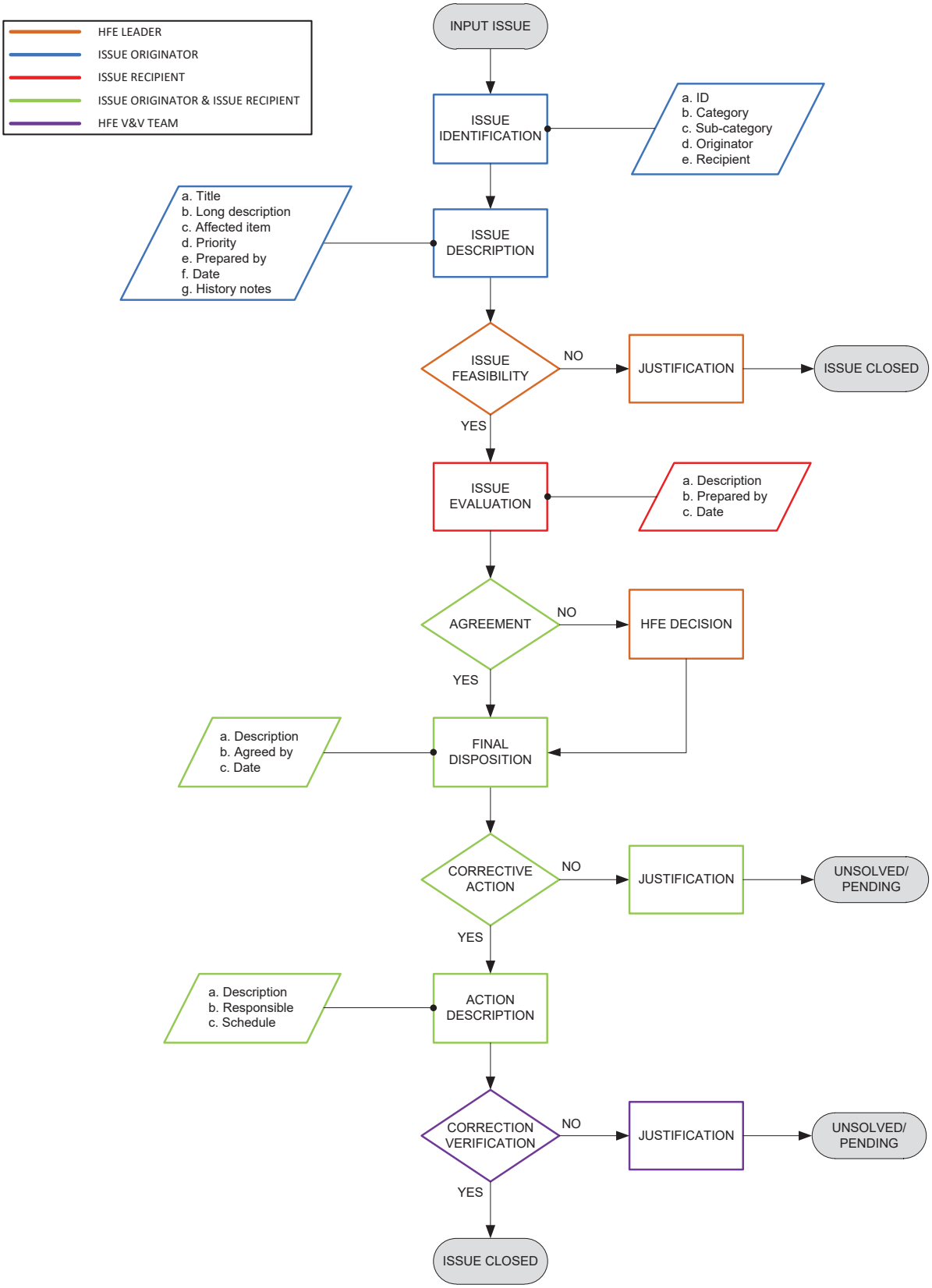

Figure 4. Flow Diagram of HFEITS

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1. Issue Identification: Any issue detected is entered into the HFEITS database. The following fields are fulfilled by the originator (which may be from any area of HFE Team):
    a. ID: the HFEITS assigns a unique tracking number.
    b. Category: General task and element of the HFE Program in which the issue is identified (corresponds to one of the HFE elements considered in the program review model of NUREG-0711 [1]).
    c. Sub-category: HFE sub-task and/or sub-element (as applicable).
    d. Originator: organization which identifies and documents the generated issue.
    e. Recipient: organization to which the generated issue is directed to.
    f. Closure Date: date in which the identified issue is closed in the HFEITS database.
    g. Closed by: member of the HFE Team who closes the identified issue.
2. Issue Description: the identified issue is described by the originator, specifying:
    a. Title: brief description of the problem.
    b. Long description: description of the identified issue, documenting the relevant information for the recipient to understand the problem (text, drawings, pictures, documents, etc.). It may include attachments (i.e. drawings, pictures, specifications, etc.) to support the issue description.
    c. Affected item: system/document/component/others affected by the identified issue and associated description.
    d. Priority: level of priority established according to the importance of the identified issue (0 Unknown; 1 High; 2 Medium; 3 Low).
    e. Prepared by: member of the HFE Team (from originator organization) who fulfills the Issue Description.
    f. Date: date in which the Issue Description is completed.
    g. History notes: since issues may be modified during the process (e.g. for priority increasing or decreasing, or recipient change), such modifications are recorded, including who fulfills the modification and when it happens.
3. Issue Feasibility: the HFE Leader verifies the issue is correctly described and evaluates its applicability to the HFE Program. As a result, issues can be either filtered out with a justification, or passed to the next step.
4. Issue Evaluation: the recipient evaluates the issue, fulfilling:
    a. Evaluation description: explanation and disposition according to the input issue, including attachments (i.e. drawings, pictures, specifications, etc.) to support the issue evaluation.
    b. Prepared by: member of the HFE Team (from recipient organization) who fulfills the Issue Recipient Evaluation.

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c. Date: date in which the Issue Recipient Evaluation is completed.

5. Final Disposition: Originator and Recipient organizations document the final disposition according to the previous Issue Description and Evaluation, detailing:

   a. Final Disposition: text which describes the final proposed resolution, including attachments (i.e. drawings, pictures, specifications, etc.) to support the disposition.

   b. Agreed by: members of the HFE Team (from both originator and recipient organizations) who agreed the issue final disposition. If no agreement is possible, the HFE Leader is involved for making an HFE decision.

   c. Date: date in which the Final Disposition is completed.

6. Corrective Action item: once the Final Disposition is described and studied, an analysis is carried out to determine corrective actions (if applicable). As a consequence and taking into account the iterative nature of the HFE process, one or several HFE Program elements may need to be updated. This field is included to verify that clearly documented potential corrective actions are documented for tracking purposes, identifying:

   a. Description: explanation of identified corrective actions and applicable items for their future development, including attachments (i.e. drawings, pictures, specifications, etc.) to support and explain the action item to be developed.

   b. Responsible: responsible for the later implementation and resolution of the issue.

   c. Schedule: expected implementation schedule.

7. Issue Correct Verification: if a corrective action is necessary, a verification team finishes the process by confirming its correct implementation.

As shown in Figure 4, the process is completed when the identified issues are properly collected and dispositioned. Tracking by the HFE Team ends when design implementation activity is completed and tracking is transferred to the plant operation license holder for actions under their corrective action program, specifying:

1. Collection of issues not feasible from HFE point of view.
2. Collection of issues feasible from HFE point of view, including:
   a. Collection of HFE issues closed.
   b. Collection of HFE issues still open due to:
      i. Unsolved status, or
      ii. Pending state (potential corrective actions which could not be verified and/or are of future application during plant operation).

7.3. INDIVIDUAL RESPONSIBILITIES SUPPORTING HFEITS

The flow diagram in Figure 4 also establishes (with the color coding showed) the responsibilities assignment in the HFEITS process, namely:

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1. HFE Leader has the overall responsibility for managing the HFEITS, including:
    a. Provide oversight of HFE issue tracking.
    b. Approve evaluation, disposition and action items indicated.
    c. Approve due date changes.
2. Originator is anyone who identifies and generates an issue, whose main responsibilities are:
    a. Identify the HFE issue, completing the mandatory fields for the future tracking.
    b. Describe and document the issue.
    c. Analyze with the recipient team their evaluation for establishing the final proposed resolution and potential corrective actions.
3. Recipient is the team which evaluates the identified issue, whose main responsibilities are:
    a. Evaluate the HFE issue.
    b. Establish and document a final disposition and proposed resolution.
    c. Analyze the resolution and corrective actions with originator HFE Team, recommending due dates.
4. Verification & Validation Team is responsible of the last step of correction verification.

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8. HFE TECHNICAL PROGRAM

Overall Technical Program Map is shown in section 9.3.

The following sections provide detail about each task development. They provide, as applicable, the following information:

1. Inputs: Minimum documentation and data to start the activity.
2. Description: Brief description of the task is provided. The description of the methodology to address the NUREG elements is included in each of the Implementation Plans.
3. Process: A diagram that represents the specific process to complete the task, considering the HFE feedback from iterative activities and the relevant inputs. Note that additional revisions shall be added if comments from the regulatory commission shall be implemented. In the same way, the iterative nature of the HFE Program might imply repetition of tasks. This technical program includes the number of deliverable revisions needed for one loop of development.
4. Outputs: Documentation including reports resulting from the task development.

Relevant tools and facilities that shall be used in the execution of the HFE Technical Program include:

1. an HFE database to provide consistency of the analysis and the relationship among the different tasks of the HFE Program;
2. a part-task simulator that can provide early HSI;
3. a simulator to perform V&V tasks;
4. mock-ups or other partial designs to perform verifications and partial validations (if available);
5. HFEITS database to register and manage issues arisen during the execution of the HFE Program.

8.1. AREA 1-TASK 1, HFE PROGRAM MANAGEMENT PLAN

As described in the first element of NUREG-0711 [1], this HFE Program Management Plan (PMP) defines the methodology for conducting the HFE Program. Section 1.1 describes the purpose of this plan. The elements of NUREG-0711 [1] are being implemented in the HFE process for the Xe-100 project.

8.2. AREA 1-TASK 2, CONCEPT OF OPERATIONS

The Concept of Operations [14] for the Xe-100 reactor is provided to the regulatory commission to provide an introduction of the staffing and HSI assumptions made at the start of the HFE Program. The HFE Program activities implement those conceptual assumptions into the HSI design, including their verification and validation.

<u>Inputs</u>

- HFE Program Management Plan, X-energy.
- NUREG-0711, Human Factors Engineering Program Review Model, revision 3, NRC.
- NUREG-0700, Human-System Interface Design Review Guidelines, revision 3, NRC.

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- NUREG/CR-7126, Human-Performance Issues Related to the Design and Operation of Small Modular Reactors, 2012.
- NS-G-2.4, Conduct of Operations at Nuclear Power Plants, IAEA, 2008.
- REGDOC-2.5.2, Design of Reactor Facilities - Nuclear Power Plant, CNSC, May 2014.
- REGDOC-2.5.1, General Design Considerations Human Factors, CNSC, March 2019.
- Xe-100 Plant System Information, such as System Design Descriptions, Flow Diagrams, Logic Diagrams.
- Conceptual design information about the operation of a Xe-100 plant, such as XE-P1-PL-G0-D24-100483, Plant Control Philosophy.

Description

The Concept of Operations has the objective to define the starting point to guide the rest of HFE activities, and consequently the design, providing:

1. high-level description of how personnel will work with HSI resources;
2. the coordination of personnel activities, such as interactions with auxiliary operators and the coordination of maintenance and operations; and
3. the initial baseline for the staffing and qualification, being the starting point to address the strategy for staffing exemption.

The Concept of Operations will address the following dimensions:

1. Design Goals
2. Purpose and associated HSI components
3. Initial baseline for Staffing & Qualifications
4. Management of normal, abnormal, and emergency operation

Process

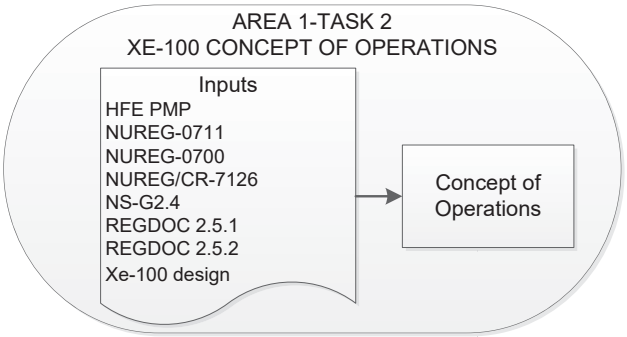

Figure 5: Concept of Operations Process Diagram

Outputs

- Concept of Operations

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8.3. AREA 1-TASK 3, CONTROL ROOM STAFFING ANALYSIS METHODOLOGY DESCRIPTION

The Control Room Staffing Analysis Methodology Description shall be conducted from the beginning, based in the Concept of Operations [14] and this Plan, to get the approval from the NRC.

Inputs

- NUREG-0800, Standard Review Plan for the Review of Safety Analysis Reports for Nuclear Power Plants: LWR Edition. Chapter 18, “Human Factors Engineering”. Revision 3.
- NUREG-0711, Human Factors Engineering Program Review Model, revision 3, NRC.
- NUREG 1791, Guidance for Assessing Exemption Requests from the Nuclear Power Plant Licensed Operator Staffing Requirements Specified in 10CFR50.54(m), July 2005, NRC.
- NUREG/CR-6838, Technical Basis for Regulatory Guidance for Assessing Exemption. Requests from Nuclear Power Plant Licensed Operator Staffing Requirements Specified in 10 CFR 50.54(m), 2004, NRC.
- SECY-11-0098, Operator Staffing for Small or Multi-Module Nuclear Power Plant Facilities, July 2011, NRC.
- HFE Program Management Plan, X-energy.
- Concept of Operations, X-energy.

Description

This task is performed for submittal of 10 CFR 50.54 (m) exemption request, so the HFE process elements, including the staffing analysis, support the construction permit and operating license process in the US.

This task is conducted with a dual purpose:

- To inform the NRC how the Xe-100 HFE Program is integrating the proposed guidance from NUREG-1791 [2] (as shown in Figure 6) into NUREG-0711 [1] technical elements.
- To inform the NRC about how the results of the HFE Program regarding the S&Q element are planned to be submitted to comply with the staffing exemption request. A separate Topical Report for Staffing Exemption will be issued.

As information from the HFE Program becomes available, this task shall be updated to compile the results and conclusions relevant to the staffing exemption request.

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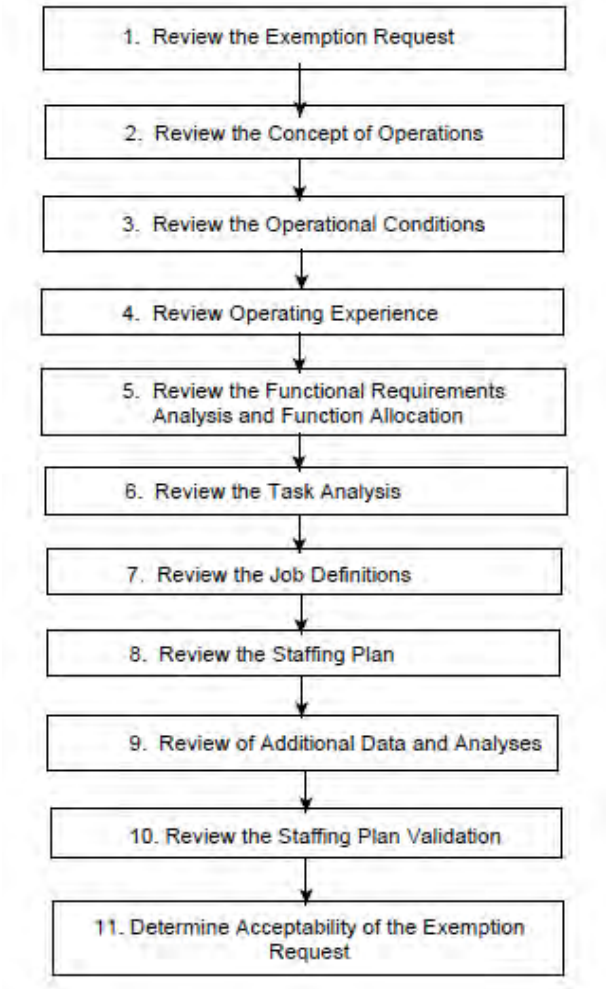

Figure 6: NUREG-1791 Staffing request review process

Process

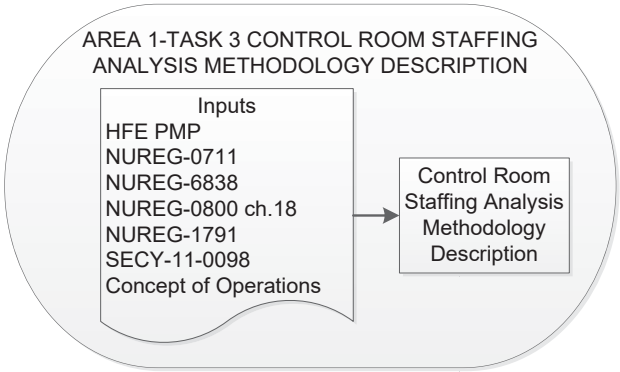

Figure 7: Control Room Staffing Analysis Methodology Description Process Diagram

Output

- Control Room Staffing Analysis Methodology Description Topical Report

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8.4. AREA 2-TASK 1, IMPLEMENTATION PLANS

Inputs

- NUREG-0800, Standard Review Plan for the Review of Safety Analysis Reports for Nuclear Power Plants: LWR Edition; Chapter 18, “Human Factors Engineering”, revision 3, NRC.
- NUREG-0711, Human Factors Engineering Program Review Model, revision 3, NRC.
- NUREG-1791, Guidance for Assessing Exemption Requests from the Nuclear Power Plant Licensed Operator Staffing Requirements Specified in 10CFR50.54(m), July 2005, NRC.
- NUREG-0700, Human-System Interface Design Review Guidelines, revision 3, NRC.
- REGDOC-2.5.2, Design of Reactor Facilities - Nuclear Power Plant, May 2014, CNSC.
- REGDOC-2.5.1, General Design Considerations Human Factors, March 2019, CNSC.
- HFE Program Management Plan, X-energy.
- Concept of Operations, X-energy.

Description

The implementation plans describe the methodology that will be followed in developing each of the HFE elements.

NUREG-0711 [1], Section 1.2.2, states that an IP review gives the applicant the opportunity to receive an NRC staff review of the methodology the applicant conducts the work associated with the element.

The implementation plans provide:

- Description of the methodology to develop each technical element
- Specific inputs and outputs for each technical element
- Guidance for review the result summary reports
- The scope and framework for the HFE developers during the HFE Program

Process

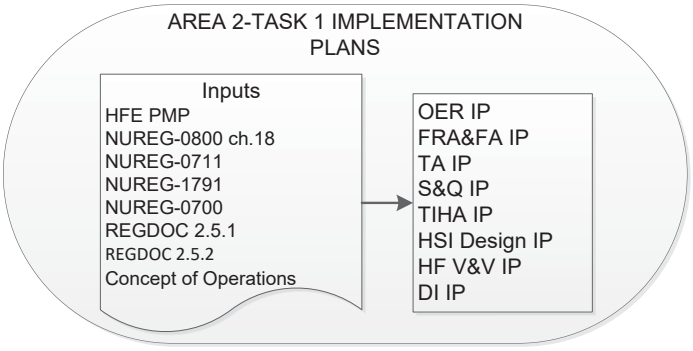

Figure 8: Implementation Plans Process Diagram

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Outputs

- Operating Experience Review Implementation Plan
- Functional Requirements Analysis and Function Allocation Implementation Plan
- Task Analysis Implementation Plan
- Staffing and Qualifications Implementation Plan
- Treatment of Important Human Actions Implementation Plan
- Human-system Interface Design Implementation Plan
- Human Factors Verification and Validation Implementation Plan
- Design Implementation Plan
- Information applicable to the preparation of the Procedures and the Training Program

8.5. AREA 3-TASK 1, OPERATING EXPERIENCE REVIEW

As described in the second element of NUREG-0711 [1], the Operating Experience Review Implementation Plan defines the methodology for conducting the OER. When the work described in the IP is completed, an RSR will be submitted.

Inputs

- NUREG-0711, Human Factors Engineering Program Review Model, revision 3, NRC.
- REGDOC-2.5.1, General Design Considerations Human Factors, March 2019, CNSC.
- HFE Program Management Plan, X-energy.
- Operating Experience Review Implementation Plan, X-energy.
- General Relevant Nuclear Industry Issues:
    1. Unresolved safety issues/generic safety issues
    2. NRC generic letters and information notices
    3. Operating plant event reports
    4. Other information available in international databases (as applicable)

Description

The OER objective is to identify HFE-related safety issues associated to the design concept to be evaluated, by analyzing information on the past performance and technical solutions of predecessor designs in other plants.

The following steps will be followed:

- Step 1: The information sources that will be considered for this OER and for the applicable design concept (considering technology, plant operations and important human actions).

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- Step 2: Selection criteria from the information sources regarding relevant issues related to the performance and technical solutions in predecessor, related designs in other plants.
- Step 3: Analysis of the operating issues selected and their impact in the considered design concept.
- Step 4: Provision of results considering:
  - Recommendations of how positive issues are to be incorporated to the design
  - Recommendations of how negative issues are to be avoided in the design

Process

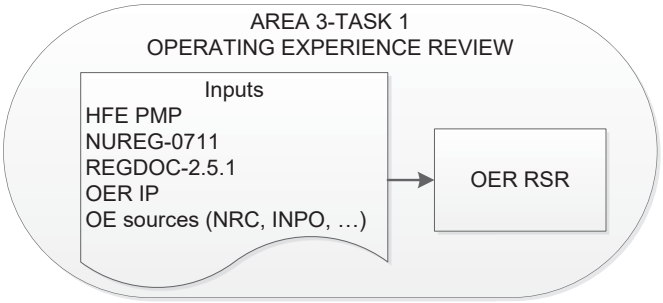

Figure 9: OER Process Diagram

Outputs

- Operating Experience Review RSR

8.6. AREA 3-TASK 2, TREATMENT OF IMPORTANT HUMAN ACTIONS

As described in the sixth element of NUREG-0711 [1], the Treatment of Important Human Actions (TIHA) Implementation Plan defines the methodology for conducting the TIHA. When the work described in the IP is completed, an RSR will be submitted.

Inputs

- NUREG-0711, Human Factors Engineering Program Review Model, revision 3, NRC.
- REGDOC-2.5.1, General Design Considerations Human Factors, March 2019, CNSC.
- HFE Program Management Plan, X-energy.
- Concept of Operations, X-energy.
- Treatment of Important Human Actions Implementation Plan, X-energy.
- PRA/HRA or preliminary equivalent, X-energy.
- Safety Analysis Report (SAR) or preliminary equivalent, X-energy.
- Defense in Depth (D3) analyses or preliminary equivalent, X-energy.
- Operating Experience Review results.

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Description

TIHA analysis identifies the important human actions (IHAs), integrate them in the HFE Program by considering its impact in the rest of HFE Elements and provide the specific treatment to be considered for each identified IHA.

TIHA analysis provides:

- Identification of IHAs: By using internal and external inputs.
- Integration of IHAs in the HFE Program: Select the potential HFE element related to the IHA.
- Specific Treatment of IHAs: Propose a strategy within the HFE Program elements to minimize the human error risk, facilitating error-detection and recovery capability associated to the IHAs.

TIHA analysis allows to limit the scope of the next analyses (FRA & FA, TA, and S&Q) and V&V by selecting those actions and scenarios relevant for plant safety.

Process

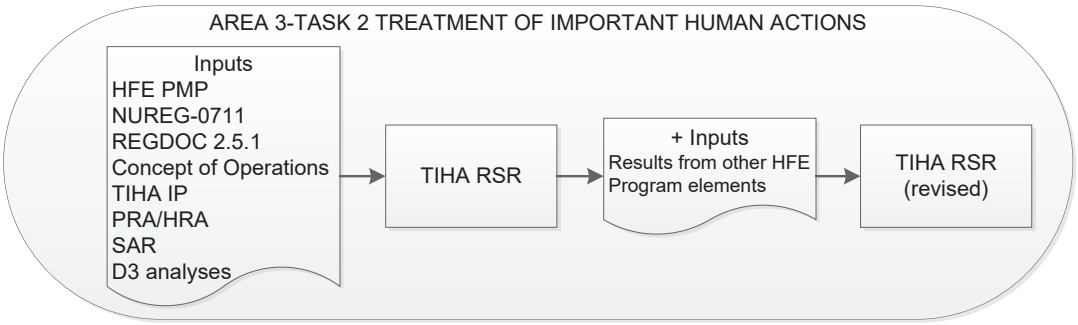

Figure 10: TIHA Process Diagram

Outputs

- Treatment of Important Human Actions RSR

8.7. AREA 3-TASK 3, FUNCTIONAL REQUIREMENTS ANALYSIS AND FUNCTION ALLOCATION

As described in the third element of NUREG-0711 [1], the Functional Requirements Analysis and Function Allocation (FRA and FA) Implementation Plan defines the methodology for conducting the FRA and FA. When the work described in the IP is completed, an RSR will be submitted.

Inputs

- NUREG-0711, Human Factors Engineering Program Review Model, revision 3, NRC.
- REGDOC-2.5.1, General Design Considerations Human Factors, March 2019, CNSC.
- NUREG/CR-3331, A Methodology for Allocation of Nuclear Power Plant Control Functions to Human and Automated Control, 1983, NRC.
- HFE Program Management Plan, X-energy.

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- Concept of Operations, X-energy.
- Functional Requirements Analysis and Function Allocation Implementation Plan, X-energy.
- Operating Experience Review results.
- Treatment of Important Human Actions results.
- The applicable information from each of the following plant system documents will be used:
    a. System design description
    b. Process Flow diagrams, P&IDs
    c. Logic diagrams, Electrical Diagrams
    d. Setpoint list
    e. Equipment List
    f. I/O List

Description

The Functional Requirements Analysis (FRA) and Function Allocation (FA) has the objective to sufficiently define and analyze the functions necessary to accomplish plant goals are sufficiently defined and analyzed so that the allocation of functions to personnel and machine resources can take advantage of human and machine strengths and avoid human and machine limitations.

The FRA and FA focuses on:

- identifying the high-level functions that have to be accomplished to meet the plant's goals and desired performance;
- delineating the relationships between high-level functions and the plant's systems and associated components responsible for performing the functions; and
- providing a framework for determining the roles and responsibilities of personnel and automation

The FRA and FA activities provides:

1. List of functions.
2. Description of function requirements, including required alignments, parameters, and components
3. Description of function allocation.
4. Recommendations, if any

After the HF V&V is performed, discrepancies in the analysis and design may be returned to Area 3 for further analysis.

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Process

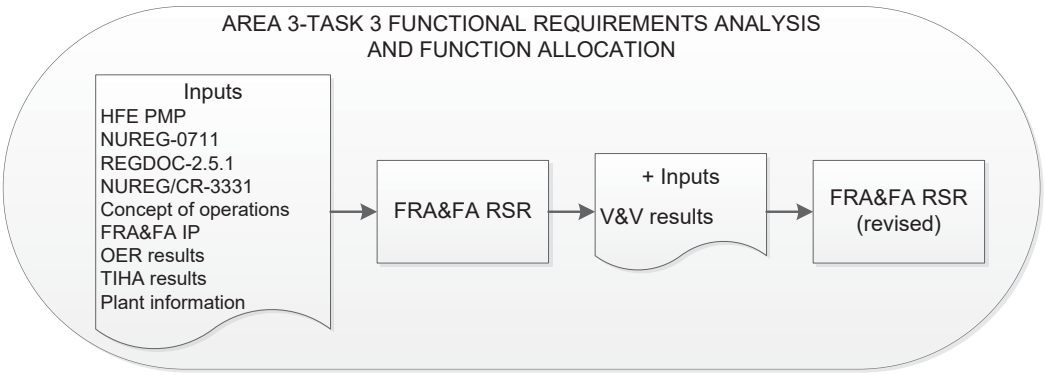

Figure 11: FRA and FA Process Diagram

Outputs

- Functional Requirements Analysis and Function Allocation RSR

8.8. AREA 3-TASK 4, TASK ANALYSIS

As described in the fourth element of NUREG-0711 [1], the Task Analysis (TA) Implementation Plan defines the methodology for conducting the TA. When the work described in the IP is completed, an RSR will be submitted.

Inputs

- NUREG-0711, Human Factors Engineering Program Review Model, revision 3, NRC.
- REGDOC-2.5.1, General Design Considerations Human Factors, March 2019, CNSC.
- Regulatory Guide 1.62, Manual Initiation of Protective Actions, Revision 1, 2010, NRC.
- ANSI/ANS-58.8, Time Response Design Criteria for Nuclear Safety Related Operator Actions, 2008.
- SSG-39, Design of Instrumentation and Control Systems for Nuclear Power Plants, IAEA.
- IEEE 603, Standard Criteria for Safety Systems for Nuclear Power Generating Systems, 1998.
- HFE Program Management Plan, X-energy.
- Concept of Operations, X-energy.
- Task Analysis Implementation Plan, X-energy.
- Operating Experience Review results.
- Treatment of Important Human Actions results.
- Functional Requirements Analysis and Function Allocation results.
- The applicable information from each of the following plant system documents will be used:
    a. System design description

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b. Process Flow diagrams, P&IDs

c. Logic diagrams, Electrical Diagrams

d. Setpoint list

e. Equipment List

f. I/O List

Description

The objective of the TA is to identify the tasks that personnel must perform to accomplish the functions identified in the previous element of FRA and FA. Tasks are a group of related activities with a common aim containing the information, control, and task support required to complete those tasks.

The TA provides:

- Inventory/list of Operator Tasks per function.
- List of activities to be performed in each defined task, including a narrative of the activities to be performed, and for those selected for a detailed analysis (critical to safety, previously identified through OER and TIHA), preliminary staffing evaluation
- For each activity:
- Inventory of alarms
- Inventory of information devices
- Inventory of controls for task executions
- Task support requirements necessary to accomplish each given task
- Initial estimation of time and workload as input for the S&Q
- The relationship between tasks (in sequence, in parallel, with conditional relationship or coordinated with others). Tools such as the operating sequence diagrams (OSDs) are used to show those relationships.
- Recommendations, if any.

After the HF V&V is performed, discrepancies in the analysis and design may be returned to Area 3 for further analysis.

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Process

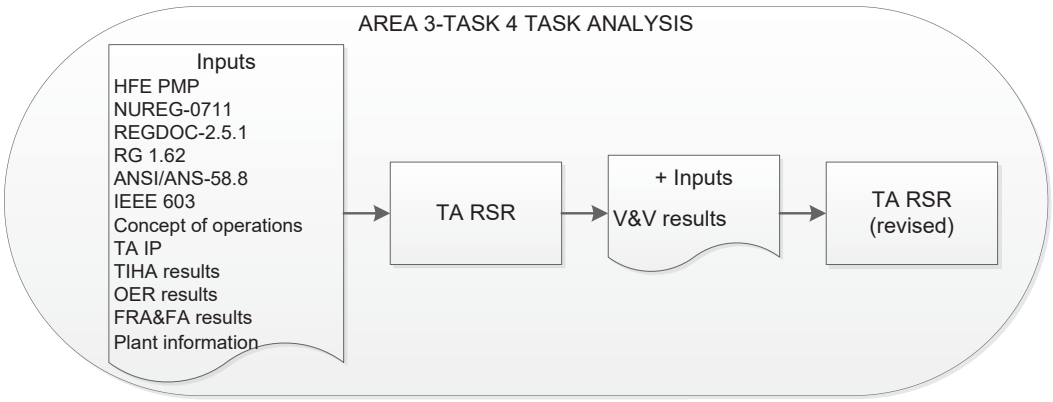

Figure 12: TA Process Diagram

Outputs

- Task Analysis RSR

8.9. AREA 3-TASK 5, STAFFING & QUALIFICATIONS

As described in fifth element of NUREG-0711 [1], the Staffing & Qualifications (S&Q) Implementation Plan defines the methodology for conducting the S&Q. When the work described in the IP is completed, an RSR will be submitted.

Inputs

- NUREG-0711, Human Factors Engineering Program Review Model, revision 3, NRC.
- NUREG-1791, Guidance for Assessing Exemption Requests from the Nuclear Power Plant Licensed Operator Staffing Requirements Specified in 10CFR50.54(m), July 2005, NRC.
- NUREG/CR-6838, Technical Basis for Regulatory Guidance for Assessing Exemption. Requests from Nuclear Power Plant Licensed Operator Staffing Requirements Specified in 10 CFR 50.54(m), 2004, NRC.
- SECY-11-0098, Operator Staffing for Small or Multi-Module Nuclear Power Plant Facilities, July 2011, NRC.
- REGDOC 2.5.1, General Design Considerations Human Factors, March 2019, CNSC.
- REGDOC-2.2.5, Human Performance Management - Minimum Staff Complement, 2019, CNSC.
- HFE Program Management Plan, X-energy.
- Concept of Operations, X-energy.
- Operating Experience Review results.
- Treatment of Important Human Actions results.
- Functional Requirements Analysis and Function Allocation results.

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- Task Analysis results.
- S&Q Implementation Plan, X-energy.
- The applicable information from each of the following plant system documents will be used:
    a. System design description
    b. Process Flow diagrams, P&IDs
    c. Logic diagrams, Electrical Diagrams
    d. Setpoint list
    e. Equipment List
    f. I/O List

Description

The activity consists in the evaluation of the operation crew size, associating the knowledge and abilities required to perform their duties and responsibilities.

The S&Q analysis is iterative; that is, the initial staffing goals, established in the Concept of Operations are modified as information from the HFE analyses from other elements becomes available (OER, TIHA, TA, FRA & FA, and V&V in the final iteration).

The S&Q provides:

- a description of the process used to determine initial and final staffing levels and personnel qualifications;
- initial and final, as the program develops, staffing levels;
- the assignment of tasks to personnel;
- a description of necessary qualifications of personnel;
- input to the staffing evaluation from the other pertinent HFE elements, or a justification why no input was included; and
- results of validating the final staffing levels (in the final revision).

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Process

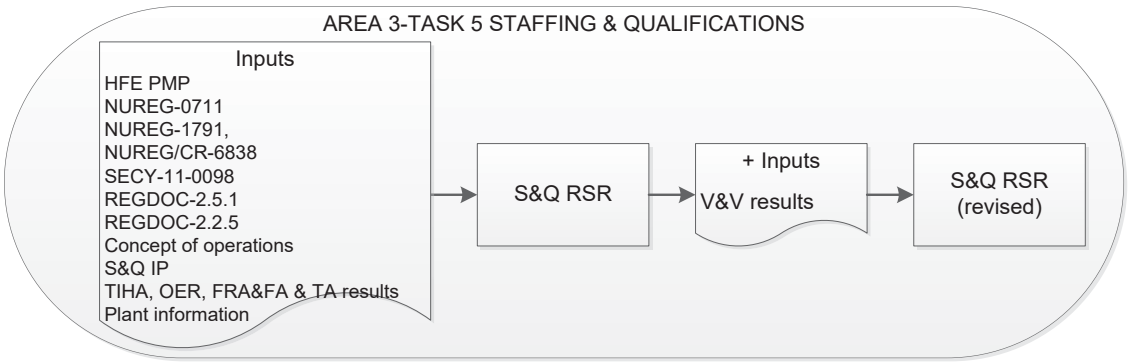

Figure 13: S&Q Process Diagram

Outputs

- Staffing & Qualifications RSR

8.10. AREA 4-TASK 0, INTEGRATION STYLE GUIDE

As described in seventh element of NUREG-0711 [1], the Human-System Interface (HSI) Implementation Plan defines the methodology for conducting the HSI. With the IP submittal, a style guide that defines the design-specific conventions for the HSI design will be prepared and be submitted. A preliminary HSI Integration SG has been prepared [15].

The ISG is a living document that is revised to reflect changes due to design information received during performance of the IP and that which may be provided by suppliers and sub-suppliers as they attempt to implement criteria from the ISG.

Inputs

- NUREG-0711, Human Factors Engineering Program Review Model, revision 3, NRC.
- NUREG-0700, Human-System Interface Design Review Guidelines, revision 3, NRC.
- REGDOC-2.5.2, Design of Reactor Facilities - Nuclear Power Plant, May 2014, CNSC.
- REGDOC-2.5.1, General Design Considerations Human Factors, March 2019, CNSC.
- Plant documentation, as available, such as:
    a. Control Room Layout
    b. Plant Control Philosophy
    c. Instrumentation and Control (I&C) systems descriptions
    d. Digital Human-System Interface system description

Description

The style guide has the objective to set basis of the design of the HSIs that are included the Xe-100 facility. Consequently, its purpose is to establish the rules that are to be followed for providing consistency among

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the HSIs where applicable, and for confirming that such HSIs are HFE compliant. The style guide evaluates the applicability of the guidelines from NUREG-0700 [3] to the Xe-100 HFE Program and addresses them if needed. The guidelines refer to the following design features:

- Computer-based HSI items: formats, elements, pages, and devices
- User-interface interaction and management
- Computer-based input devices
- Conventional control devices
- Alarm system
- Safety function and parameter monitoring system
- Group-View display system
- Soft control system
- Workstation design
- Workplace design

Regarding REGDOC-2.5.1 [8], it is expected that the Integration Style Guide addresses:

- Alarm annunciation
- Abbreviations and acronyms
- Panel device selection and layout
- Color usage

REGDOC-2.5.1 [8] states that prepared guides should be comprehensive and up to date. Besides, REGDOC-2.5.2 [7], section 7.21, confirms that NUREG-0700 [3] is also a design guidance.

Process

This process considers possible revisions that include outputs from different areas of the HFE Program. Number of revisions may be simplified as necessary.

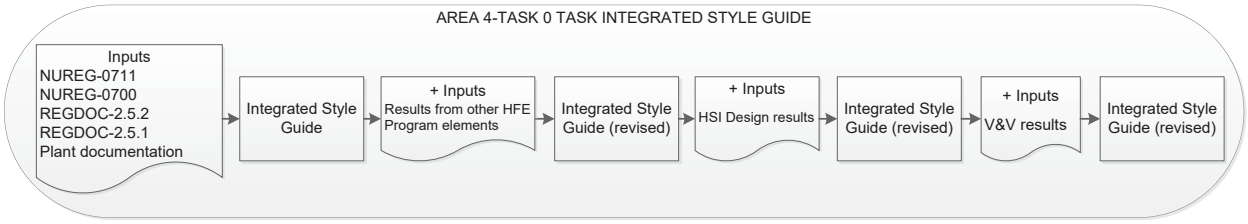

Figure 14: Integrated Style Guide Process Diagram

Outputs

- Integration Style Guide

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8.11. AREA 4-TASK 1, HUMAN-SYSTEM INTERFACE DESIGN

As described in the seventh element of NUREG-0711 [1], the Human-System Interface (HSI) Design Implementation Plan defines the methodology for conducting the HSI design. When the work in the IP is completed, an RSR will be prepared and submitted.

Inputs

- NUREG-0711, Human Factors Engineering Program Review Model, revision 3, NRC.
- NUREG-0700, Human-System Interface Design Review Guidelines, revision 3, NRC.
- REGDOC-2.5.2, Design of Reactor Facilities - Nuclear Power Plant, May 2014, CNSC.
- REGDOC-2.5.1, General Design Considerations Human Factors, March 2019, CNSC.
- EPRI 3002004310, HF Guidance for Control Room and Digital HSI Design & Modification, December 2015.
- HFE Program Management Plan, X-energy.
- Concept of Operations, X-energy.
- HSI Design Implementation Plan.
- Operating Experience Review results.
- Treatment of Important Human Actions results.
- Functional Requirements Analysis and Function Allocation results.
- Task Analysis results.
- Staffing & Qualifications results.
- Integration Style Guide.

Description

The HSI design process represents the translation of function and task requirements into HSI characteristics and functions. The activity objective is consequently to translate functional and task requirements into a detailed design of alarms, indications, controls, and other aspects of the HSI through the systematic application of HFE principles and criteria, specified in the Integration Style Guide.

The final step of this analysis is to provide the location of the equipment, controls, and indications within the different interfaces (software or hardware), providing the design of the displays, such as plant system displays and high-level monitoring displays.

HSIs shall cover the following facilities, as applicable: MCR, TSC, EOF, RSS and any local control station.

The HSI covers the technical bases of the design, demonstrating that they constitute a state-of-the-art HSI design supporting personnel performance. Including a description of:

- Facility hardware and software layouts, including workstations, large screen displays.
- Working positions.

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- Key HSI resources and their functionality, such as alarms, displays, controls, computer-based procedures (if any), and other support and job aids.
- Technologies to support teamwork and communication within the MCR and between the rest of monitoring and control applicable facilities.
- Use of the interfaces for monitoring, interacting, and overriding automatic systems and for interacting with computerized procedures systems and other computerized operator support systems station, as applicable.

The HSIs are designed in a first approach, taking as input the Concept of Operations [14] and the results from the previous HFE Program elements (OER, TIHA, FRA & FA, TA, S&Q). The results are subject to the V&V activities, being verified first and later validated through tests in the Integrated System validation activity. Therefore, three revisions are foreseen as a minimum, as shown in the process diagram below.

Process

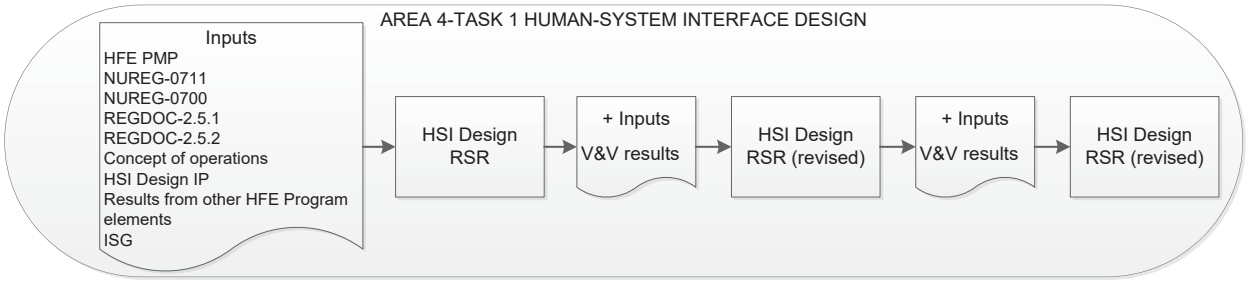

Figure 15: HSI Design Process Diagram

Outputs

- HSI Design RSR

8.12. AREA 5-TASK 1, HUMAN FACTORS VERIFICATION AND VALIDATION

As described in the tenth element of NUREG-0711 [1], the Human Factors Verification and Validation Implementation Plan defines the methodology for conducting HF V&V. When the work in the IP is completed, the set of RSR will be prepared and submitted.

Inputs

- NUREG-0711, Human Factors Engineering Program Review Model, revision 3, NRC.
- NUREG-0700, Human-System Interface Design Review Guidelines, revision 3, NRC.
- REGDOC-2.5.2, Design of Reactor Facilities - Nuclear Power Plant, May 2014, CNSC.
- REGDOC-2.5.1, General Design Considerations Human Factors, March 2019, CNSC.
- NUREG-0800, Standard Review Plan for the Review of Safety Analysis Reports for Nuclear Power Plants: LWR Edition. Chapter 18, Attachment B “Methodology to Assess the Workload of Challenging Operational Conditions”. Revision 3, NRC.
- IEC 61771, Nuclear Power Plants Main Control Rooms-Verification and Validation of Design, 1995.

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- NUREG/CR-7190, Workload, Situation Awareness and Teamwork, 2015, NRC.
- NUREG/CR-6393, Integrated System Validation: Methodology and Review Criteria, 1997, NRC.
- ANSI/AIAA G-035A-2000, Guide to Human Performance Measurements, 2001.
- ANSI/ANS 3.5-2009, Nuclear Power Plant Simulators for Use in Operator Training, 2009.
- HFE Program Management Plan, X-energy.
- Human Factors V&V Implementation Plan.
- Operating Experience Review results.
- Treatment of Important Human Actions results.
- Functional Requirements Analysis and Function Allocation results.
- Task Analysis results.
- Staffing & Qualifications results.
- Integration Style Guide.
- HSI Design results.

Description

The Human Factors Verification and Validation element encompasses several activities:

a. HSI Task Support Verification (TSV).

b. HSI Design Verification (DV).

c. Integrated System Validation (ISV).

d. Human Engineering Discrepancy (HED) Management (through HFEITS).

Due to the large number of potential applicable HSIs, V&V activities shall be limited to a certain number of interfaces and scenarios by selecting them following sampling criteria. These sampling criteria includes a diverse range of operational conditions that could be encountered by the operators during plant life.

The main inputs for selecting V&V applicable HSIs and scenarios come from the previous HFE elements: HSI Design, TA and TIHA. The implementation plan allows to add additional HSIs or scenarios to verify and validate them upon necessity.

The V&V element must be developed by people not directly responsible of the design, to provide independence.

A brief explanation of each activity is written below.

- HSI Task Support Verification (TSV).

  Using the outputs from the HSI design and Task Analysis, this verification pursues:

  - To verify that the HSI provides the needed alarms, information, controls, and task support for personnel to perform their tasks, defined by the task analysis.

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- HSI features match the requirements of the personnel tasks.

- HSI Design Verification (DV).

  The HSIs are checked for compliance with the applicable HFE Guidelines of NUREG-0700 [3] and the criteria in the Integration Style Guide.

- Integrated System Validation (ISV).

  The ISV is the final test to validate the design from the HFE perspective. The validation is conducted over a simulator; thus, the operational conditions are simulated.

  A group of selected scenarios are role-played by the operators, following the procedures, meanwhile a group of V&V observers is monitoring the operator actions.

  The result of the ISV is the final acceptance of the tested HSIs. However, additional recommendations arise such as:

  - Minor HFE improvements to the design, considering that the equipment is already manufactured;
  - Recommendations to procedure development; and
  - Recommendations to training program development

  The level of performance during the ISV set an initial point for the HPM.

- Human Engineering Discrepancy (HED) Management (through HFEITS).

  Although the HFEITS is introduced from the beginning of the HFE Program, as the main HFE issues originator is typically the V&V element, the management is part of the execution of the V&V element.

  The deviations and discrepancies, detected as a result of the Verification and Validation activities explained above, they are called Human Engineering Discrepancies (HEDs) and shall be registered and tracked in the HFEITS tool.

  One initial RSR revision is planned to be issued for each activity. The resolution of pending items and HEDs and the summary of results will be gathered in a single HFE V&V RSR. It shall be noted that the number of revisions and reports might vary, if, upon project necessity, the verification and validation activities are performed in separate stages or partially.

  In addition, as the ISV is the critical activity for the acceptance of the goals from the HFE Program, a previous procedure shall be developed for establishing the activity framework: acceptance criteria, performance measures, testbed conditions, scenarios, and participants.

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Process

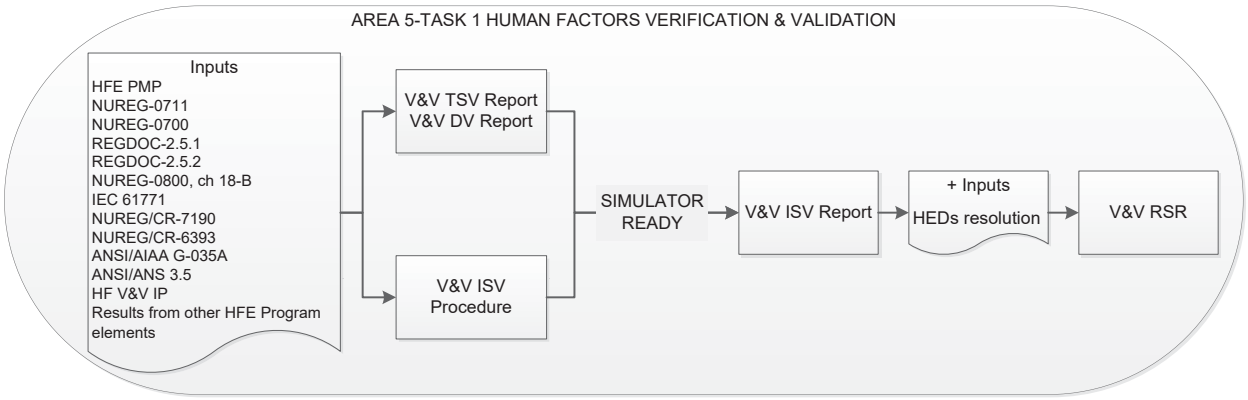

Figure 16: HF V&V Process Diagram

Outputs

- V&V: Task Support Verification Report
- V&V: Design Verification Report
- V&V: Integrated System Validation Procedure
- V&V: Integrated System Validation Report
- V&V RSR

8.13. AREA 6-TASK 1, CONTROL ROOM STAFFING ANALYSIS METHODOLOGY DESCRIPTION

Inputs

- NUREG-0800, Standard Review Plan for the Review of Safety Analysis Reports for Nuclear Power Plants: LWR Edition. Chapter 18, “Human Factors Engineering”. Revision 3, NRC.
- NUREG-0711, Human Factors Engineering Program Review Model, revision 3, NRC.
- NUREG 1791, Guidance for Assessing Exemption Requests from the Nuclear Power Plant Licensed Operator Staffing Requirements Specified in 10CFR50.54(m), July 2005, NRC.
- NUREG/CR-6838, Technical Basis for Regulatory Guidance for Assessing Exemption. Requests from Nuclear Power Plant Licensed Operator Staffing Requirements Specified in 10 CFR 50.54(m), 2004, NRC.
- SECY-11-0098, Operator Staffing for Small or Multi-Module Nuclear Power Plant Facilities, July 2011, NRC.
- HFE Program Management Plan, X-energy.
- Concept of Operations, X-energy.
- Operating Experience Review results.
- Treatment of Important Human Actions results.

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- Functional Requirements Analysis and Function Allocation results.
- Task Analysis results.
- Staffing & Qualifications results.
- Integration Style Guide.
- HSI Design results.
- V&V results.

Description

This task is performed to support submittal of 10 CFR 50.54 (m) exemption request.

Based on the results from the HFE Program elements and following the guidance from NUREG-1791 [2] and NUREG/CR-6838 [4], a topical report shall be prepared.

The topical report provides:

- summary of the final S&Q results, describing the processes followed during the HFE Program;
- HFE Technical basis to allow the NRC to review the Staffing Exemption; and
- justification based in the HF V&V ISV results that the final S&Q meets the requirements to operate the plant safely.

Process

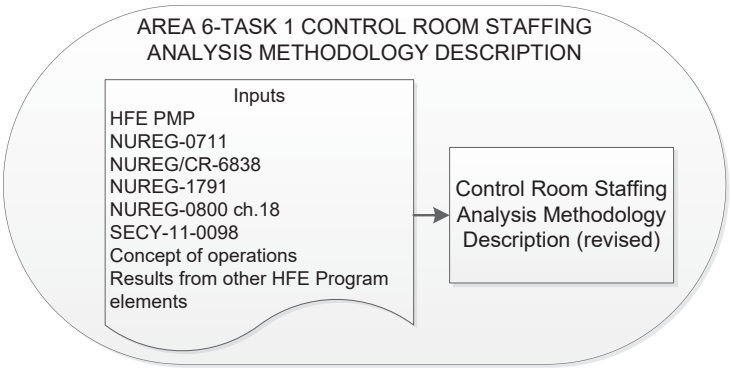

Figure 17: Control Room Staffing Analysis Methodology Description Process Diagram

Outputs

- Control Room Staffing Analysis Methodology Description Topical Report

8.14. AREA 6-TASK 2, MINIMUM STAFF COMPONENT PROCEDURE

Inputs

- REGDOC-2.2.1, Human Factors, March 2019, CNSC.
- REGDOC-2.5.2, Design of Reactor Facilities - Nuclear Power Plant, May 2014, CNSC.

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- REGDOC-2.5.1, General Design Considerations Human Factors, March 2019, CNSC.
- REGDOC-2.2.5, Minimum Staff Complement, April 2019, CNSC.
- ANSI/ANS 3.5-2009, Nuclear Power Plant Simulators for Use in Operator Training, 2009.
- HFE Program Management Plan, X-energy.
- Concept of Operations, X-energy.
- Operating Experience Review results.
- Treatment of Important Human Actions results.
- Functional Requirements Analysis and Function Allocation results.
- Task Analysis results.
- Staffing & Qualifications results.
- Integration Style Guide.
- HSI Design results.
- V&V results.

Description

This task is performed to comply with CNSC REGDOC-2.2.5, Minimum Staff Complement [9], so the output is part only of the design certification documents in Canada.

Based on the results of the technical elements of the HFE Program, with a focus in the final S&Q results, the minimum staff procedure provides:

- the specific number of personnel to be present onsite, in the facility, and in the MCR (if one exists), and the composition of the minimum staff complement with reference to specific positions or qualifications;
- for nuclear facilities that modify their minimum staff complement for different operational states, the specific number and composition of the minimum staff complement with reference to specific positions or qualifications for each operational state;
- consistent terminology when referring to specific positions or staff qualifications;
- the specific restrictions on the location of individuals in the facility (for example, it may be necessary to limit the location of certain workers within the facility if they must be able to return to the MCR within a specified time limit);
- a description of the measures in place to monitor compliance with the minimum staff complement and to prevent non-compliance with the minimum staff complement; and
- specific actions to be taken to reduce the risk to the facility in the event of non-compliance with the minimum staff complement.

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Process

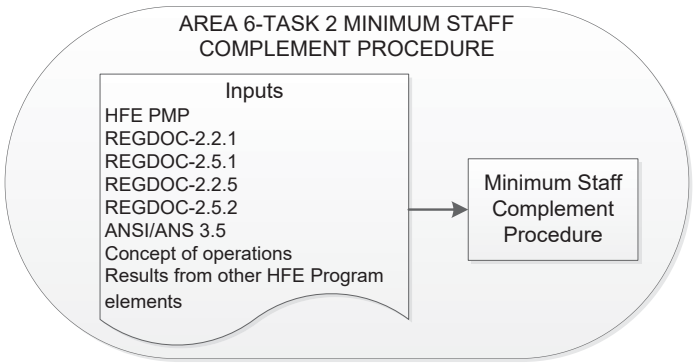

Figure 18: Minimum Staff Complement Procedure Process Diagram

Outputs

- Minimum Staff Complement Procedure

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9. APPENDICES

9.1. APPENDIX A: COMPLIANCE WITH NUREG-0711

Table 5 provides a mapping of the sections in this HFE PMP where each NUREG-0711 [1] review criterion is met.

Table 5: Compliance with NUREG-0711

NUREG-0711 reference	Requirement	HFE PMP reference
2.4.1 (1)	HFE Program Goals – The applicant should state the general objectives of the program in "human-centered" terms. As the HFE program develops, they should be further defined and used as a basis for HFE tests and evaluations.	4.1
2.4.1 (2)	Assumptions and Constraints – The applicant should identify the design assumptions and constraints.	4.4
2.4.1 (3)	HFE Program Duration – The applicant's HFE program should be in effect at least from the start of the design cycle through completion of initial plant start-up test program.	4.5
2.4.1 (4)	Facilities – The applicant's HFE program should cover the main control room (MCR), remote shutdown facility (RSF), technical support center (TSC), emergency operations facility (EOF), and local control stations (LCSs). The 12 HFE elements should be applied to each of them, unless otherwise noted for a specific HFE element. However, applicants may apply the elements of the HFE program in a graded fashion to facilities other than the MCR and RSF, providing justification in the HFE program plan.	4.6
2.4.1 (5)	HSIs, Procedures and Training – The applicant's HFE program should address the design of HSIs and identify inputs to the development of procedures and training for all operations, accident management, maintenance, test, inspections, and surveillance tasks that operational personnel will perform or supervise. In addition, the HFE design process should identify training program input for the following personnel identified in 10 CFR 50.120: instrument and control technician, electrical maintenance personnel, mechanical maintenance personnel, radiological protection technician, chemistry technician, and engineering support personnel. In addition, any other personnel who perform tasks directly related to plant safety should be included,	4.7

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NUREG-0711 reference	Requirement	HFE PMP reference
	such as information technology technicians who troubleshoot and maintain support systems and their HSIs.	
2.4.1 (6)	Personnel – The applicant's HFE program should consider operations staffing and qualifications, including licensed control-room operators as defined in 10 CFR Part 55, and the following categories of personnel: non-licensed operators, shift supervisor, and shift technical advisor.	4.8
2.4.1 (7)	Additional Considerations for Reviewing the HFE Aspects of Plant Modifications	N/A
2.4.2 (1)	Responsibility – The applicant's team should be responsible for: • developing all HFE plans and procedures • overseeing and reviewing all activities in HFE design, development, test, and evaluation, including the initiation, recommendation, and provision of solutions through designated channels for problems identified in implementing the HFE work • verifying that the team's recommendations are implemented • assuring that all HFE activities comply with the HFE plans and procedures • scheduling work and milestones	5.1
2.4.2 (2)	Organizational Placement and Authority – The applicant should describe the primary HFE organization(s) or function(s) within the engineering organization designing the plant or modification. The organization should be illustrated to show organizational and functional relationships, reporting relationships, and lines of communication. The applicant also should address the following: • When more than one organization is responsible for HFE [such as instrumentation and control (I&C) and operations], the lead organizational unit answerable for the HFE program plan should be identified. If organization changes are expected over time (e.g., from design through construction to start-up) necessary transitions between responsible organizations should be described. • The team should have the authority and organizational placement to reasonably assure that all its areas of responsibility are completed, and to identify problems in establishing the overall plan or modifying its design. • The team should have the authority to control further processing,	5.2

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NUREG-0711 reference	Requirement	HFE PMP reference
	delivery, installation, or use of HFE products until the disposition of a nonconformance, deficiency, or unsatisfactory condition is resolved.	
2.4.2 (3)	Composition – The applicant's HFE design team should include the expertise described in the appendix to this report.	5.3
2.4.2 (4)	Team Staffing – The applicant should describe team staffing in terms of job descriptions and assignments of team personnel.	5.3
2.4.3 (1)	General Process Procedures – The applicant should identify the process through which the team will execute its responsibilities. It should include procedures for the following: • assigning HFE activities to individual team members • governing the internal management of the team • making decisions on managing the HFE program • making HFE design decisions • controlling changes in design of equipment • reviewing of HFE products	6.1
2.4.3 (2)	Process Management Tools – The applicant should identify the tools and techniques (e.g., review forms) the team uses to verify that they fulfilled their responsibilities.	6.2
2.4.3 (3)	Integration of HFE and Other Plant or Modification Design Activities – The applicant should describe the process for integrating the design activities (i.e., the inputs from other design work to the HFE program, and the outputs from the HFE program to other plant design activities). The applicant should also discuss the iterative aspects of the HFE design process.	6.4
2.4.3 (4)	HFE Program Milestones – The applicant should identify HFE milestones that show the relationship of the elements of the HFE program to the integrated plant design, development, and licensing schedule. A relative program schedule of HFE tasks should be available for the NRC staff's review showing relationships between the HFE elements and the activities, products, and reviews	6.3
2.4.3 (5)	HFE Documentation – The applicant should identify the HFE documentation items, such as RSRs and their supporting materials, and briefly describe them, along with the procedures for their retention and for making them available to the NRC staff for review.	6.5

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NUREG-0711 reference	Requirement	HFE PMP reference
2.4.3 (6)	Subcontractor HFE Efforts – The applicant should include HFE requirements in each subcontract contributing to the HFE program. The applicant should periodically verify the subcontractor's compliance with HFE requirements. The HFE plan should describe milestones and the methods used for this verification	6.6
2.4.4 (1)	Availability – The applicant should have a tracking system to address human factors issues that are: • known to the industry (defined in the Operating Experience Review element) • identified throughout the life cycle of the HFE aspects of design, development, and evaluation • deemed by the HFE program as human engineering discrepancies (HEDs)	7.1
2.4.4 (2)	Method – The applicant's method should: • establish criteria for when issues are entered into the system • track issues until the potential for negative effects on human performance is reduced to an acceptable level.	7.2
2.4.4 (3)	Documentation – The applicant should document the actions taken to address each issue in the system; if no action is required, this should be justified.	7.2
2.4.4 (4)	Responsibility – After identifying an issue, the applicant's tracking procedures should describe individual responsibilities for logging, tracking, and resolving it, along with the acceptance of the outcome	7.3
2.4.5 (1)	The applicant should describe the applicability and status of each of the following HFE elements: • Operating Experience Review • Functional Requirements Analysis and Function Allocation • Task Analysis • Staffing and Qualifications • Treatment of Important Human Actions • HSI Design • Procedure Development (Described in SRP, Chapter 13 submittal) • Training Development (Described SRP, Chapter 13 submittal) • Human Factors Verification and Validation • Design Implementation • Human Performance Monitoring	8.1 to 8.14

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NUREG-0711 reference	Requirement	HFE PMP reference
2.4.5 (2)	The applicant should identify the approximate schedule for completing any HFE activities that are unfinished at the time of the application.	6.3
2.4.5 (3)	The applicant's plan should identify and describe the standards and specifications that are sources of the HFE requirements.	8.1 to 8.14
2.4.5 (4)	The applicant's plan should specify HFE facilities, equipment, tools, and techniques (such as laboratories, simulators, rapid prototyping software) that the HFE program will employ.	8
2.4.5 (5)	Additional Considerations for Reviewing the HFE Aspects of Plant Modifications	N/A

9.2. APPENDIX B: COMPLIANCE WITH REGDOC-2.5.1

Table 6 provides a mapping of the sections in this HFE PMP where each REGDOC-2.5.1 [8] criterion is met.

Table 6. Compliance with REGDOC-2.5.1

REGDOC-2.5.1 reference	Requirement	HFE PMP reference
4.1	Goals of the plan - Provide concise statements about the objectives of the plan. The goals will normally be driven by the nature of the licensable activity. Goal definition early in development is vital to the Plan's effectiveness and validity.	4.1
4.2	Scope of the plan - The scope of the HFEPP should consider safety critical activities and hazardous interactions. It should also specify areas, systems and components involved, and the phases of the licensable activity in which human factors engineering will be incorporated. Adequate justification for any exclusions should also be provided in this section and discussed in the "Criteria" section, as described in subsection 4.4. The HFEPP should include documentation on any constraints, limitations, and assumptions that apply to the human factors work. These may relate to level of technology, resource limitations, time constraints, consistency and compatibility with existing design or operational features, or any other restrictions or requirements imposed on the project team or the Plan.	4.2, 4.5, 4.6 and 4.8

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REGDOC-2.5.1 reference	Requirement	HFE PMP reference
4.3	Background of the Activity - Provide a brief description of the licensable activity including purpose, scope, and time frames.	4
4.4	Criteria for Determining Areas of Consideration - Provide a description of the type of criteria that will be used to determine which aspects of the activity warrant human factors consideration. It is recommended that criteria be based on function, task importance, or risk, and that criteria statements be clear, concise, and objective.	Note 1
4.5.1	Roles and Responsibilities Clearly define the role of any persons performing human factors work associated with the licensable activity for which the Plan is being prepared. Expand on that role definition with a statement about any part of the licensable activity which will require human factors involvement and input.	5.1 and 5.3
4.5.2	Training Needs - Familiarity with established human factors principles, benefits, techniques and guidelines is important to successful implementation of the HFEPP. If training in these matters is required by persons performing human factors work associated with the licensable activity, indicate those training needs and the plans for addressing them	5.3
4.5.3	Related Groups - To varying degrees, the human factors elements addressed in the technical basis of the Plan will overlap and interface with other functions and disciplines within the licensable activity. Identify, at a high level, all groups that may be impacted by the Plan, and indicate how their input will be considered or incorporated.	5.2 and 6.4
4.6.1	Technical Basis of the plan - Clearly state the technical basis for the HFEPP, such as specific license applicant's policies and procedures for human factors, regulatory documents, and industry documents such as consensus standards and guides.	2, and 8.1 to 8.14
4.6.2	The following technical elements should be included in the plan: • human-machine interface system • human-machine allocation of function • human reliability • job design • operating experience review • physical working environment	 8.11 8.7 8.6, 8.12 8.8, 8.9 8.5 8.11

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REGDOC-2.5.1 reference	Requirement	HFE PMP reference
	• activities with potentially hazardous human interactions • procedures development • shift-work systems • staffing • validation • verification	8.6 6.4 3.1 8.9 8.12 8.12
4.6.3	Methods for Addressing the Technical Elements - Describe the methods and techniques that will be used to address each of the technical elements for review	8.4
4.6.4	Intended Tools - Indicate the human factors facilities, equipment and tools that will be used to support the licensable activity.	8
4.6.5	Technical guides - During development of the detailed design phase of a licensable activity, it is expected that various human factors guides will be used to address such topics as • alarm annunciation; • abbreviations and acronyms; • panel device selection and layout; and • colour usage. Whether guidelines are developed specifically for the licensable activity to standardize operational practices and conventions, or selected from applicable published material, they should be relevant to the current facility and activity, level of technology, and user population. In addition, all guides should be comprehensive and up to date.	Note 1
4.7.1	To ensure consistency across the various work elements of the HFEPP, identify the steps required for its implementation.	6.4, 9.3
4.7.2	Timelines - On a timeline, plot the work activities related to human factors to show their place within the project development cycle for the activity to be licensed. Reference to the master project schedule may be appropriate if it incorporates information relevant to the purposes of the timeline	6.3, 6.4
4.7.3	Documentation - Specify how human factors data will be incorporated into the existing design documentation structure for the project (i.e., activity to be licensed). For large projects, a document hierarchy diagram should be included to illustrate this incorporation.	6.5

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REGDOC-2.5.1 reference	Requirement	HFE PMP reference
4.7.4	Disposition of Human Factors Issues - Determine a reasonable method for recording, categorizing, tracking, and responding to the issues and recommendations that arise during implementation of the plan. Development of the processes and procedures for this aspect of the plan should take into account the ultimate goals of the human factors work, as well as any anticipated limitations to those goals. Provide a description of how tracking of unanticipated human factors issues will be conducted to ensure consideration in development of future HFEPP. It is anticipated that project groups affected by the recommendations arising from the human factors work may, at times, disagree with those recommendations. The process for resolving differences of opinion that might be generated by human factors issues should include an explanation of the authority structure to clarify how and by whom final decisions are to be made.	7
4.7.5	CNSC Contact - Include a proposal for maintaining contact with CNSC staff during plan implementation, listing proposed submissions supporting the Plan, meetings to discuss progress of the plan, and communications processes.	Note 2
Note 1 – Compliance with this item is addressed in the HFE Program (e.g., IPs). **Note 2 –** Compliance with this item shall be addressed separately at the beginning of the licensing process with the CNSC		

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9.3. APPENDIX C: HFE PROCESS

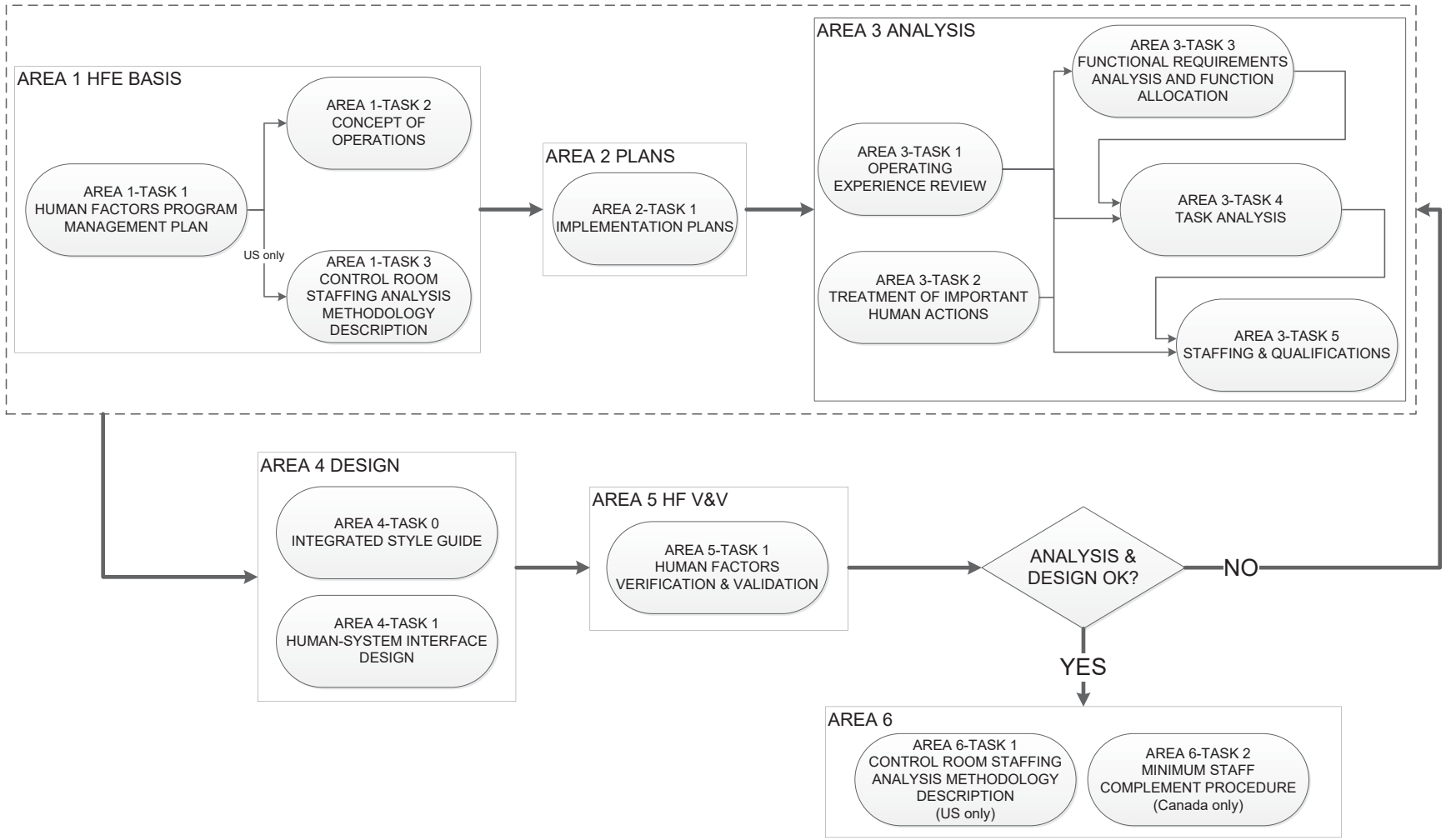

Figure 19. HFE Program process

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Enclosure 3

Xe-100 Operating Experience Review Implementation Plan

Xe-100

Operating Experience Review Implementation Plan

Configuration Classification	:	**XE00-R-R1ZZ-RDZZ-X**
Revision	:	**1**
Status	:	**Approved**
Issue Date	:	**23-Apr-2021**
Project	:	**Xe-100**
Project Phase	:	**Concept**

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SYNOPSIS

This document provides the methodology to be followed to perform Operating Experience Review element of the Human Factors Engineering Program.

CONFIGURATION CONTROL

Document Change History

Rev.	Date	Preparer	Changes
0A	26-Mar-2021	Hector Martinez-Pinna	Initial issue
1	23-Apr-2021	Hector Martinez-Pinna	Typos correction and minor changes

Document Approval

Action	Designation	Name	Signature	Date
Preparer	Tecnatom, Senior Human Factors Engineer	Hector Martinez-Pinna	DocuSigned by: Héctor Martínez-Pinna 31F691A6CD5B488...	4/24/2021 | 4:56 AM EDT
Reviewer	Tecnatom, Human Factor Principal Engineer	Richard Gutierrez	DocuSigned by: Richard Gutierrez A36744F44A30427...	4/24/2021 | 8:15 PM EDT
Reviewer	Tecnatom, Project QA Engineer	Santiago Lucas	DocuSigned by: FAEE967DCC7F49D...	4/27/2021 | 2:08 AM EDT
Reviewer	Senior Operator Training Engineer	Gregg Crannick	DocuSigned by: Gregg Crannick 3FA08AA7EDBD4BC...	4/26/2021 | 10:05 AM EDT
Reviewer	Senior Human Factors Lead	Paul Hippely	DocuSigned by: Paul Hippely 1AAE19CE8E784BD...	4/25/2021 | 7:22 PM EDT
Approver	Operator Training Simulator Manager	Yvotte Brits	DocuSigned by: Yvotte Brits E24E75C19AFA4BB...	4/27/2021 | 6:13 AM PDT

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ABBREVIATIONS

This list contains the abbreviations used in this document.

Abbreviation or Acronym	Definition
CFR	Code of Federal Regulation
CNSC	Canadian Nuclear Safety Commission
FA	Function Allocation
FRA	Functional Requirements Analysis
HFE	Human Factors Engineering
HFEITS	Human Factors Engineering Issue Tracking System
HSI	Human-System Interface
HTGR	High Temperature Gas-cooled Reactor
IAEA	International Atomic Energy Agency
INPO	Institute of Nuclear Power Operations
IP	Implementation Plan
NEA	Nuclear Energy Agency
NRC	(United States) Nuclear Regulatory Commission
OE	Operating Experience
OER	Operating Experience Review
PMP	Project Management Plan
S&Q	Staffing and Qualifications
SMR	Small Modular Reactor
TA	Task Analysis
TIHA	Treatment of Important Human Actions
V&V	(Human Factors) Verification and Validation

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DEFINITIONS

This list contains the terms of glossary used in this document.

Term	Definition
Element	From NUREG-0711 [1] the four general activities are separated into the following twelve elements: • HFE Program Management • Operating Experience Review • Functional Requirements Analysis and Function Allocation • Task Analysis • Staffing & Qualification • Treatment of Important Human Actions • Human-System Interface Design • Procedure Development • Training Program Development • Human Factors Verification and Validation • Design Implementation • Human Performance Monitoring
Apparent cause	The most probable cause of a problem based on readily available information.
Operating experience	Any industry experience including its improvement actions and lessons learned.
Implementation Plan	Document that describes the proposed methodology for conducting an HFE element and is reviewed by the NRC staff to reasonably assure that it will generate acceptable results that satisfy the staff's review criteria.
Results Summary Report	Document that summarizes the results of a completed HFE element and cites documents or files that contain the complete results.

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1. INTRODUCTION

The Xe-100 is an innovative design of a nuclear reactor categorized as Small Modular Reactor (SMR) due to its relatively low power, 200 MWt or 80 MWe. Its design allows for the fabrication and testing in a factory environment, then it can be shipped to the site where it is installed as a single component. From a technological and regulatory point of view, the Xe-100 is a High Temperature Gas-cooled Reactor (HTGR) cooled by helium and moderated by graphite, implementing features that make the reactor inherently safe.

The plant configuration consists of four Xe-100 reactors, whose design is optimized since each unit shares like systems. The main purpose of a Xe-100 plant is to safely convert nuclear energy to electricity, in addition, the plant design ensures multiple missions, such as process heat applications.

The Operating Experience Review (OER), an element of the Human Factors Engineering (HFE) Program and licensing process, is prepared to identify HFE-related safety issues. Using proven systematic analysis techniques, human factors issues will be addressed in the performance of the design process. The OER provides the design team with information on the past performance of predecessor designs. Predecessor designs may be those earlier designs upon which the Xe-100 is based.

More specifically, predecessor designs are those plants, systems, human system interfaces (HSIs), and operational approaches that are the basis for the plant's design. They may include reference to non-nuclear and nuclear industry applications.

The Xe-100 is an evolutionary design, based on changes to past HTGR designs that employs new technology or operational approaches to realize improvements in safety, performance, availability, and reliability.

The resolution of OER issues identified in the OER process may create changes to the function allocation, automation, HSI equipment design, procedures, training, etc., as applicable. It is during the OER process that HFE-related issues identified in previous designs are considered for the design process.

As stated in NUREG-0711 [1], table 3.1, information gathered during the performance of the OER process may contribute inputs to other HFE Program elements. The OER outputs become inputs to the following HFE Program elements:

- Functional Requirements Analysis and Function Allocation
- Task Analysis
- Staffing and Qualifications
- Treatment of Important Human Actions
- Human-System Interface Design
- Human Factors Verification and Validation

1.1. PURPOSE

The purpose of this document is to describe the methodology to be followed in the development of the second element of NUREG-0711 [1], the Operating Experience Review, and to establish the specific

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requirements of its Results Summary Report. This review will verify that the design as proposed has identified and analyzed applicable HFE related problems and issues encountered previously in designs and human tasks similar to the planned design. In this sense, issues that could potentially hinder human performance can be identified and addressed.

1.2. SCOPE

The scope of this Implementation Plan (IP) applies to the Operating Experience Review that will be performed as part of the HFE Program for the HFE licensing of the Xe-100 plant design. This OER addresses the operating histories of plant systems, human actions, procedures, and HSI technologies. Therefore, the document is under the considerations and limitations established in the HFE Program Management Plan (HFE PMP) [10].

1.3. RELATIONSHIP TO OTHER DOCUMENTS

This IP is part of the HFE Program described in the HFE PMP [10], which includes high-level considerations that shall be known by the reader of this IP. Other HFE Program elements are related to the OER; therefore, the IPs of these elements are cross-referenced where needed. Figure 1 shows relationships between OER IP and other documents within the HFE Program.

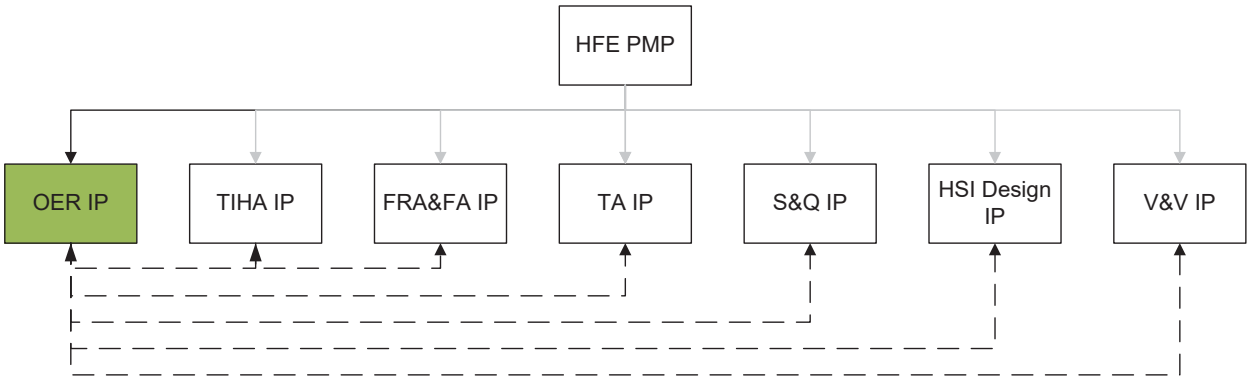

Figure 1: Relationship of OER IP to other documents within the HFE Program

1.4. DOCUMENT LAYOUT

The OER IP is formatted as follows. Section 1 addresses the document introduction, purpose, scope and relationship to other documents. Section 2 identifies the references used in this IP. Section 3 describes the methodology, from the inputs, through the process and the expected outputs. Section 4 addresses how the outputs shall be documented. Section 5 includes as an appendix a checklist to verify compliance of this IP with the corresponding NUREG-0711 [1] review criteria.

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2. REFERENCES

The following documents are referenced within this document.

	Document Title	Preparer/Author	Document Number	Revision or Date of Issue	Classification	Applicable[1] (Yes/No)
[1]	NUREG-0711, Human Factors Engineering Program Review Model	NRC	N/A	Rev 3	N/A	Yes
[2]	REGDOC-2.2.1, Human performance management Human Factors	CNSC	N/A	2019	N/A	Yes
[3]	10 CFR 50.34, Contents of applications; technical information	NRC	N/A	2019	N/A	Yes
[4]	NUREG-0800, Standard Review Plan for the Review of Safety Analysis Reports for Nuclear Power Plants: LWR Edition, Chapter 13, “Conduct of Operations”	NRC	N/A	2016	N/A	Yes
[5]	NUREG-0800, Standard Review Plan for the Review of Safety Analysis Reports for Nuclear Power Plants: LWR Edition, Chapter 18, “Human Factors Engineering”	NRC	N/A	2016	N/A	Yes
[6]	NUREG-1764, Guidance for the Review of Changes to Human Actions	NRC	N/A	Rev 1	N/A	Yes
[7]	NUREG-1791, Guidance for Assessing Exemption Requests from the Nuclear Power Plant Licensed Operator Staffing Requirements Specified in 10 CFR 50.54(m)	NRC	N/A	2005	N/A	Yes
[8]	NUREG/CR-6753, Review of Findings for Human Performance Contribution to Risk in Operating Events	NRC	N/A	2002	N/A	Yes
[9]	NUREG/CR-6400, Human Factors Engineering (HFE) Insights for Advanced Reactors Based Upon Operating Experience	NRC	N/A	1997	N/A	Yes

1 Applicable documents are applicable to the extent specified within this document and thus deemed to form part of this document.

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Document Title	Preparer/Author	Document Number	Revision or Date of Issue	Classification	Applicable[1] (Yes/No)
[10] TEC-XE100-HFE-PMP, HFE Services for the Xe-100 Plant Design – Human Factors Engineering Program Management Plan	Tecnatom	N/A	Rev 0	N/A	Yes
[11] TEC-XE100-HFE-TRS, Control Room Staffing Analysis Methodology	Tecnatom	N/A	Rev 0	N/A	Yes
[12] TEC-XE100-HFE-COO, Concept of Operations	Tecnatom	N/A	Rev 0	N/A	Yes

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3. DEVELOPMENT

This section includes a description of main documents or sources required to perform the analysis, followed by a systematic process definition for the further development of the element, and a collection of the outputs expected as a result of the methodology implementation.

The OER addresses the operating histories of plant systems, human actions, procedures, and human-system interface (HSI) technologies from available reference plants or designs related to the current HFE Program. The HFE team's evaluation should be conducted in accordance with the review criteria of NUREG-0711 [1] and NUREG-1764 [6].

3.1. INPUTS

As the Xe-100 design can be considered first-of-a-kind, the operational experience from existing plants is limited. This affects the development of the OER in terms of the availability of direct information pertaining to industry or regulatory experience related to human-related issues. The HTGR differs significantly from light water reactor designs, however, there may be HFE-related issues previously identified, both in designs and in human tasks that are similar to the Xe-100 design. This allows issues that could potentially hinder human performance to be addressed.

Inputs are categorized according to the information available. The first being the information base that allows to narrow and limit the search, and secondly, the sources identified where the search will be performed. Categories are listed below and detailed in the following sections:

- Inputs that set the search parameters:
  a. Applicable regulatory documents and industry documents (NUREGs, INEL HTGR reports, IEEE, IEC, etc.).
  b. Xe-100 plant specific documents.
- Sources of potential OE:
  a. International information issues and international databases.
  b. Non-nuclear industry reports or databases.

3.1.1. Inputs: Search Base Parameters

3.1.1.1. Applicable Regulatory and Industry Documents

Regulatory criteria applicable to the OER element has been considered in the preparation of this IP. International codes and standards along with general design inputs are some of the documentation required to develop the OER activities. This set of documents includes, but it is not limited to, the following:

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NRC

- NUREG-0711 [1], Human Factors Engineering Program Review Model, revision 3, NRC, 2012. More specifically, the review criteria included in this document for OER.
- NUREG-0800 [5], Standard Review Plan for the Review of Safety Analysis Reports for Nuclear Power Plants: LWR Edition, Chapter 18, "Human Factors Engineering", revision, NRC, 2016.
- NUREG-0800 [4], Standard Review Plan for the Review of Safety Analysis Reports for Nuclear Power Plants: LWR Edition, Chapter 13, "Conduct of Operations", Section 13.1.1, revision 5, NRC, 2016. This chapter addresses staffing requirements.
- NUREG/CR-6753 [8], Review of Findings for Human Performance Contribution to Risk in Operating Events, NRC, 2002.
- NUREG/CR-6400 [9], Human Factors Engineering (HFE) Insights for Advanced Reactors Based Upon Operating Experience, NRC, 1997.
- NUREG-7190, "Workload, Situation Awareness, and Teamwork", NRC, 2015. This document provides information regarding analysis methods to evaluate factors that might interfere with the task performance of the control room staff, such as high workload, inattention, and poor situation awareness.
- REGULATORY GUIDE 1.196, Control Room Habitability at Light-Water Nuclear Power Reactors, NRC, 2003.

3.1.1.2. Xe-100 Plant Specific Documents

The document Concept of Operations [12] includes all the relevant information related to the design and operation of the Xe-100. The document also provides the instrumentation and control (I&C) systems, the planned control room design, and HSI design.

The information provided in the concept of operations assists in identifying the type of information necessary to begin the OER data search.

3.1.2. Inputs: Sources of Potential Operating Experience

3.1.2.1. International Information Issues and International Databases

The following databases are sources of information that will allow for the performance of the OER. The searches of these sources will be targeted to:

- Industry recognized HFE issues (resolved and unresolved).
- Industry experience with technologies similar to those being considered for incorporation.
- Issues identified by plant operations personnel as provided in reports.

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NRC

Database:

- ADAMS (Agencywide Documents Access and Management System)

Scientific and technical publications:

- NRC Generic Letters
- Information Notices.

IAEA

Database:

- IRS (International Reporting System [for Operating Experience])
- ARIS (Advanced Reactors Information System)

Scientific and technical publications:

- Safety Standards Series: Specific Safety Guides
- Nuclear Security Series
- Nuclear Energy Series
- TECDOCs
- Advances in Small Modular Reactor Technology Developments

INPO

Database:

- IRIS (Industry Reporting and Information System)

OE documents:

- INPO Event Reports (IER), levels 1 to 4

SEE-IN Program Documents

- Significant Operating Experience Reports (SOERs)
- Significant Event Reports (SERs)
- Significant Event Notifications (SENs)
- Topical Reports
- Operations and Maintenance Reminders (O&MRs)
- Operating Experience Digests
- Tracking Trends

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- Analysis Digests
- Reports

Training - Briefing Documents

- Just-In Time Training Briefing Material (JITs)
- Industry Good practices

Technical Topics & Technical Reports

INPO Safety Standard Series

Leveraging Operating Experience

NEA

Scientific and technical publications

- NEA Resources & Data bank
- NEA Document
- NEA Publications and reports

Besides, there are other sources of information that could be useful in the search for OE. In this regard, nuclear operators of CANDU plants maintain an OE source specific for this technology, where only nuclear operators, sponsors or partners have access to. This source includes the following information:

CANDU

Database:

- COG OPEX database
- CANDU Event Notification Forums

Technical publications

- Industry Good Practices and Innovations
- Newsletters and Station Technical Reports
- Just-in-Time (JIT) Briefings, RapidOPEX & Handbooks

The HFE Program of the CANDU reactors has close similarities as it relates to the concept of operation for the proposed Xe-100 design, such as a single control room for multiple units and online refueling features.

3.1.2.2. Non-Nuclear Industry Reports or Databases

Comparison of the innovative design of the Xe-100 nuclear reactor to a wide variety of previously designed plants with similar features is very limited. The number of SMRs in operation is not large and as such, other industries with similar designs will be considered for the purpose of collecting operational information.

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Human performance-related OE found in non-nuclear industrial applications that use digital screen based HSI technology as proposed for the Xe-100 design, will be reviewed. The review will be limited to HFE-related problems with main control rooms and applicable control stations outside the main control room. At a minimum, sources from the following industries are included:

- Non-nuclear Electric Generating Stations
- Chemical industry
- Transportation industry (marine, piping, railroad, aviation)
  - National Transportation Safety Board
  - Aviation Safety Network

3.2. METHODOLOGY

This section describes the process that will be used to identify important HFE-related lessons learned from OE's and their subsequent analyses applicable to the Xe-100 plant design. Lessons learned will be incorporated into the HFE design.

Although several OE resources from both nuclear and other industries have been described previously, the availability of OE for new SMR is limited. The OE research shall be oriented to past high-temperature gas-cooled reactor designs, prototype reactors, and recent modular designs. Multi-unit operation experiences in commercial industry, as well as some nuclear application, may serve useful, with some extrapolations, to the Xe-100 plant operation. The criteria under which the sources of OE will be used are described further in this IP.

The OER methodology contains the most relevant sources of OE information initially planned to be reviewed during the OER process (see section 3.1). However, the final referenced sources may be limited during the OER analysis due to availability of information applicable to the HFE Program.

Regardless of the information obtained in the sources listed (see sections 3.1.2.1 and 3.1.2.2), the OER methodology will always follow the same sequence, as a way to maintain continuous improvement, as shown in Figure 2.

Figure 2: OER methodology process

As previously stated, OE and the identification of lessons learned from the industry prior to this plant are scarce. In recent years, some SMRs are being developed and put into operation. Their HFE issues should also be identified, analyzed and tracked. OER results shall be considered for application and incorporation to the HFE program elements. The OE will change over the course of the HFE Program, as such a regular update of the results and potentially, a review of the rest of the HFE Program elements affected may be necessary. For performing this analysis, the steps included in Figure 2 and Figure 3 are considered.

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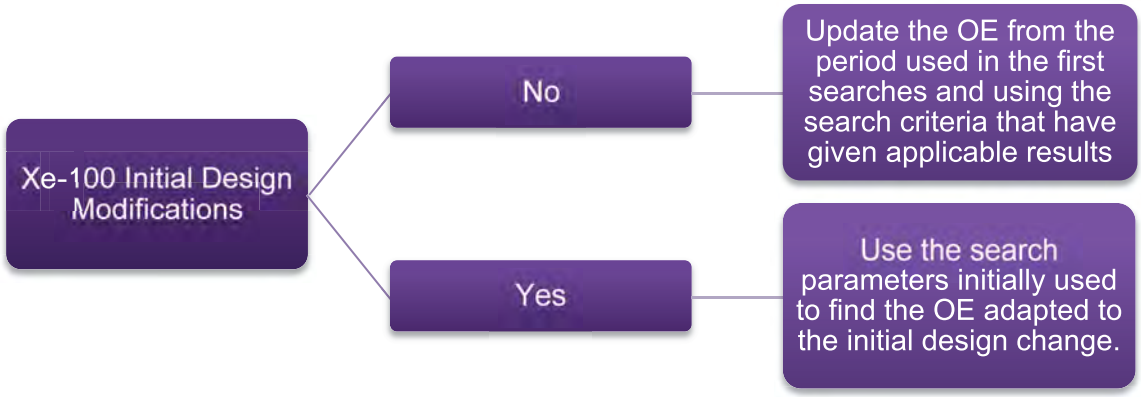

Figure 3: Methodology of periodical OE search

3.2.1. OER Planning, OE Search, and Information Screening

The main activities to perform in this step are to:

a. Plan the OE search process.

b. Execute the intended search in order to obtain OE from the sources.

c. Filter the results in order to get the OE relevant to the HFE Program.

3.2.1.1. OER Planning

In this sub-step the OE search process is planned with the objective of getting the most relevant OE in the most efficient way. As part of the planning, the applicable initial criteria is set. This includes plants, systems, HSIs, and operational approaches that are relevant to the Xe-100 plant design. Inputs in section 3.1.1 shall be reviewed.

Sources of OE information to be used have been determined. Inputs in section 3.1.2 shall be considered as potential sources.

At the end of this sub-step, search parameters shall be recorded to identify those searches from which useful results have been obtained, and to identify those which do not obtain applicable information.

3.2.1.2. OE Search

To perform the OE search keywords are used to find relevant results in the sources. Keywords are changeable during each search, so that using proper and accurate terms tailors the search to each source.

As part of this sub-step, the results of each search will be reviewed in order to assess whether the information is applicable to the Xe-100 plant or if it is necessary to perform a new search to obtain better results.

OE search will start with some usual terms related to recognized industry HFE issues and related technologies (see section 3.1.2), which produce relevant OE results. Additional search terms can be used

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in the OER analysis based on the results that are being obtained. These terms will be related to the type of reactor, plant design, or specific knowledge of HFE.

3.2.1.3. Information Screening

This sub-step of the process is based on the screening of the OE information compiled from the search in order to assess, under the evaluator judgment, whether or not it is considered applicable to the Xe-100 plant design concept. Examples of this assessment are:

- Screening by personnel role and work design, including, but not limited to, levels and types of automation, work practices and task design, task allocation to crew members, teamwork, crew communication and coordination, supervision, important human actions and potential for error, task location, and training.
- Screening by HSI design and technologies employed, including, but not limited to, alarm presentation, operator aids and support systems, procedure design and implementation, control room layout and environment, and control room panels design.
- Screening by unanticipated situations that may lead to the same undesired event.

In this part of the process, experience in the implementation of OER activities indicates that an extraordinarily large number of findings can be generated. It is to be expected that most 20th century OE will already be incorporated into the standards applicable to the Xe-100 plant project design and its HFE Program.

Therefore, following the recommendations and requirements of these standards an assumption can be made that the lessons learned from older OE have been incorporated into more current documents whether regulatory or industry. Considering the date of publication of the standards used (e.g. NUREG-1791 [7] was published in 2005), it is more efficient to narrow the search for findings to the 21st century (starting on January 1st, 2001 onwards). In some cases, however, the current document being reviewed may include references to a past revision, so some applicable documents that are outside of the review criteria may still be used.

The results from OE analysis and reviews shall be recorded, including their source and individual identification information needed to properly trace each result to its origin. This includes a justification as to why an industry document whether regulatory or commercial is not being used. These OE results shall be further analyzed in the following step.

3.2.2. Results, Analysis and Review

Most of the negative OEs include an assessment of the root cause of the experience determined by the organization responsible for the plant or technology involved in the OE. For OEs without an identified lesson learned, an attempt will be made to extract details, based on the information found from the event and on the reviewers' technical expertise, including technical disciplines other than human factors that may be beneficial. The OE reviewer then develops a lesson learned statement for each OE. For example, if the root cause or apparent cause is operator error related to the color coding in the user interface

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AUTO/MANUAL of a particular motor-controlled valve, the lesson learned statement is worded to provide reasonable assurance that it is applied to the design of the Xe-100.

At the end of this step, all the OE with its detailed information shall be recorded and made available in a later step. The information recorded shall include, but not be limited to:

- Unique OE identification code
- OE source and enough information to trace the OE to its origin
- OE descriptions, including its lessons learned
- HSI design device involved in the OE (e.g., control room layout, alarm presentation, operating procedure presentation, operator training module, local panel, etc.)
- Key human factors issues affecting the OE

3.2.3. Operating Experience Treatment in the HFE Program

Each OE shall be reviewed within each other element of the HFE Program. During the development of each element, applicability of each OE shall be identified, and, if applicability is positive, a description of how the OE is addressed within the element shall be given. As a result, a statement shall be provided to determine whether the Xe-100 plant design currently incorporates an improvement that addresses the OE, or if an action needs to be taken, or whether a solution is not yet known.

Note that any given OE may be identified to apply and be addressed in one, some, or all the HFE Program elements.

3.3. OUTPUTS

The outputs to be obtained from the inputs defined in section 3.1 and following the methodology described in section 3.2 are:

- A list of searches and relevant parameters, as described in section 3.1.1.
- A list of OE, that are analyzed and will be addressed in other elements of the HFE Program, as described in section 3.2.3.
- A list of pending OE issues, to be included in the HFE Issue Tracking System (HFEITS), following the process established in the HFE PMP [10].

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4. DOCUMENTATION

All the information and data resulting from the development of the OER process, as described in section 3.3 shall be recorded in a software tool specific for the OER process within the HFE Program, namely *HFE OER database*. This tool shall be implemented in a way that all HFE team members access to review as they may deem necessary. The revision to the database will be controlled. Additions and/or changes will be under administrative control so that the information provided is protected for quality.

Additionally, OER activities shall be documented in the OER Results Summary Report, which will include an evaluation of the results and its conclusions, as well as the reasoning behind the conclusions. Although the actual structure may vary, it is expected that the report will contain the following information:

- A summary of data included in the HFE OER database, including a statistical balance sheet.
- A list of relevant OE and how they are being addressed in the current design or with planned improvements, in accordance with the HFE program process. OE issues shall also be incorporated into the HFEITS.

Note that a software tool shall implement the HFEITS in a way that allows the HFE team members to follow the process detailed in the HFE PMP [10].

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5. APPENDICES

5.1. APPENDIX A: COMPLIANCE CHECKLIST

Table 1 details the specific requirements defined in NUREG-0711 [1] related to the criteria that the OER activities shall meet. It also provides the reference to this IP where the corresponding requirement is addressed and explained in order to facilitate the development of OER activities.

Table 1: NUREG-0711 compliance list

NUREG-0711 reference	Requirement	IP reference
3.4.1 (1)	*Predecessor/Related Plants and Systems* – The applicant's OER should include information about human factors issues in the predecessor plant(s) or highly similar plants, systems, and HSIs, including the following: • The OER should identify previous or predecessor design(s)/plant(s) used as part of the design basis of the plant being reviewed. • The OER should define the relevance of each predecessor plant/design to the new design, when there is more than one predecessor. • The OER should detail how the applicant identified and analyzed any HFE-related problems in the previous plants/designs, and how these issues are avoided in the new design. • The OER should address how the applicant identified, evaluated, and incorporated or retained any positive features of previous plants/designs. • The OER should describe the predecessor plant(s) and systems, explaining the relationship of each to the new design. • For applicants proposing to use new technology or systems that were not used in the predecessor plants, the OER should review and describe the operating experience of any other facilities that already use that technology.	3.1.1.1 and 3.1.2.1
3.4.1 (2)	*Recognized Industry HFE Issues* – The applicant should address the HFE issues identified in NUREG/CR-6400. The issues are organized into the following categories: • unresolved safety issues/generic safety issues (See 10 CFR 52.47(a)(21) and NUREG-0933) • TMI issues • NRC generic letters and information notices	3.1.1.1 and 3.1.2.1

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NUREG-0711 reference	Requirement	IP reference
	• operating experience reports in the NUREG-1275 series, Vol. 1 through 14 • low power and shut down operations • operating plant event reports Additionally, the applicant should review and discuss all operating experience in the preceding categories that was published since NUREG/CR-6400 was published in 1996.	
3.4.1 (3)	*Related HSI Technology* – The applicant's OER should cover operating experience with the proposed HSI technology in the applicant's design.	3.1.2
3.4.1 (4)	*Issues Identified by Plant Personnel* – The applicant's OER should discuss issues identified through interviews with plant personnel based on their operating experience with plants or systems applicable to the new design. As a minimum, the interviews should include the following topics: • Plant Operations • HFE Design Topics	Note 1
3.4.1 (5)	*Important Human Actions* – The applicant's OER should identify important HAs in the predecessor plants or systems and determine whether they remain important in the applicant's design. Additional considerations cover the following: • For the important HAs, the OER should identify the scenarios wherein actions are needed, and state whether they were needed and successfully completed. Those aspects of the design that helped ensure success should be identified. • If errors occurred in the execution of the HAs, the applicant should identify insights to the needed improvements in human performance. • When important HAs for the new plant are determined to differ from those of the predecessor plant, the OER should specify whether there is any operational experience with these different HAs.	3.2.2
3.4.2 (1)	*OER Process* – The applicant should discuss the administrative procedures for evaluating the operating, design, and construction experience, and for ensuring that applicable important industry experiences will be provided in a timely manner to those designing and constructing the plant.	3.2

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NUREG-0711 reference	Requirement	IP reference
3.4.2 (2)	*Analysis Content* – The applicant should analyze issues to identify: • human performance issues and sources of human error • design elements supporting and enhancing human performance	3.2.2
3.4.2 (3)	*Documentation* – The applicant should document the analysis of operating experience.	4
3.4.2 (4)	*Incorporation into the Tracking System* – The applicant should document each issue determined to be relevant to the design, but yet to be addressed, in the issue-tracking system.	3.2.1, 3.2.2, 3.3 and 4
3.4.3 (1)	*Additional Considerations for Reviewing the HFE Aspects of Plant Modifications.*	N/A

Note 1. Due to the uniqueness of the modular Xe-100 plant design, information regarding plant operation and plant personnel experiences are not readily available or not available at all.

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Enclosure 3

Xe-100 Treatment of Important Human Actions Implementation Plan

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Enclosure 4

Xe-100 Functional Requirements Analysis and Function Allocation Implementation Plan

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Xe-100

Functional Requirements Analysis and Function Allocation Implementation Plan

Configuration Classification	:	**XE00-R-R1ZZ-RDZZ-X**
Revision	:	**1**
Status	:	**Approved**
Issue Date	:	**21-May-2021**
Project	:	**Xe-100**
Project Phase	:	**Concept**

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SYNOPSIS

This document provides the methodology to be followed to perform the Treatment of Important Human Actions element of the Human Factors Engineering Program.

CONFIGURATION CONTROL

Document Change History

Rev.	Date	Preparer	Changes
0A	26-Apr-2021	Hector Martinez-Pinna	Initial issue
1	21-May-2021	Hector Martinez-Pinna	Typos correction and minor changes.

Document Approval

Action	Designation	Name	Signature	Date
Preparer	Tecnatom, Senior Human Factors Engineer	Hector Martinez-Pinna	DocuSigned by: 31F691A6CD5B488...	5/24/2021 | 1:11 PM EDT
Reviewer	Tecnatom, Human Factors Principal Engineer	Richard Gutierrez	DocuSigned by: Richard Gutierrez A36744F44A30427...	5/24/2021 | 1:19 PM EDT
Reviewer	Tecnatom, Project QA Engineer	Santiago Lucas	DocuSigned by: FAEE967DCC7F49D...	6/2/2021 | 1:45 AM EDT
Reviewer	Senior Operator Training Engineer	Gregg Crannick	DocuSigned by: Gregg Crannick 3FA08AA7EDBD4BC...	6/2/2021 | 7:59 AM EDT
Reviewer	Senior Human Factors Lead	Paul Hippely	DocuSigned by: Paul Hippely 1AAE19CE8E784BD...	6/2/2021 | 8:02 AM EDT
Approver	Operator Training Simulator Manager	Yvotte Brits	DocuSigned by: Yvotte Brits E24E75C19AFA4BB...	6/2/2021 | 7:17 AM PDT

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Figure 11: Function Allocation flowchart.....23

TABLES

Table 1: NUREG-0711 compliance list 27

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ABBREVIATIONS

This list contains the abbreviations used in this document.

Abbreviation or Acronym	Definition
CNSC	Canadian Nuclear Safety Commission
FA	Function Allocation
FRA	Functional Requirements Analysis
HFE	Human Factors Engineering
IP	Implementation Plan
MCR	Main Control Room
NRC	(United States) Nuclear Regulatory Commission
OER	Operating Experience Review
RSR	Results Summary Report

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DEFINITIONS

This list contains the terms of glossary used in this document.

Term	Definition
Actuation Stage	Each one of the three parts (tasks) that set up an operating alignment change. An actuation stage can be Initiation, Performance or Verification
Agent	Human (fully manual operations); automation (fully automatic operations, including passive, self-controlling phenomena); or both automation and human (shared responsibility at any degree)
Element	Each of the twelve parts in which an HFE Program based on NUREG-0711 is divided, which are: • HFE Program Management • Operating Experience Review • Functional Requirements Analysis and Function Allocation • Task Analysis • Staffing and Qualifications • Treatment of Important Human Actions • Human-System Interface Design • Procedure Development • Training Program Development, • Human Factors Verification and Validation • Design Implementation • Human Performance Monitoring
Implementation Plan	Document that describes the proposed methodology for conducting an HFE element, which is reviewed by the NRC staff to reasonably assure that it will generate acceptable results that satisfy the staff's review criteria
Performance Conditions	One or several components of an operating alignment that are key to determine whether the system function is being accomplished or not
Results Summary Report	Document that summarizes the results of a completed HFE element and cites documents or files that contain the complete results

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1. INTRODUCTION

The Xe-100 nuclear reactor is an innovative design that is categorized as a Small Modular Reactor due to its relatively low power, 200 MWt or 80 MWe. Its design allows for the fabrication and testing in a factory environment then it can be shipped to the site where it is installed as a single component. From a technological and regulatory point of view, the Xe-100 is a High Temperature Gas-cooled Reactor (HTGR) cooled by helium and moderated by graphite, implementing features that make the reactor inherently safe.

The plant configuration consists of four Xe-100 reactors, whose design is optimized since each unit shares like systems. The main purpose of a Xe-100 plant is to safely convert nuclear energy to electricity. In addition, the plant design ensures multiple missions, such as process heat applications.

As required by the licensing process and NUREG-0711 [1], a Human Factors Engineering (HFE) Program shall be developed[1], with proven systematic analysis techniques to address human factors issues within the design process. The HFE Program and its products reflect state-of-the-art human factors principles.

As described in the HFE Program Management Plan [6], one of the first steps in the HFE Program is the preparation of Implementation Plans (IPs), that describe the proposed methodology for the performance of a specific HFE program element.

In accordance with NUREG-0711 [1], an IP provides an opportunity to obtain a review and concurrence from the regulatory staff of the proposed methodology before performing the work associated with the element. This early review is desirable, because it offers the staff an opportunity to identify potential issues with the methodology and to provide the Xe-100 design team with early input in the analysis or design processes, when staff concerns can more easily be addressed, rather than when the element has been completed.

This is the implementation plan (IP) for the Functional Requirements Analysis (FRA) and Function Allocation (FA), the third element of NUREG-0711 [1].

1.1. PURPOSE

The purpose of this document is to describe the methodology to be followed in the performance of the IP for the Functional Requirements Analysis (FRA) and Function Allocation (FA). Moreover, this document establishes the specific requirements to develop its Results Summary Report (RSR).

1.2. SCOPE

This IP applies to the FRA and FA that will be performed as part of the HFE Program for the HFE licensing of the Xe-100 plant design.

The FRA and FA IP establishes the methods and criteria for conducting the Functional Requirements Analysis in accordance with accepted human factors principles and practices. The FRA is the first of the system operations analyses used to establish design requirements in a Human-System Interface (HSI)

[1] Refer to 10 CFR 50.34 (f)(2)(ii), 10 CFR 50.34 (f)(2)(iii) [3], and REGDOC-2.2.1, Human Factors [2].

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design process, examining operational aspects of the plant and assisting in determining the design of the plant and the plant HSIs.

The FRA and FA is performed to define the high-level functions that must be accomplished to meet the plant's goals and desired performance; delineate the relationships between high-level functions and the plant's systems (e.g., plant configurations or success paths) responsible for performing the functions; and provide a framework for determining the roles and responsibilities of personnel and automation.

The FRA and FA collects parameters affecting plant operation, identifies information required by operations personnel, and provides control options available for allocation to hardware, software, and/or operations personnel for safe and economic plant operation.

This IP is under the considerations and limitations established in the HFE Program Management Plan (HFE PMP) [6].

1.3. RELATIONSHIP TO OTHER DOCUMENTS

This IP is part of the HFE Program described in the HFE PMP [6], which includes high-level considerations that shall be known by the reader of this IP. Other HFE Program elements are related to the FRA and FA; therefore, the IPs of these elements are cross-referenced where needed. Figure 1 shows relationships between FRA and FA IP and other documents within the HFE Program.

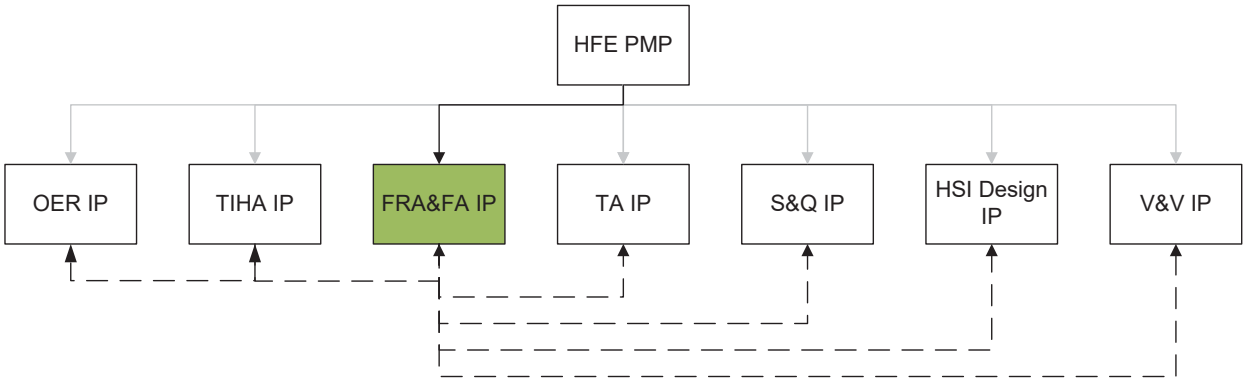

Figure 1: Relationship of FRA and FA IP to other documents within the HFE Program

1.4. DOCUMENT LAYOUT

This FRA and FA IP is formatted as follows. Section 1 addresses the document introduction, purpose, scope, and relationship to other documents. Section 2 identifies the references used in this IP. Section 3 describes the methodology, from the inputs, through the process and the expected outputs. Section 4 addresses how the outputs shall be documented. Section 5 includes as an appendix a checklist to verify compliance of this IP with the corresponding NUREG-0711 [1] review criteria.

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2. REFERENCES

The following documents are referenced within this document.

	Document Title	Preparer/Author	Document Number	Revision or Date of Issue	Classification	Applicable[2] (Yes/No)
[1]	NUREG-0711, Human Factors Engineering Program Review Model	NRC	N/A	Rev 3	N/A	Yes
[2]	REGDOC-2.2.1, Human performance management Human Factors	CNSC	N/A	2019	N/A	Yes
[3]	10 CFR 50.34, Contents of applications; technical information	NRC	N/A	2019	N/A	Yes
[4]	NUREG/CR-3331, A Methodology for Allocating Nuclear Power Plant Control Functions to Human or Automatic Control	NRC	N/A	1983	N/A	Yes
[5]	TEC-XE100-HFE-COO, HFE Services for the Xe-100 Plant Design – Concept of Operations	Tecnatom	N/A	Rev 0	N/A	Yes
[6]	TEC-XE100-HFE-PMP, HFE Services for the Xe-100 Plant Design – Human Factors Engineering Program Management Plan	Tecnatom	N/A	Rev 0	N/A	Yes
[7]	Xe-100 Operating Experience Review Implementation Plan	Tecnatom	000982	Rev 1	XE00-R-R1ZZ-RDZZ-X	Yes
[8]	Xe-100 Task Analysis Implementation Plan	Tecnatom	000986	Rev 1	XE00-R-R1ZZ-RDZZ-X	Yes

2 Applicable documents are applicable to the extent specified within this document and thus deemed to form part of this document.

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3. DEVELOPMENT

3.1. INPUTS

Documents that are outputs of other HFE activities within the current scope of work are necessary for the development of the FRA and FA activity. Latest revisions at the beginning of the activity will be used. These documents are the following:

- TEC-XE100-HFE-PMP, HFE Services for the Xe-100 Plant Design – Human Factors Engineering Program Management Plan, revision in force, Tecnatom.
- TEC-XE100-HFE-COO, HFE Services for the Xe-100 Plant Design – Concept of Operations, revision in force, Tecnatom.
- Results from Operating Experience Review and Treatment of Important Human Actions.

During the development of the FRA and FA activity, international codes and standards are used as general design inputs, as applicable in each case for the project scope of work. This set of documents includes, but it is not limited to, the following:

- NUREG-0711, Human Factors Engineering Program Review Model, revision 3, NRC, 2012.

In addition, Xe-100 specific design documents are needed to properly develop the FRA and FA activity. The information needed is considered in the Concept of Operations [5], already included as input, but some detailed information may be needed. These documents that include this detailed information are:

- XE-P1-PL-G0-D24-000423, Preliminary Xe-100 Plant Control Philosophy, revision in force, X-Energy.
- XE00-B-G1ZZ-GLZZ-E-000561, Systems Engineering Management Plan, revision in force, X-Energy.
- XE00-B-G1ZZ-GLZZ-D-000450, Xe-100 Nuclear Power Plant Modes & States, revision in force.

System-specific functions are only available in design documentation. The following is a descriptive list of additional Xe-100 specific design documents necessary to perform the FRA and FA process. Additional documentation may be identified during the performance of the activity. If any of the following documents are not available, the HFE team will provide reasonable assumptions, properly recorded as such, to allow for the activity to be completed. It is assumed that some or all these documents may be preliminary to comply with the licensing process.

- System Design Descriptions
- Piping and Instrumentation Diagrams
- Single-line Diagrams
- Logic and Analogic Diagrams
- Preliminary technical specifications

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3.2. METHODOLOGY

Figure 2 shows the complete overall process. FRA and FA are considered together in the same IP because they are very closely related. However, outputs can be clearly identified separately.

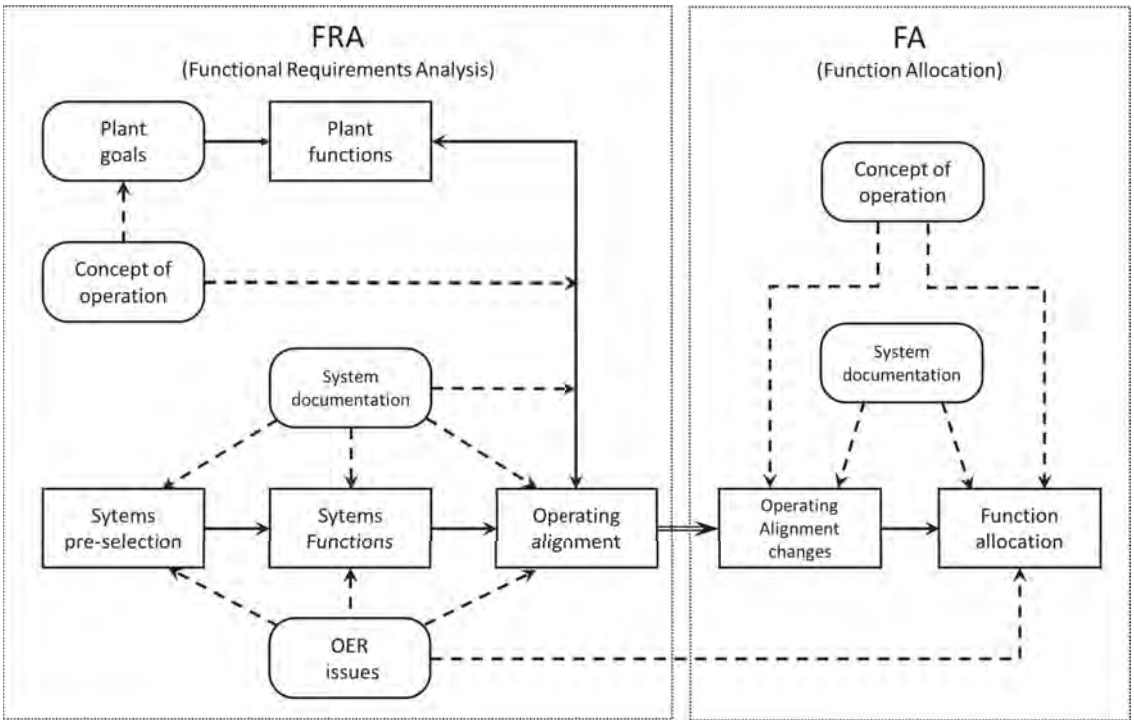

Figure 2: FRA and FA overall process

As explained below, some design modifications may come from FRA and FA results. Moreover, as stated in the HFE PMP [6], HFE activities are an iterative process. For each iteration, the process shall be totally or partially reviewed and/or repeated, if necessary.

Functional Requirements Analysis will be conducted to ensure that the functions necessary to accomplish plant goals are identified and sufficiently defined. The analysis will consist of a functional breakdown, where plant goals are in the top level and plant component statuses are in the lowest level. A plant goal is met if the related plant components are operating in their specified status. Hence, the functional requirements to accomplish the plant goals are the plant components properly operating. Figure 3 shows this concept.

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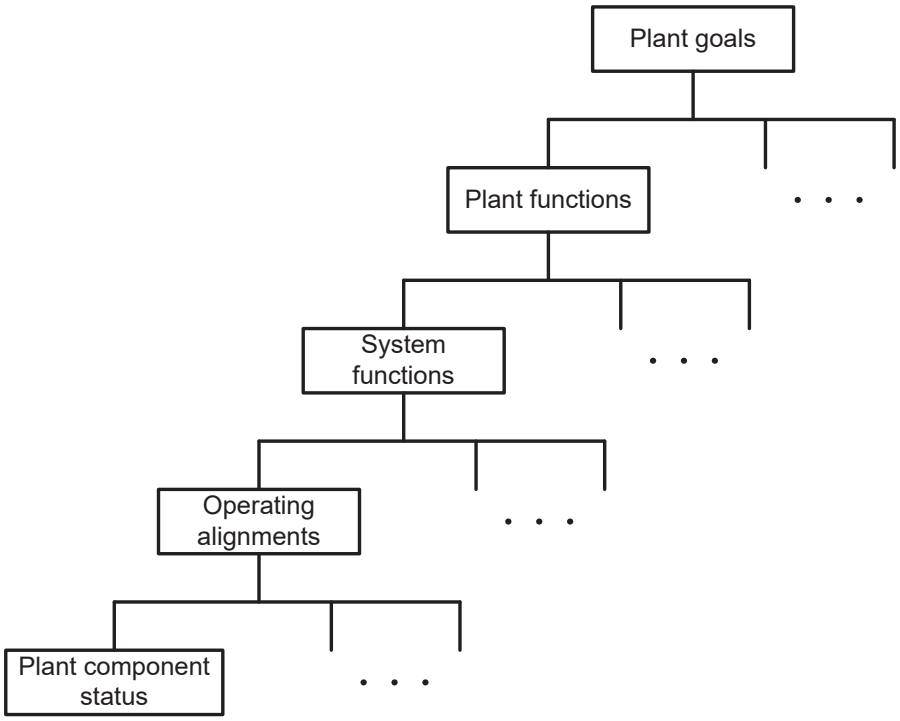

Figure 3: Functional breakdown

Using one of the FRA results (the operating alignment level), the best responsible agent for each function can be determined. This is developed in the following stage, the Function Allocation.

Function Allocation will be performed to assign the functions to personnel and/or automation, considering their relative capabilities, strengths, and weaknesses. Therefore, the allocation methodology is based on HFE criteria. The objective is to avoid operation mistakes and maximize efficiency and reliability of the plant by maintaining the operator's awareness of the plant status.

The results of the FA will provide the aggregate of human actions needed to perform the functions. These human actions will be further analyzed in the Task Analysis (details can be found in Xe-100 Task Analysis Implementation Plan [8]).

During the development of the FRA and FA activities described in this section, HFE-related issues may be identified. Previously identified HFE-related issues (either within FRA and FA or any other element), may be addressed while performing FRA and FA activities. In any of these cases, these issues shall be properly recorded in the HFE Issue Tracking System (HFEITS), as described in the HFE PMP [6].

3.2.1. Plant Goals and Definitions

The first step in FRA development is to identify and define the plant goals that are planned to be accomplished through the main control room (MCR). The Concept of Operations [5] is the key input.

Figure 4 shows the position of the plant goals definition process within the functional breakdown.

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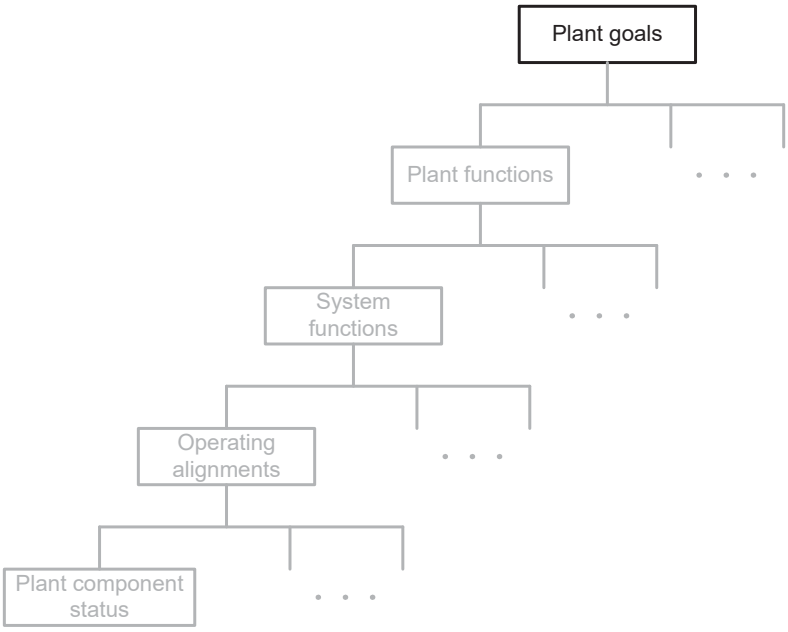

Figure 4: Plant goals definition within the functional breakdown

As it is already defined (see Concept of Operations [5]), the Xe-100 plant goals are:

a. Ensure the safe nuclear operation by
   i. prevention of accidents or mitigation of their consequences; and
   ii. protection of the personnel, public and environment against the effects of abnormal radiation rate

b. Ensure the production and transmission of electric power to the external grid by an efficient conversion of nuclear energy into electricity with the output parameters required by the grid.

These goals will be simplified by the terms *nuclear safety goal* and *production goal,* respectively.

3.2.2. Plant Functions Definition

The aim of this stage is to identify and define the plant functions needed to fulfil each plant goal. Plant functions will be defined in terms of operational processes that take place in the facility (e.g. nuclear heat generation, conversion from thermal energy to shaft work, fuel management, etc.).

Several plant functions may be necessary to be accomplished at the same time to fulfil a plant goal. Furthermore, plant conditions affect the required plant functions.

Figure 5 shows the position of the plant functions definition process within the functional breakdown.

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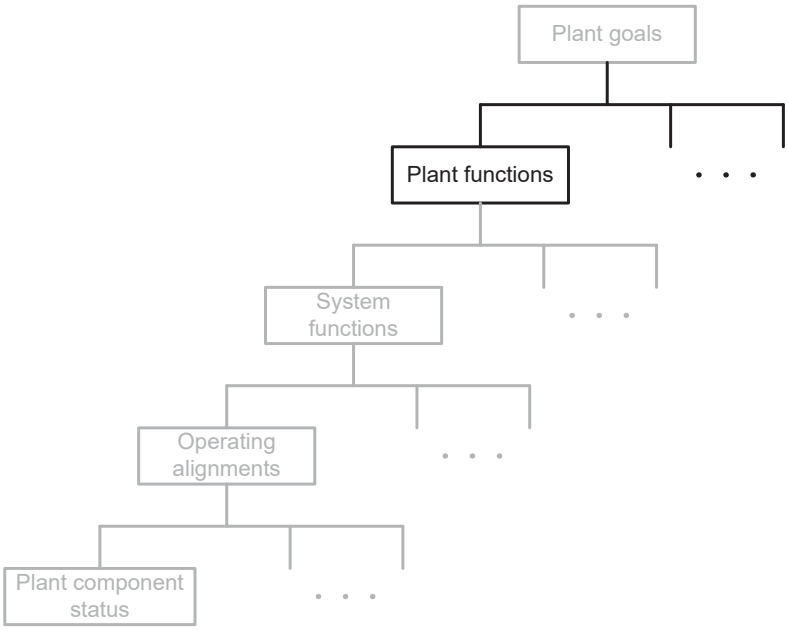

Figure 5: Plant functions definition within the functional breakdown

The output of this stage will be the relationship between plant goals and plant functions (considering plant conditions).

Regarding plant conditions, they are described in the Concept of Operations document [5]. However, they shall be validated. A summary of plant conditions to be considered are listed below.

- Normal Operation (i.e., plant modes and states):
  - Defueled Cold Shutdown
  - De-pressurized Cold Shutdown
  - Cold Shutdown
  - Uncooled Hot Shutdown
  - Cooled Hot Shutdown
  - Nuclear Heat Operation
  - Operation ready
  - House Load
  - Reduced Power Operation
  - Normal Power Operation
- Abnormal conditions
  - Plant parameter threshold value exceeded
  - Key equipment failure
  - MCR inhabitability or inoperability

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- Emergency conditions
  - Safety parameter threshold value exceeded.

Plant functions will be coded using an alphanumeric scheme. As the two plant goals have already been defined, plant functions will be codified as follows:

SF[nn]	Plant functions related to nuclear safety goal
PF[mm]	Plant functions related to production goal
nn	Correlative number beginning from 01
mm	Correlative number beginning from 01

For each plant function, the following specific information (key parameters) will be identified[3]:

- conditions indicating that the plant function is needed
- parameters indicating that the plant function is available
- parameters indicating that the plant function is operating
- parameters indicating that the plant function is achieving its purpose
- parameters indicating that the operation of the plant function can or should be terminated
- the degree to which the functions of the design differs from predecessor design

To sum up, the information to be provided related to plant functions will be the following:

a. identification code
b. name
c. description
d. key parameters
e. relationship with plant goals

3.2.3. System Functions Identification

The high-level system functions will be identified using the system documentation and the outputs of the previous stage, that is plant functions. System design functions are typically based upon design and operating experience, regulatory requirements, industry requirements, and project requirements. Descriptions of both plant and safety system functions shall be completed in a way that their accomplishment can be measured by means of objective parameters, either quantitative (e.g. pressure, flow, level or temperature) or qualitative (system or component status). For each plant and safety-system

[3] These key parameters are specifically required in NUREG–0711 [1].

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function, the parameters and conditions that assure that the function is accomplished will be determined and identified.

Figure 6 shows the position of the system functions identification process within the functional breakdown.

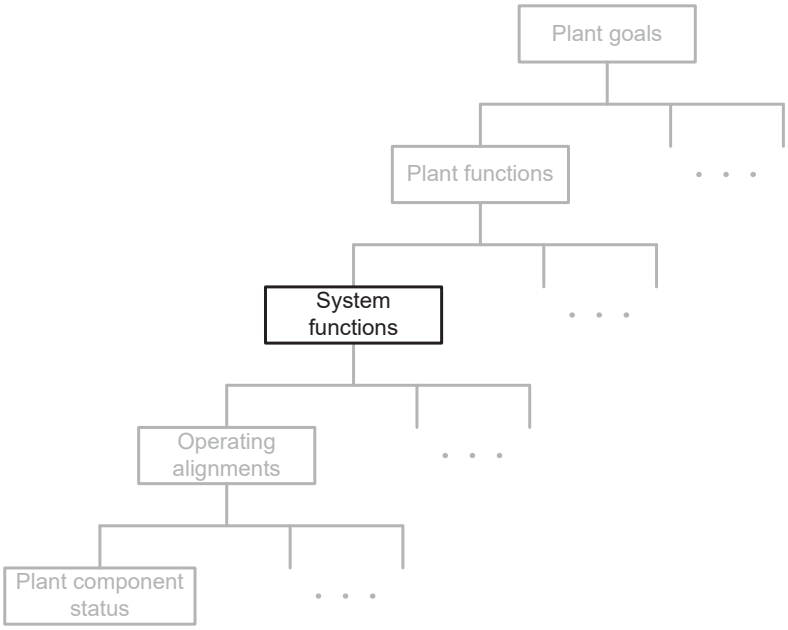

Figure 6: System functions definition within the functional breakdown

Prior to the detailed descriptions of the system functions, a preliminary study of the plant system organization will be performed. The aims of this study are to:

- consider grouping of several plant systems into one, for HFE analysis purposes only
- pre-select those systems that are related to the operation in the MCR via plant functions

Note that system functions are high level and are not related with a specific plant function at this point of the analysis. However, the plant function definitions may be considered to have a better description of system functions.

System functions will be coded using the following scheme:

[SysID]-F[nn]	System function identification (FuncID)
SysID	System identification defined by System documentation
nn	Correlative number beginning from 01 for each system

Additionally, for each system function, a brief description, and the control strategy applicable to the operation of the system shall be provided (relationships with other system functions, limitations and/or restrictions may also be included).

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For each safety function and other plant function (e.g., electrical power generation), the set of system configurations will be defined.

The information to be provided related to system functions will be the following:

a. identification code

b. name

c. description

d. control strategy

e. operating alignment definitions (as described in section 3.2.4 below)

3.2.4. Operating Alignment Definition

Plant systems are designed to accomplish one or several functions. The means that allows a system to accomplish a specific function will be called an operating alignment. Many systems can accomplish the same function by different means. Therefore, several operating alignments may be associated with a single plant function.

An operating alignment will be defined by the set of plant components needed to perform its associated function. The identification of these components shall be supplemented with the specific status required to perform the function (e.g. valve - opened or valve - closed). Note that plant variables (e.g. flow, level, or temperature) may be part of the operating alignment working as they are needed to verify the system is operating or the function is being accomplished.

Note that two or more trains or divisions of analogous components, all of them capable of performing the same function, may be considered the same operating alignment.

Figure 7 shows the position of the operating alignment definition process within the functional breakdown.

Operating alignments will be coded using the following scheme:

[FuncID]-AL[nn]	Operating alignment identification
FuncID	Identifier of the system function (as defined in section 3.2.3)
nn	Correlative number beginning from 01 for each system function

One or several components of an operating alignment are key to determining whether the system function is being accomplished or not. These components, generally one or more plant variables, are defined as *performance conditions*. Performance conditions are important for the development of following HFE activities, such as Task Analysis. Therefore, the performance conditions of each operating alignment shall be identified.

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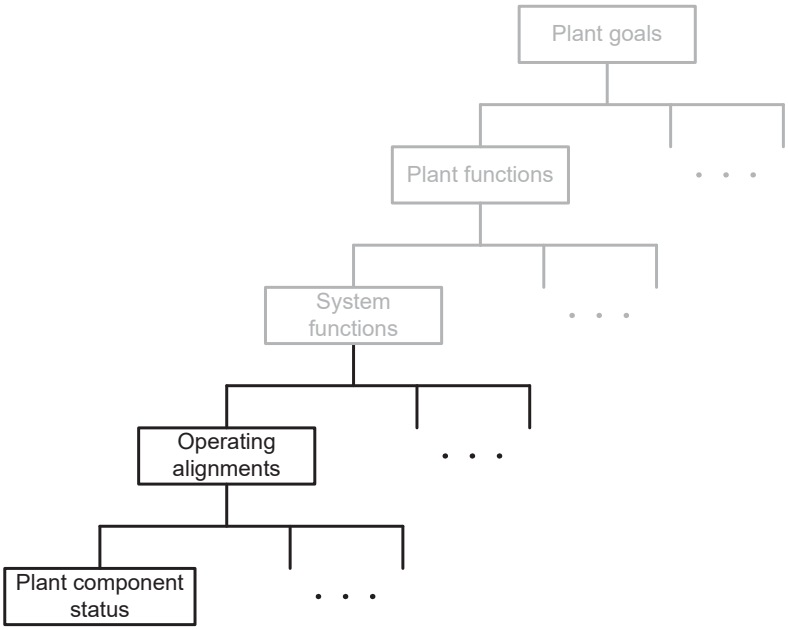

Figure 7: Operating alignment definition within the functional breakdown

To sum up, the information to be provided related to operating alignments will be the following:

a. identification code

b. name

c. plant components list

d. performance conditions

e. relationship with plant functions (as described in section 3.2.5 below)

Special operations such as equipment tests, conditioning, and maintenance are studied as a separate function. Local operations are considered at a global level.

3.2.5. Relations Between System Functions and Plant Functions

System functions will be associated with plant functions at the operating alignment level. That is, each operating alignment of a system function might be assigned to different plant functions.

Figure 8 shows the association of system functions with plant functions, which completes the functional breakdown introduced with Figure 3.

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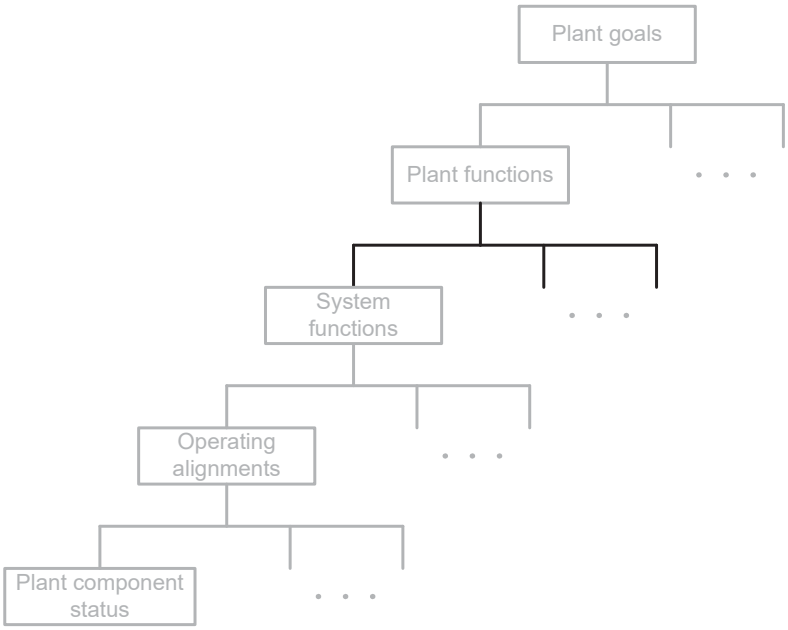

Figure 8: Association of system functions with plant functions within the functional breakdown

The relation can be done using the information provided in each one of the previous steps. Concept of Operations [5], functional descriptions, and system documentation may also be used as needed to assure a proper relation definition.

Listed below are some additional important concepts that need to be defined to clarify special situations that may arise.

- Alternative/preferred operating alignment - Applies to different operation alignments belonging to the same system function. Preferred operating alignment is considered the first option to accomplish the function, while alternative operating alignment is designed as a back-up.
- Supporting functions - Those system functions designed to provide services to other systems to make them capable to perform their functions, while operating continuously in all plant conditions. Typical examples are electrical supply, cooling, and heating and ventilation.
- Goal accomplishing functions - Refers to system functions directly related to the accomplishment of any plant function.
- Independent functions - Refers to system functions that cannot easily be associated to any plant function. They will be properly identified, but they will not be associated to plant functions.

The association of system functions with plant functions is verified to determine whether the pre-selection of systems was correct. It may happen that additional system functions are necessary to assure that the plant functions are accomplished.

Figure 9 depicts the overall process for the Functional Requirements Analysis. At this point, since the plant goals, high-level functions, functional requirements, and all relationships are defined, the FRA is completed.

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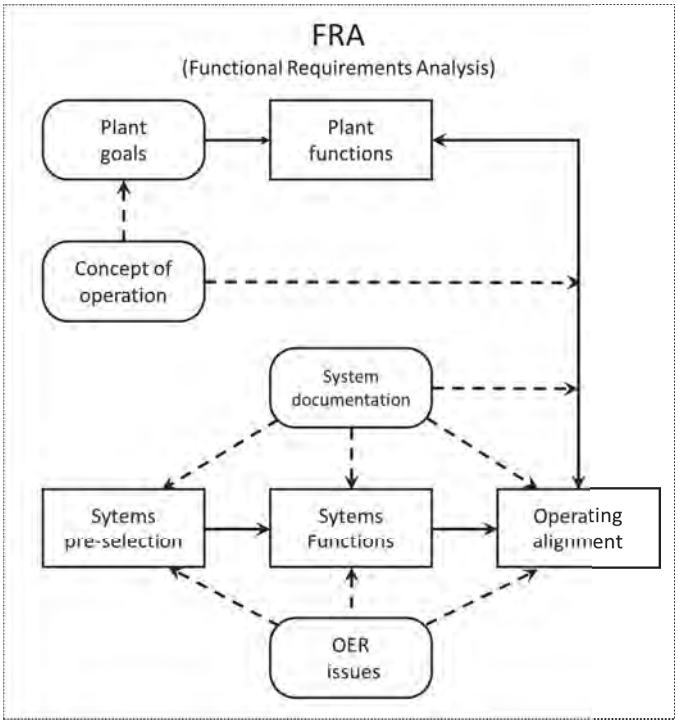

Figure 9: Functional Requirements Analysis overall process

3.2.6. Operating Alignment Changes

This stage corresponds to the first step of the Function Allocation. The overall process for the Function Allocation is shown in Figure 10.

The operation of the plant requires changes in the operating alignments to fulfil system or plant functions during the evolution of the plant conditions. The evolution can be either planned or occur due to unexpected events. In any case, new plant conditions may require different system functions to be fulfilled, so that different operating alignments are also required.

During this stage, possible and sensible operating alignment changes will be identified. In this context, sensible is understood as “according to the operation philosophy and system design capabilities and restrictions”; therefore, some combinations of operating alignments will not be considered operating alignment changes.

To define completely the operating alignment changes, a new concept needs to be defined. A system will be said out of service when its components are not performing together for any intended function. Therefore, if the fulfilment of a system function is required, the corresponding operating alignment needs to be placed in service and such change shall be identified in the list of operating alignment changes. Inversely, when the fulfilment of a system function is not needed any more, the operating alignment change to the out of service condition shall also be identified.

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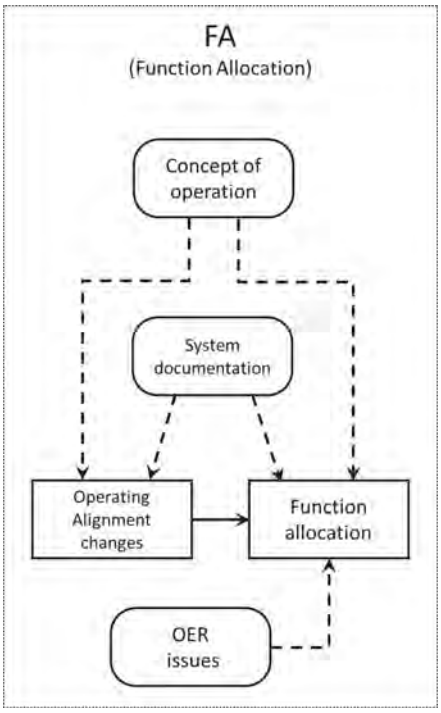

Figure 10: Function Allocation overall process

To sum up, the cases of alignment in each system are as follows:

a. from out of service to an operating alignment,

b. from an operating alignment to out of service,

c. from one operating alignment to another to fulfill the same system function

d. from one operating alignment to another to fulfill a different system function

Operating alignment changes will be coded using the following scheme:

[AlOrigin] – [AlDest]	Operating alignment change identification
AlOrigin	Initial operating alignment as defined in section 3.2.4
AlDest	Final operating alignment as defined in section 3.2.4

Note 1: Initial or final out of service will be coded as [FuncID]-OoS.

Note 2: For simplification, system identification will only be included once.

3.2.7. Allocation Flow Chart

This stage of the FA consists of assigning a responsible agent to each “part” of an operating alignment change. These ‘parts’ of an operating alignment change are called process stages. A proper alignment change will be divided into three process stages.

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1. Initiation- This stage involves the decision-making process related to the need of the operating alignment change, including the gathering and evaluation of data.
2. Performance- This stage includes the execution of the actions required to change component statuses, and the individual verification of the proper result of such actions, including the evolution of the plant variables.
3. Verification- This stage is limited to the verification of the fulfillment of the system function after the operating alignment change is completed. Note that the performance conditions, defined in section 3.2.4, provide the most valuable information for this stage.

Using the allocation flow chart (Figure 11), each process stage will be effectively assigned a responsible agent. The possible responsible agents for allocation will be limited to the following:

- human (fully manual operations)
- automation (fully automatic operations, including passive, self-controlling phenomena),
- both automation and human (shared responsibility at any degree)

The following general considerations will be considered in the assignment process:

- Automation is more efficient performing functions which can be programmed in detailed, complex instructions.
- Automation can protect the plant against human errors and variable human behavior.
- Automation can reduce operator mental workload, especially when performing very complex tasks that require considering a large amount of information.
- Actions performed by automation and human should be balanced.
- Professional motivation and psychological well-being of the operator should be an evaluation factor.
- Operator should have authority to cancel or start an automatic actuation.
- Operator should be aware of automatic actions, as well as the objective of such actions.
- Primary allocations to personnel (those functions for which personnel have the primary responsibility), including their responsibilities to monitor automatic functions, detect degradations and failures, and to assume manual control when necessary.

The flow chart shown in Figure 11 will be used[4] to help in the assignment process. It consists of a set of questions in a conditional sequence, which leads to a proposed assignment: human, automation or both. In the latter case, a description of the specific roles assigned to each responsible agent will be provided.

[4] The flow chart is based on the guidelines found in NUREG/CR-3331 [4].

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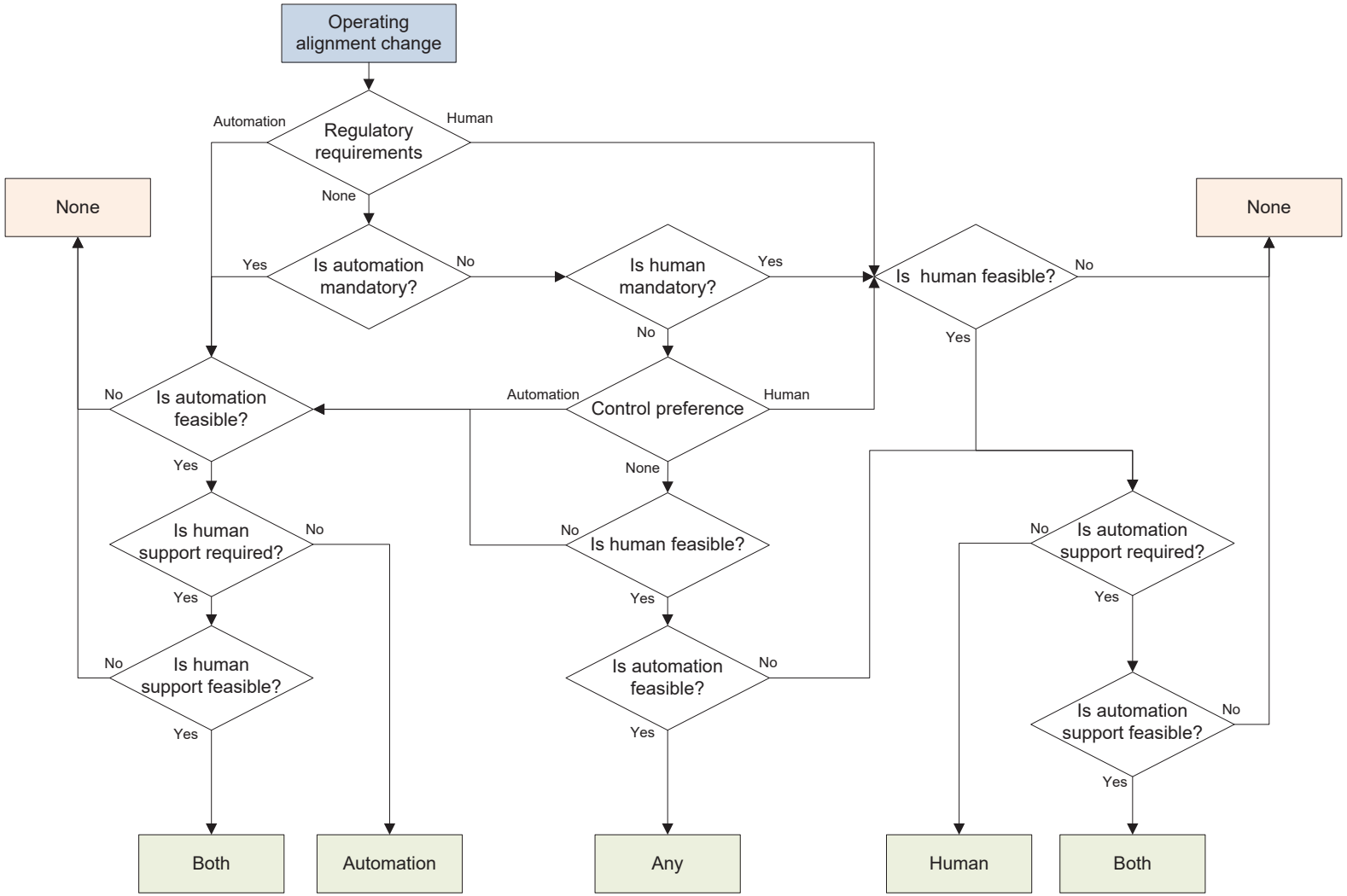

Figure 11: Function Allocation flowchart

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The flow chart can also lead to two additional outputs, “None and Any.” These are only preliminary assignment options.

a. “None” implies that the process tends to a non-feasible assignation and it shall be redefined; therefore, ‘none’ will not be a valid proposed assignation.

b. “Any” means that the process cannot determine which is better, human or automation; therefore, one option (human, automation, or both) will be selected under HFE analysts’ judgment. In that sense, ‘any’ is a valid assignation, but must be completed with the proposed selection.

The process stages of the operating alignment changes that are assigned to human, either completely or partially, are further analyzed in the Task Analysis (refer to TA IP [8]).

This is the first allocation in this iterative process. Further analysis may determine that the initial allocation is incorrect and may need some level of modification.

3.3. OUTPUTS

Using the inputs defined in section 3.1 and following the methodology described in section 3.2, FRA and FA results will provide the following:

a. Name, identification code and description of plant and system functions (including safety functions) and operating alignments (Section 3.2.3)

b. The final set of allocations from the methodology (refer to Sections 3.2.6 and 3.2.7)

c. Key parameters of plant functions (Section 3.2.2)

d. Control strategy for system functions (Section 3.2.3)

e. Performance conditions of operating alignment (Section 3.2.4)

f. Relationships between levels according to functional breakdown (Section 3.2.5)

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4. DOCUMENTATION

All the information and data resulting from the development of the activities of this element shall be recorded in a software tool, which will be shared among all activities within the HFE Program. Using this single tool enables the HFE team to share common information and reduces the likelihood of making mistakes while performing HFE activities.

The tool consists of a relational database and an interface with the user. The database is configured in such a way that data within the same element and from different ones are related as described in the corresponding IPs. The interface allows for entering new or modifying existing data in a user-friendly way. Through the interface, users can perform queries to the database to extract pieces of information in a user-readable format.

Additionally, FRA and FA results will be documented in a Results Summary Report (RSR). This report will include, at least, a summary of the most important data. These important data are inputs for the first stage of the process (plant functions) and final outputs (function allocation). Regarding function allocation, only pending issues and those needed for the next element within the HFE program will be detailed in the RSR. The information provided with these data will be according to sections 3.2.2 and 3.2.7:

- Plant functions:
  - identification code
  - name
  - description
  - key parameters
  - relationship with plant goals
- Allocation of functions: those that include actuation stages assigned to human or both responsible agents, identifying:
  - operating alignment change
  - initiation responsible agent (though it is Automation)
  - performance responsible agent (though it is Automation)
  - verification responsible agent (though it is Automation)
- Allocation of functions: those that include a non-feasible assignation (output ‘none’ in the flow chart), identifying:
  - operating alignment change
  - initiation responsible agent
  - performance responsible agent
  - verification responsible agent

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Additionally, an evaluation of the applicability of the FRA to control rooms other than the MCR, such as the Reserve Shutdown Station (RSS) will be described. The conclusion regarding the need for extending the analysis to any other control room will be provided.

It is important to note that the FRA/FA process is iterative. The RSR will unambiguously define the inputs considered for the analysis performed for a specific revision and/or date. As the design evolves, potential impacts to the original FRA/FA will be evaluated for effect on the conclusions as documented in the RSR and if appropriate, the RSR will be revised.

HFE-related issues that are identified during the performance of this element shall be recorded in the HFEITS. The HFEITS will also be reviewed to identify previously recorded HFE issues and identify those issues that may be addressed and resolved by outputs from activities performed in this HFE element. A software tool shall implement the HFEITS in a way that allows the HFE team members to follow the process detailed in the HFE PMP [6].

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5. APPENDICES

5.1. APPENDIX A: COMPLIANCE CHECKLIST

Table 1 details the specific requirements defined in NUREG-0711 [1] related to the criteria that the FRA and FA activities shall meet. It also references sections of this IP where the corresponding requirement is addressed and explained to facilitate the FRA and FA activities development.

Table 1: NUREG-0711 compliance list

NUREG-0711 reference	Requirement	IP reference
4.4 (1)	The applicant should use a structured, documented methodology reflecting HFE principles to perform functional requirements analysis and function allocation.	3.2
4.4 (2)	The applicant's FRA and FA should be performed iteratively to keep it current during design development and operation up to decommissioning, so that it can be used as a design basis when modifications are considered.	3.2
4.4 (3)	The applicant should describe the plant's functional hierarchy, including, as appropriate goals, functions, processes, and systems.	3.2.1, 3.2.2, 3.2.3, and 3.2.5
4.4 (4)	For each high-level function, the applicant should identify requirements related to: • purpose of the high-level function, • conditions indicating that the high-level function is needed, • parameters indicating that the high-level function is available, • parameters indicating that the high-level function is operating (e.g., flow indication), • parameters indicating that the high-level function is achieving its purpose (e.g., reactor vessel level returning to normal), and • parameters indicating that the operation of the high-level function can or should be terminated.	3.2.2
4.4 (5)	Applicants should allocate functions to a level of automation (e.g., from manual to fully automatic) and identify the technical bases for the allocations.	3.2.7

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NUREG-0711 reference	Requirement	IP reference
4.4 (6)	The applicant's FA should consider not only the primary allocations to personnel (those functions for which personnel have the primary responsibility), but also their responsibilities to monitor automatic functions, detect degradations and failures, and to assume manual control when necessary.	3.2.7
4.4 (7)	The applicant should describe the overall role of personnel by considering all functions allocated to them.	3.2.7
4.4 (8)	The applicant should verify that the FRA and FA accomplish the following: • all the high-level functions needed to achieve safe operation are identified, • all requirements of each high-level function are identified, and • the allocation of functions to humans and automatic systems assures a role for personnel that takes advantage of human strengths and avoids human limitations.	3.2.7
4.4 (9)	Additional Considerations for Reviewing the HFE Aspects of Plant Modifications.	N/A

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Enclosure 5

Xe-100 Task Analysis Implementation Plan

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Xe-100

Task Analysis Implementation Plan

Configuration Classification	:	**XE00-R-R1ZZ-RDZZ-X**
Revision	:	**1**
Status	:	**Approved**
Issue Date	:	**21-May-2021**
Project	:	**Xe-100**
Project Phase	:	**Concept**

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SYNOPSIS

This document provides the methodology to be followed to perform the Task Analysis element of the Human Factors Engineering Program.

CONFIGURATION CONTROL

Document Change History

Rev.	Date	Preparer	Changes
0A	26-Apr-2021	Hector Martinez-Pinna	Initial issue
1	21-May-2021	Hector Martinez-Pinna	Typos correction and minor changes

Document Approval

Action	Designation	Name	Signature	Date
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Reviewer	Tecnatom, Human Factors Principal Engineer	Richard Gutierrez	DocuSigned by: Richard Gutierrez A36744F44A30427...	5/24/2021 | 1:18 PM EDT
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ABBREVIATIONS

This list contains the abbreviations used in this document.

Abbreviation or Acronym	Definition
ANS	American Nuclear Society
ANSI	American Nuclear Standards Institute
COO	Concepts of Operations
CNSC	Canadian Nuclear Safety Commission
EOP	Emergency Operating Procedure
FA	Function Allocation
FRA	Functional Requirements Analysis
HA	Human Action
HFE	Human Factors Engineering
HSI	Human System Interface
IAEA	International Atomic Energy Agency
IP	Implementation Plan
MCR	Main Control Room
NRC	(United States) Nuclear Regulatory Commission
OER	Operating Experience Review
PMP	Project Management Plan
RSS	Reserve Shutdown Station
S&Q	Staffing & Qualifications
TA	Task Analysis
TIHA	Treatment of Important Human Actions
V&V	(Human Factors) Verification and Validation

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DEFINITIONS

This list contains the terms of glossary used in this document.

Term	Definition
Activity	Single operator action over a plant component, an interface element, or a communication device. It can also refer to the specific action of a thought process that the operator must carry out.
Actuation stage	Each of the three sequential steps that must be executed to complete an operating alignment change: initiation, performance and verification.
Element	From NUREG-0711 [1] the four general activities are separated into the following twelve elements: • HFE Program Management • Operating Experience Review • Functional Requirements Analysis and Function Allocation • Task Analysis • Staffing & Qualifications • Treatment of Important Human Actions • Human-System Interface Design • Procedure Development • Training Program Development • Human Factors Verification and Validation • Design Implementation • Human Performance Monitoring
Event	Scheduled or unexpected occurrences that require the plant response to fulfill the program objective and/or to maintain the facility stability and safety.
Implementation Plan	Document that describes the proposed methodology for conducting an HFE element and is reviewed by the NRC staff to reasonably assure that it will generate acceptable results that satisfy the staff's review criteria.
Operating alignment	Set of plant components needed to perform a system function and verify its proper operation.
Results Summary Report	Document that summarizes the results of a completed HFE element and cites documents or files that contain the complete results.
Task	Group of activities in sequential order based on each actuation stage in an operating alignment change: initiation, performance, verification.

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1. INTRODUCTION

The Xe-100 nuclear reactor is an innovative design that is categorized as a Small Modular Reactor (SMR) due to its relatively low power, 200 MWt or 80 MWe. Its design allows for the fabrication and testing to be performed in a factory environment, so that it can be shipped to a site where it is installed as a single component. From a technological and regulatory point of view, the Xe-100 is a High Temperature Gas-cooled Reactor (HTGR) cooled by helium and moderated by graphite, implementing features that make the reactor inherently safe.

The plant configuration consists of four Xe-100 reactors, whose design is optimized since each unit shares like systems. The main purpose of a Xe-100 plant is to safely convert nuclear energy to electricity, in addition, the plant design accommodates multiple missions such as process heat applications.

As required by the licensing process and NUREG-0711 [1], a Human Factors Engineering (HFE) Program shall be developed[1], with proven systematic analysis techniques to address human factors issues within the design process. The HFE program and its products reflect state-of-the-art human factors principles.

As described in the HFE Program Management Plan (HFE PMP) [7], one of the first steps in the HFE Program is the preparation of Implementation Plans (IPs) that describe the proposed methodology for the performance of a specific HFE program element.

In accordance with NUREG-0711 [1] and NUREG/CR-3371 [4], an IP provides an opportunity to obtain a review and concurrence from the regulatory staff of the proposed methodology before performing the work associated with the element. This early review is desirable because it offers the staff an opportunity to identify potential issues with the methodology and to provide the Xe-100 design team with early input to the analysis or design processes, when staff concerns can more easily be addressed, rather than when the element has been completed.

Task Analysis (TA) covers a range of techniques used by the HFE design team to describe and evaluate the Human-Machine and Human-Human interactions in systems. TA identifies actions and/or cognitive processes operations personnel are required to fulfill system functions. TA can also be used to document the information processing and control capabilities necessary to carry out the tasks.

In addition, the TA:

- Ensures all functions allocated to operations personnel in the Function Allocation (FA) are considered in the TA.
- Ensures methods and criteria for conducting the TA are in accordance with accepted Human Factors practices and principles.
- Develops narrative descriptions of operations personnel activities required for successful completion of each task.

[1] Refer to 10 CFR 50.34 (f)(2)(ii), 10 CFR 50.34 (f)(2)(iii) [3], and REGDOC-2.2.1, Human Factors [2].

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- Provides one of the bases for making design decisions, e.g., determining before hardware fabrication, to the extent practicable, whether system performance requirements can be met by combinations of anticipated equipment, software, and personnel.
- Ensures operations performed at the Main Control Room (MCR) and four Reserve Shutdown Stations (RSS) are included.
- Assures human performance requirements do not exceed human capabilities.
- Provides basic information for developing manning, skills, training, and communications requirements of the system.
- Ensures tasks critical to safety are identified.
- Forms the basis for specifying the requirements for the display interface design, data processing, and controls needed to carry out tasks.

Performing a TA early in the design process establishes a two-way flow of information with knowledge about human performance requirements and limitations feeding into the Human-System Interface (HSI) design process, and design preferences and constraints feeding into the TA. The timing of TA is a critical determinant of the usefulness of the results, especially if used to assist in optimization of system design.

1.1. PURPOSE

The purpose of this document is to describe the methodology to be followed in the development of the fourth element of NUREG-0711 [1], TA, and to establish the specific requirements of its Results Summary Report.

The TA process identifies and examines the tasks performed by users interacting with systems and evaluating the system performance requirements, by placing demands on an operating crew to identify the task requirements for accomplishing the functions allocated to the task. The tasks performed by operations personnel are defined by the required responses to system indicators and alarms using postulated controls, by functions assigned to plant equipment monitored by operations personnel, and by functions shared by operations personnel and plant equipment.

A task is defined as the collection of activities performed by a person or by a machine directed toward achieving a single sub-function. Performance of a TA applied to those functions allocated to humans is basic for determining:

- Information requirements
- Decision-making requirements
- Response requirements
- Feedback requirements
- Staffing and communications requirements
- Workplace factors

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- Personnel workload
- Associated task support requirements
- Task-associated hazards
- Estimation of automation options

The objective of the TA IP is to provide methods and criteria for performance of TA consistent with accepted HFE practices and principles.

The performance of the TA IP will also review operations personnel performance during other activities such as load following if it is presented as a scenario. With an automated design, there may be the need for the operator to change the generation of electricity to match the expected electrical demand as closely as possible. Load following as currently performed requires communication between the operators in the MCR and the grid control center.

In addition to the tasks performed by the control room staff, scenarios that involve the skill set from the Shift Technical Advisor (STA) will also be reviewed if applicable. The current interpretation of the STA policy is that operating crews need to include one person with a degree in either a physical science, engineering, or engineering technology. The goal is to evaluate the ability of the planned staffing level and include tasks that may be allocated to the STA.

1.2. SCOPE

This TA IP defines the methodology that will support the TA performance as part of the HFE Program for the HFE licensing of the Xe-100 plant design certification. This IP is implemented in accordance with the criteria as defined in the HFE PMP [7].

The IP methodology covers the identification of tasks directed to the full range of plant operating modes, including startup, normal operations, abnormal operations, transient conditions, shutdown conditions, and MCR habitability. The MCR staff will monitor the performance of planned maintenance activities. The level of operator participation in maintenance activities will be identified during the performance of the TA. The initial TA addresses any required support by the MCR staff of maintenance activities being performed out in the plant. This may include such tasks as changing valve lineups, stopping equipment, etc. Tasks and activities will be addressed as much as the preliminary documentation allows.

Those maintenance tasks and activities outside the MCR or RSS are not considered in this TA IP.

1.3. RELATIONSHIP TO OTHER DOCUMENTS

This IP is part of the HFE Program described in the HFE PMP [7], which includes high-level considerations that shall be known by the reader of this IP. Other HFE Program elements are related to the TA, therefore, the IPs of these elements are cross-referenced where needed. Figure 1 shows relationships between TA IP and other documents within the HFE Program.

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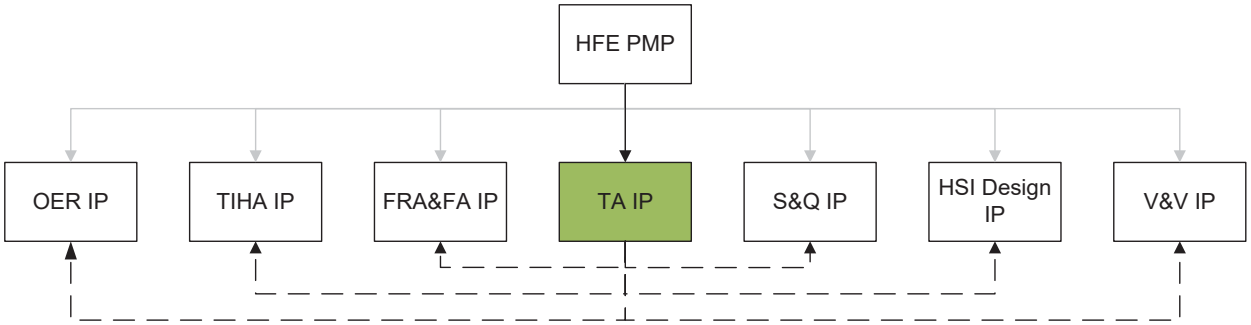

Figure 1: Relationship of TA IP to other documents within the HFE Program

1.4. DOCUMENT LAYOUT

This TA IP is formatted as follows:

- Section 1 addresses the document introduction, purpose, scope, and relationship to other documents.
- Section 2 identifies the references used in this IP.
- Section 3 describes the methodology, from the inputs, through the process and the expected outputs.
- Section 4 addresses how the outputs shall be documented.
- Section 5 includes a checklist to verify compliance of this IP with the corresponding NUREG-0711 [1] review criteria.

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2. REFERENCES

The following documents are referenced within this document.

	Document Title	Preparer/Author	Document Number	Revision or Date of Issue	Classification	Applicable[2] (Yes/No)
[1]	NUREG-0711, Human Factors Engineering Program Review Model	NRC	N/A	Rev 3	N/A	Yes
[2]	REGDOC-2.2.1, Human performance management Human Factors	CNSC	N/A	2019	N/A	Yes
[3]	10 CFR 50.34, Contents of applications; technical information	NRC	N/A	2019	N/A	Yes
[4]	NUREG/CR-3371, Task Analysis of Nuclear Power Plant Control Room Crews	NRC	N/A	1983	N/A	Yes
[5]	NUREG-0700, Guidelines for Control Room Design Reviews	NRC	N/A	Rev 3	N/A	Yes
[6]	EPRI-NP-3701, Computer-generated Display System Guidelines (Vol. I and II)	NRC	N/A	1984	N/A	Yes
[7]	TEC-XE100-HFE-PMP, HFE Services for the Xe-100 Plant Design – Human Factors Engineering Program Management Plan	Tecnatom	N/A	Rev 0	N/A	Yes
[8]	TEC-XE100-HFE-COO, Concept of Operations	Tecnatom	N/A	Rev 0	N/A	Yes
[9]	TEC-XE100-HFE-TRS, Control Room Staffing Analysis Methodology	Tecnatom	N/A	Rev 0	N/A	Yes
[10]	Operating Experience Review Implementation Plan	Tecnatom	000982	Rev 1	XE00-R-R1ZZ-RDZZ-X	Yes
[11]	Treatment of Important Human Actions Implementation Plan	Tecnatom	000984	Rev 1	XE00-R-R1ZZ-RDZZ-X	Yes

2 Applicable documents are applicable to the extent specified within this document and thus deemed to form part of this document.

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Document Title	Preparer/Author	Document Number	Revision or Date of Issue	Classification	Applicable[2] (Yes/No)
[12] Functional Requirements Analysis and Function Allocation Implementation Plan	Tecnatom	000985	Rev 1	XE00-R-R1ZZ-RDZZ-X	Yes
[13] Human-System Interface Design Implementation Plan	Tecnatom	000988	Rev 1	XE00-R-R1ZZ-RDZZ-X	Yes

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3. DEVELOPMENT

TA is a method of collecting and organizing information. Data collected is used to make various judgments or design decisions. The application of TA provides the designer with a "blueprint" of human integration with a system and viewing the system from a human perspective. The structured information obtained is applied to ensure compatibility of system hardware and software functions with human capabilities and limitations.

The TA identifies operations personnel needs for information, controls, and alarms for performance of operations tasks, including operations tasks during periods of maintenance and testing of plant systems and equipment including the HSI equipment.

The TA enables verification that the task performance of the operator does not exceed their capabilities. Furthermore, it also provides relevant information concerning the design of the MCR and RSS, especially focused on the HSI.

A task is defined as the collection of activities performed by a person, directed toward achieving a single sub-function. Performance of a TA applied to those functions allocated to humans is basic for determining:

- Information requirements
- Decision-making requirements
- Response requirements
- Feedback requirements
- Staffing and communications requirements
- Workplace factors
- Personnel workload
- Associated task support requirements
- Task-associated hazards
- Estimation of automation options

3.1. INPUTS

This section identifies the inputs that provide the information necessary for the preparation and performance of the TA. These inputs are in three categories:

a. General design bases inputs - International standards and normativism are used as general design inputs, as applicable for the scope of work. This set of documents includes, but is not limited to:

   i. NRC NUREG-0711, Human Factors Engineering Program Review Model, revision 3

   ii. NRC RG 1.62, Manual Initiation of Protective Actions, revision 1, 2010

   iii. ANSI/ANS-58.8, Time Response Design Criteria for Nuclear Safety Related Operator Actions, R2008IAEA SSG-39, Design of Instrumentation and Control Systems for Nuclear Power Plants

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iv. IEEE 603, Standard Criteria for Safety Systems for Nuclear Power Generating Stations, 1998

v. CNSC Regdoc 2.5.1, General Design Considerations Human Factors

b. Inputs from HFE program

Documents generated as the HFE Program evolves are considered for the TA development. Reports such as the HFE Program Management Plan and the Concept of Operations shall be taken into account from the very beginning. Outputs from the Operating Experience Review (OER), Functional Requirement Analysis and Function Allocation (FRA&FA) and Treatment of Important Human Actions (TIHA) performance also provide input for the TA development.

c. Specific Xe-100 inputs

i. Xe-100 plant specifications and general documents

ii. Xe-100 plant systems design documents:

a) Logic Diagrams

b) System Design Description

c) I/O List

d) Piping and Instrumentation Diagrams

e) Process Diagrams

f) Setpoint Lists

g) Electric Line Diagrams

iii. Emergency Procedures Guidelines

iv. Xe-100 plant Probabilistic Risk Assessment

v. Xe-100 Safety Analysis Report

3.2. METHODOLOGY

Performance of the TA is rarely a "one-step" process; usually it requires one or more iterations as more detailed information about the plant or its systems becomes established and the roles of various personnel become clearer. As the design progresses, the TA becomes more detailed. TA and system design (including interface design) initially consider the types of information personnel need to understand about the current system status and requirements for information processing and display. In parallel, the types of controls necessary for response to presented information are also identified. After information and response requirements (e.g., displays, controls, procedures, etc.) are identified, ways the requirements are to be satisfied are specified. The importance of this formal and systematic approach becomes evident when considering the complexity of some human operations within system operations and the coordination required to integrate various design decisions affecting human tasks at different stages during the design process.

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The objective of an initial TA is collection and organization of information (data) and facilitating subsequent use of the information for a variety of purposes (e.g., development of training requirements and training content, input to HFE design and design review, etc.). Specifically, the purpose of TA is an appropriate HFE design so the information is managed and structured toward defining the optimum human-system interface based on the requirements made evident by the inherent predictive nature of TA.

The information compiled and analysis conducted are predictive. The goal is to determine requirements of an optimum human-system interface based on the information derived from the system design bases and experience of the industry. Information is also sought concerning the training requirements of operations and maintenance personnel and requirements for plant procedures.

To optimize the results of the TA, the steps for compiling and organizing information are structured as follows:

- Converting functions to operating sequences
- Developing narrative task descriptions
- Developing detailed task descriptions

3.2.1. Converting Functions to Operating Sequences

The TA process develops high-level, sequential descriptions of the operations carried out to fulfill the system functional requirements identified during the Functional Requirements Analysis (FRA). The sequential operations descriptions (namely, Operating Sequences) are developed to be consistent with the Function Allocation, and are focused on those actions needed to perform operating alignment changes allocated to the human agent (refer to FRA&FA IP [12] for details).

Because the operation of a system forms part of the overall operation of the plant, the operating conditions of the operating sequence under study must be defined. Thus, operating sequence initiators, or *events*, shall be identified, for example:

- Plant start-up
- Plant shutdown
- Plant operating modes changes
- Alternative operating alignments or functions, identified in FRA&FA
- Independent and supporting functions, identified in FRA&FA
- Safety-important operating sequences, identified in TIHA, such as Design Basis Accidents and the most likely Beyond Design Basis Accident
- Functional tests of safety systems

Events are developed in one or several operating sequences, so that the latter are defined narrowly enough to not have too many sub-levels and are defined broadly enough to reduce the total number of

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operating sequences defined. The operating sequences may have different purposes depending on the nature of the event. For unexpected events that cause a deviation from normal operation, the objective of the operating sequence is stabilizing and bringing the plant to a safe condition. For scheduled events, the objective of the operating sequence is bringing the plant to the new condition according to the schedule.

Each operating sequence is characterized by:

- related events
- plant conditions before starting the operating sequence
- plant conditions after completing the operating sequence
- estimation of the occurrence frequency
- plant functions associated to the operating sequence
- maneuvers involved in the operation (refer to section 3.2.2)

Each operating sequence will be coded using a single identifier within the analysis that will follow the scheme OS[nnn], where [nnn] is a correlative number between 001 and 999.

3.2.2. Developing Narrative Task Descriptions

A task description is a statement of basic task requirements, proceeding from general task description statements to specific display, control, and decision-activity details. The level of detail required for specifying task activities is about the same as those in an instruction manual for a novice. To prevent ambiguity and ensure consistency in development of narrative Task Descriptions, criteria for descriptions in Task Analysis, presented in Table 1 are applied. These criteria are applied throughout the entire TA process. Tasks may be classified as actions, perceptual-motor activities, or straight monitoring, communicating, decision-making, or problem-solving activities.

Table 1: Criteria for descriptions in Task Analysis

Requirement	Task statement	Example
Clarity	Use wording that is easily understood.	Use words like “Compare written description to actual performance”. Don’t use “Relate results to needs of fields.”
	Be precise so it means the same thing to all personnel.	Don’t use words such as “check, coordinate, assist”, they are vague.

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Requirement	Task statement	Example
	Write separate specific statements for each. Avoid combining vague items of skill, knowledge, or responsibility.	Use clear statements such as “Supervise file” or “Maintain files”. Avoid general statements such as “Have responsibility for maintaining files.”
Completeness	Use abbreviations only after spelling out the term.	“Human-System Interface (HSI)” or “Complete Task Description Worksheet (Form No. XXX).”
	Include both form and title number when the task is to complete a form, unless all that is needed is the general type of form.	
Conciseness	Be brief.	“Write production and control reports.” Avoid statements such as “Accomplish necessary reports involved in the process of maintaining production and control procedures.”
	Begin with a present-tense action word (subject “I” or “you” is understood).	“Clean” or “Write.”
	Indicate an object of the action to be performed.	“Clean engine.” Or “Write report.”
	Use terminology that is currently used on the job.	Use most recent industry documentation.
Relevance	Do not state a person’s qualifications.	Do not use “Has one-year computer training.” Instead use “Load computer tapes.”
	Do not include items on receiving instructions, unless actual work is performed.	Do not use “Attend lecture.” Instead use “Prepare lab report.”

Tasks within each operating sequence are coded as [OpSeq]-T[nn], where [OpSeq] is the operating sequence identifier and [nn] is a correlative number between 01 and 99 that restarts in each operating sequence.

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Once all tasks necessary for a system to fulfill a function have been identified, the tasks are decomposed into individual activities. An individual activity is defined as a single action performed by the operator contributing to the completion of a task.

The definition of the individual activities will be based on:

- Operational experience
- Data from the manufacturers of the equipment and components
- Technical design characteristics of the equipment and components
- System design information (System Design Descriptions, piping and instrumentation diagrams, process diagrams, logic diagrams, etc.)
- Technical Specifications
- Procedures used in earlier HTGR plants as applicable

Activities will be coded as [OpSeqT]-A[nn], where [OpSeqT] is the corresponding task identified and [nn] is a correlative number between 01 and 99 that restarts in each task.

Each activity will be associated with its active component (e.g., plant component). An assessment will be carried out to establish the requirements for the human-system interface design that ensure a successful performance of the activity. The requirements will be classified into three options, not mutually exclusive:

- Control - if the operator must operate the component
- Indication - if the operator must be aware of the component status or value to perform the activity
- Alarm - if the operator must be alerted to an abnormal component situation during the activity.

Once all the tasks and activities are defined in the operating sequence, each task will be evaluated to determine communication requirements with personnel outside the main control room to ensure successful task performance. In the same way, the need of job performance aids will be also determined.

3.2.3. Developing Detailed Task Descriptions

TA is a continuation of the FRA, providing details about the inputs, actions/decisions (throughputs), and outputs involved in implementing a function. Particular attention is given to describing decision-making tasks, ensuring all data needed for performance of these tasks is defined. As in the FRA, the detailed task descriptions specify the subsystems impacted by operations personnel actions, helping to define the dynamic response needed from instruments, displays, and indicators for operations personnel to perform assigned tasks successfully. Because TA supports the HSI detailed design process and the evaluation of control room equipment, the focus is on establishing operations personnel action-decision relationships, and the instrumentation, control, and equipment requirements for actions and decision-making.

Detailed task descriptions are developed for operating sequences which affect plant safety while applying a graded approach to the TA. Therefore, tasks required to fulfill *important operating sequences* identified in the Treatment of Important Human Action process (refer to TIHA IP [11]) will be thoroughly described.

Detailed task descriptions provide:

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- Information required (parameters, units, precision, accuracy)
- Information source (alarms, displays, verbal communication, etc.)
- Actions to be taken
- Overlap of task requirements (serial vs. parallel tasks)
- Frequency
- Time available for operator response based on the plant response characteristics
- Temporal constraints (task ordering)
- Tolerance and accuracy
- Operational limits of personnel performance, and of machine and software
- Feedback required to indicate adequacy of the actions taken
- Cognitive and physical workload
- Tools and equipment required
- Computer processing support aids
- Workspace location
- Number of personnel, their technical specialty, and their specific skills
- Communication required, including type
- Personnel interaction when more than one person is involved
- Job aids or reference materials required

To develop detailed task descriptions, activities within a task will be grouped in *steps*. A step is a sequence of related activities that must be performed uninterruptedly. Steps are assigned to a single operator. Each step will be coded using a single identifier within the analysis that will follow the scheme [OpSeq]-S[nnn], where [OpSeq] is the operating sequence ID and [nnn] is a correlative number between 001 and 999 that restarts in each OS.

Data collected in the detailed task descriptions enable the analyst to:

- Identify information and control requirements forming the basis for specification of the detailed design requirements for controls, displays, alarms, and data processing needed to carry out the tasks.
- Maintain human performance requirements within human capabilities.
- Provide input to development of personnel staffing and qualifications, training, procedures, and communications requirements.

In addition, data collected in the detailed task descriptions provide:

- The means to easily translate the step-by-step format of the TA into a procedure.

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- The basis for updating the Human Reliability Analysis, investigating the probability of human error, and evaluating the consequences resulting from such errors.
- Control and information requirements for determining the type of equipment, hardware, and software necessary in the overall HSI design, and identifying the plant parameters monitored or manipulated to accomplish the tasks.
- Lists of the components, controls and indications, enabling analysis of whether sufficient indication is given when a control is manipulated.
- Sequential accumulation of task times, enabling evaluation of the capability of operations personnel to perform all assigned tasks in the time required for maintaining plant safety and availability.
- Information required for derivation of a link analysis, helping to achieve a near-optimal design for the workplace and avoiding congestion of personnel activities.

3.3. OUTPUTS

Main outputs derived from the methodology implementation are all the related operating sequences subject to analysis and the overall set of tasks and activities required to fulfil them.

Associated to each operating sequence, task and activity, related data (refer to section 3.2 for details) will be gathered that allows for a better evaluation of the results by the analyst.

Among other conclusions, the TA will comprise the following information:

- Identification of personnel tasks needed
- Description of tasks previously identified, including a narrative of the activities to be performed, and the alarms, information, controls, and task support needed to accomplish the task
- Relationship between tasks
- An estimate of the time needed to perform each task
- An estimate of the people needed
- Designation of the knowledge and abilities needed

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4. DOCUMENTATION

All the information and data resulting from the development of the activities of this element shall be recorded in a software tool, which will be shared among all activities within the HFE Program. Using this single tool enables the HFE team to share common information and reduces the likelihood of making mistakes while performing HFE activities.

The tool consists of a relational database and an interface with the user. The database is configured in such a way that data within the same element and from different ones are related as described in the corresponding IPs. The interface allows for entering new or modifying existing data in a user-friendly way. Through the interface, users can perform queries to the database to extract pieces of information in a human-readable format.

Furthermore, a Results Summary Report will be prepared. This report will address results collected on the different steps of the methodology. It will also present the most relevant conclusions drawn from the TA and provide a summary of the general knowledge and abilities needed in the performance of tasks from an overall perspective.

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5. APPENDICES

5.1. APPENDIX A: COMPLIANCE CHECKLIST

Table 2 details the specific requirements defined in NUREG-0711 [1] related to the criteria that the TA activities shall meet. It also provides the reference to this IP where the corresponding requirement is addressed and explained to facilitate the development of TA activities.

Table 2: NUREG-0711 compliance list

NUREG-0711 reference	Requirement	IP reference
5.4 (1)	The scope of the applicant's task analysis should include: • All important HAs as determined by probabilistic and deterministic means. • The applicant should select tasks for analysis that represent the full range of plant operating modes, including startup, normal operations, low-power and shutdown conditions, transient conditions, abnormal conditions, emergency conditions, and severe accident conditions. The chosen tasks should cover: - tasks that were not identified as "important HAs" but have negative consequences if performed incorrectly - tasks that are new compared to those in predecessor plants, such as ones related to new systems or procedures - tasks that, while not new, are performed significantly differently from predecessor plants - tasks related to monitoring of automated systems that are important to plant safety, and the use of automated support aids for personnel, such as computer-based procedures - tasks related to identifying the failure or degradation of automation, and implementing backup responses - tasks anticipated to impose high demands on personnel, e.g., little time or high workload (such as administrative tasks that contribute to workload and challenge ability to monitor the plant) - tasks important to plant safety that are undertaken during maintenance, tests, inspections, and surveillances - tasks with potential concerns for personnel safety (such as maintenance tasks performed in the containment)	3.1 3.2.1 3.2.3

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NUREG-0711 reference	Requirement	IP reference
5.4 (2)	The applicant should describe the screening methodology used to select the tasks for analysis, based on criteria specifically established to determine whether analyzing a particular task is necessary.	3.2.1 3.2.2 3.2.3
5.4 (3)	The applicant should begin task analysis with detailed narratives of what personnel have to do. The analysis should be sufficiently detailed to define the alarms, information, controls, and task support needed to accomplish the task. The detailed task descriptions should address (as applicable to the task) the topics listed in Table 5-1.	3.2.3
5.4 (4)	The applicant should identify the relationships among tasks.	3.2.3
5.4 (5)	The applicant should estimate the time required to perform each task.	3.2.3
5.4 (6)	The applicant should identify the number of people required to perform each task.	3.2.3 (Note 1)
5.4 (7)	The applicant should identify the knowledge and abilities required to perform each task.	3.2.3 (Note 2)
5.4 (8)	The applicant's task analysis should be iterative and updated as the design is better defined.	3.2
5.4 (9)	Applicants should provide an analysis of the feasibility and reliability for important HAs that address the following: • The analysis establishes the time available using an analysis method and acceptance criteria consistent with the regulatory guidance associated with the actions. The basis for the time available is documented. • The analysis of the time required is based on a documented sequence of operator actions (based on task analysis, vendor-provided generic technical guidelines for emergency operating procedure development, or plant-specific EOPs, depending on the maturity of the design). • Techniques to minimize bias are used when estimates of time required are derived using methods that are dependent on expert judgment. Uncertainties in the analysis of time required are identified and assessed.	3.2.1 3.2.2 3.2.3

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NUREG-0711 reference	Requirement	IP reference
	• The sequence of actions uses only alarms, controls, and displays that would be available and operable during the assumed scenario(s). • The estimated time for operators to complete the credited action is sufficient to allow successful execution of applicable steps in the EOPs. • Staffing for analysis is justified, and if credited manual actions require additional operators beyond the assumed staffing, the justification for timely availability of the additional staffing is provided and the estimate of time required includes any time needed for calling in additional personnel. • The analysis of the action sequence is conducted at a level of detail sufficient to identify individual task components, including cognitive elements such as diagnosis and selection of appropriate response. • The analysis identifies a time margin to be added to the time required and the basis for the adequacy of the margin.	
5.4 (10)	Additional Considerations for Reviewing the HFE Aspects of Plant Modifications.	N/A

Note 1. The staffing will be thoroughly assessed in the Staffing & Qualification analysis, as stated in NUREG-0711 [1].

Note 2. The staffing qualification will be thoroughly assessed in the Staffing & Qualification analysis, as stated in NUREG-0711 [1].

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Enclosure 6

Xe-100 Staffing and Qualifications Implementation Plan

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Xe-100

Staffing and Qualifications Implementation Plan

Configuration Classification	:	**XE00-R-R1ZZ-RDZZ-X**
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Status	:	**Approved**
Issue Date	:	**21-May-2021**
Project	:	**Xe-100**
Project Phase	:	**Concept**

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SYNOPSIS

This document provides the methodology to be followed to perform the Staffing and Qualifications element of the Human Factors Engineering Program.

CONFIGURATION CONTROL

Document Change History

Rev.	Date	Preparer	Changes
0A	27-Apr-2021	Hector Martinez-Pinna	Initial issue
1	21-May-2021	Hector Martinez-Pinna	Typos correction and minor changes

Document Approval

Action	Designation	Name	Signature	Date
Preparer	Tecnatom, Senior Human Factors Engineer	Hector Martinez-Pinna	DocuSigned by: Hector Martinez-Pinna 31F691A6CD5B488...	5/24/2021 | 12:22 PM EDT
Reviewer	Tecnatom, Human Factors Principal Engineer	Richard Gutierrez	DocuSigned by: Richard Gutierrez A36744F44A30427...	5/24/2021 | 12:59 PM EDT
Reviewer	Tecnatom, Project QA Engineer	Santiago Lucas	DocuSigned by: FAEE967DCC7F49D...	6/2/2021 | 1:45 AM EDT
Reviewer	Senior Operator Training Engineer	Gregg Crannick	DocuSigned by: Gregg Crannick 3FA08AA7EDBD4BC...	6/2/2021 | 7:57 AM EDT
Reviewer	Senior Human Factors Lead	Paul Hippely	DocuSigned by: Paul Hippely 1AAE19CE8E784BD...	6/2/2021 | 8:00 AM EDT
Approver	Operator Training Simulator Manager	Yvotte Brits	DocuSigned by: Yvotte Brits E24E75C19AFA4BB...	6/2/2021 | 7:15 AM PDT

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ABBREVIATIONS

This list contains the abbreviations used in this document.

Abbreviation or Acronym	Definition
AOF	Allocation Of Functions
ANS	American National Standard
ANSI	American National Standard Institute
AOF	Allocation of Functions
CFR	Code of Federal Regulation
CNSC	Canadian Nuclear Safety Commission
FA	Function Allocation
FRA	Functional Requirements Analysis
HA	Human Action
HFE	Human Factors Engineering
HFEITS	Human Factors Engineering Issue Tracking System
HRA	Human Reliability Analysis
HSI	Human-System Interface
HTGR	High Temperature Gas-cooled Reactor
IHA	Important Human Action
IP	Implementation Plan
ISV	Integrated System Validation
NRC	(United States) Nuclear Regulatory Commission
OER	Operating Experience Review
PMP	Project Management Plan
PRA	Probabilistic Risk Analysis
S&Q	Staffing and Qualifications
TA	Task Analysis
TIHA	Treatment of Important Human Actions
V&V	(Human Factors) Verification and Validation

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DEFINITIONS

This list contains the terms of glossary used in this document.

Term	Definition
Element	From NUREG-0711 [1] the four general activities are separated into the following twelve elements: • HFE Program Management • Operating Experience Review • Functional Requirements Analysis and Function Allocation • Task Analysis • Staffing & Qualifications • Treatment of Important Human Actions • Human-System Interface Design • Procedure Development • Training Program Development • Human Factors Verification and Validation • Design Implementation • Human Performance Monitoring
Implementation Plan	Document that describes the proposed methodology for conducting an HFE element and is reviewed by the NRC staff to reasonably assure that it will generate acceptable results that satisfy the staff's review criteria.
Results Summary Report	Document that summarizes the results of a completed HFE element and cites documents or files that contain the complete results.

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1. INTRODUCTION

The Xe-100 nuclear reactor is an innovative design that is categorized as a Small Modular Reactor (SMR) due to its relatively low power, 200 MWt or 80 MWe. Its design allows for the fabrication and testing to be performed in a factory environment, so that it can be shipped to a site where it is installed as a single component. From a technological and regulatory point of view, the Xe-100 is a High Temperature Gas-cooled Reactor (HTGR) cooled by helium and moderated by graphite, implementing features that make the reactor inherently safe.

The plant configuration consists of four Xe-100 reactors, whose design is optimized since each unit shares like systems. The main purpose of a Xe-100 plant is to safely convert nuclear energy to electricity, in addition, the plant design accommodates multiple missions such as process heat applications.

As required by the licensing process and NUREG-0711 [1], a Human Factors Engineering (HFE) Program shall be developed[1], with proven systematic analysis techniques to address human factors issues within the design process. The HFE program and its products reflect state-of-the-art human factors principles.

As described in the HFE Program Management Plan (HFE PMP) [12], one of the first steps in the HFE Program is the preparation of Implementation Plans (IPs) that describe the proposed methodology for the performance of a specific HFE program element.

In accordance with NUREG-0711 [1] an IP provides an opportunity to obtain a review and concurrence from the regulatory staff of the proposed methodology before performing the work associated with the element. This early review is desirable, because it offers the staff an opportunity to identify potential issues with the methodology and to provide the Xe-100 design team with early input to the analysis or design processes, when staff concerns can more easily be addressed, rather than when the element has been completed.

1.1. PURPOSE

The purpose of this document is to describe the methodology to be followed in the development of the fifth element of NUREG-0711 [1], Staffing and Qualifications (S&Q), to establish the staffing level needed for the control room that ensures safe plant operation and also defines the personnel qualifications required for that staff.

The operations staff for the Xe-100 plant, in addition to performing monitoring tasks, will also be expected to perform predefined maintenance tasks when they are not on shift. These maintenance activities, to be defined, will be performed when the operator staff is not participating in any planned training.

Operations personnel staffing levels and qualifications are important considerations throughout the Human-System Interface (HSI) design process. The initial baseline staffing level is established based on experience with HTGR predecessor plants, X-energy staffing goals, and regulatory staffing requirements for nuclear reactors. S&Q development activities include re-examination of the initial baseline staffing assumptions during the Function Allocation (FA), Task Analysis (TA), Treatment of Important Human Actions (TIHA), and HSI Design activities.

[1] Refer to 10 CFR 50.34 (f)(2)(ii), 10 CFR 50.34 (f)(2)(iii) [4], and REGDOC-2.2.1 [2], Human Factors.

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Structure, content, and details of the Xe-100 plant's Training Program and Procedures are verified and validated during the HSI design process in accordance with the proposed staffing level and qualification requirements.

Modifications in the Xe-100 plant HSI design, including introduction of advanced HSI technologies, can potentially decrease the number of operations personnel required in the Main Control Room (MCR), as well as potentially increase the skill levels required of the Xe-100 plant HSI maintenance personnel. Tasks with no direct interface to safety-related functions may be screened from the staffing level and qualification development process.

With the goal of the Xe-100 plant being that the staffing requirements will be reduced in both control room operations and maintenance from the legacy nuclear power plants, the HFE design team will use both 10 CFR 50.54 [5] with added guidance from NUREG-1791 [9] as input to validate the staffing size.

1.2. SCOPE

This IP applies to the S&Q that will be performed as part of the HFE Program for the HFE licensing of the Xe-100 plant design. This IP is implemented in accordance with the criteria as defined in the HFE PMP [12].

The proposed S&Q IP will be supported by the results of the Functional Requirements Analysis (FRA) and FA, TA, and the job definitions for each position required under the operational conditions considered.

The HFE S&Q development activity focuses on operations and maintenance personnel related to actual plant operation. The following personnel are not included in the HFE S&Q development activity:

- administration
- security
- training
- engineering
- fire/hazard response
- personnel necessary for planning and conducting work for planned outages
- personnel necessary for handling and storage of new or spent fuel and radioactive materials
- access monitoring
- local services
- other

1.3. RELATIONSHIP TO OTHER DOCUMENTS

This IP is part of the HFE Program described in the HFE PMP [12], which includes high-level considerations that shall be known by the reader of this IP. Other HFE Program elements are related to the S&Q; therefore, the IPs of these elements are cross-referenced where needed. Figure 1 shows relationships between S&Q IP and other documents within the HFE Program.

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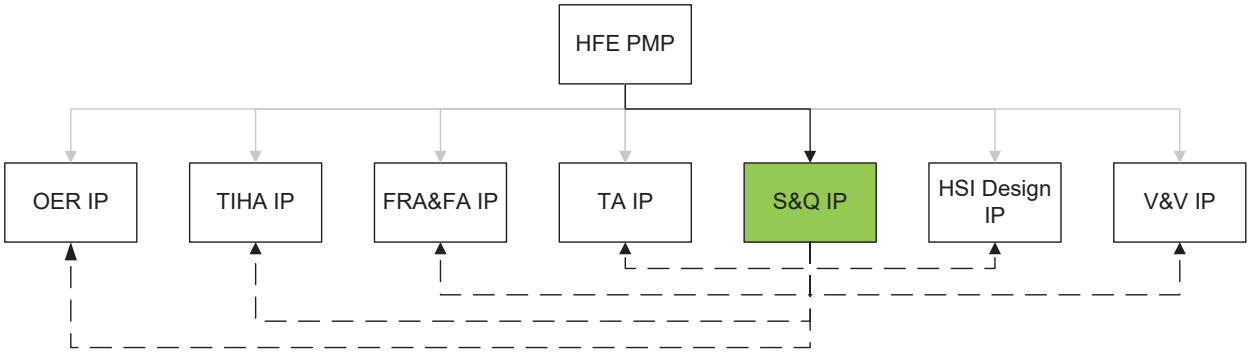

Figure 1: Relationship of S&Q IP to other documents within the HFE Program

1.4. DOCUMENT LAYOUT

This IP is formatted as follows: Section 1 addresses the document introduction, purpose, scope and relationship to other documents. Section 2 identifies the references used in this IP. Section 3 describes the methodology, from the inputs, through the process and the expected outputs. Section 4 addresses how the outputs shall be documented. Section 5 includes as an appendix a checklist to verify compliance of this IP with the corresponding NUREG-0711 [1] review criteria.

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2. REFERENCES

The following documents are referenced within this document.

	Document Title	Preparer/Author	Document Number	Revision or Date of Issue	Classification	Applicable[2] (Yes/No)
[1]	NUREG-0711, Human Factors Engineering Program Review Model	NRC	N/A	Rev 3	N/A	Yes
[2]	REGDOC-2.2.1, Human performance management Human Factors	CNSC	N/A	2019	N/A	Yes
[3]	REGDOC-2.2.5, Minimum Staff Complement	CNSC	N/A	2019	N/A	Yes
[4]	10 CFR 50.34, Contents of applications, technical information	NRC	N/A	2019	N/A	Yes
[5]	10 CFR 50.54, Conditions of licenses	NRC	N/A	2021	N/A	Yes
[6]	NUREG-0800, Standard Review Plan for the Review of Safety Analysis Reports for Nuclear Power Plants: LWR Edition, Chapter 13, “Conduct of Operations”	NRC	N/A	2016	N/A	Yes
[7]	NUREG-0800, Standard Review Plan for the Review of Safety Analysis Reports for Nuclear Power Plants: LWR Edition, Chapter 18, “Human Factors Engineering”	NRC	N/A	2016	N/A	Yes
[8]	NUREG/CR-7126, Human-Performance Issues Related to the Design and Operation of Small Modular Reactors	NRC	N/A	2012	N/A	Yes
[9]	NUREG-1791, Guidance for Assessing Exemption Requests from the Nuclear Power Plant Licensed Operator Staffing Requirements Specified in 10CFR50.54(m)	NRC	N/A	2005	N/A	Yes

2 Applicable documents are applicable to the extent specified within this document and thus deemed to form part of this document.

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	Document Title	Preparer/Author	Document Number	Revision or Date of Issue	Classification	Applicable[2] (Yes/No)
[10]	NUREG/CR-6838, Technical Basis for Regulatory Guidance for Assessing Exemption Requests from the Nuclear Power Plant Licensed Operator Staffing Requirements Specified in 10 CFR 50.54(m)	NRC	N/A	2004	N/A	Yes
[11]	SECY-11-0098, Operator Staffing for Small or Multi-Module Nuclear Power Plant Facilities	NRC	N/A	2011	N/A	Yes
[12]	TEC-XE100-HFE-PMP, Human Factors Engineering Program Management Plan	Tecnatom	N/A	Rev 0	N/A	Yes
[13]	TEC-XE100-HFE-COO, Concept of Operations	Tecnatom	N/A	Rev 0	N/A	Yes
[14]	TEC-XE100-HFE-TRS, Control Room Staffing Analysis Methodology	Tecnatom	N/A	Rev 0	N/A	Yes
[15]	Operating Experience Review Implementation Plan	Tecnatom	000982	Rev 1	XE00-R-R1ZZ-RDZZ-X	Yes
[16]	Treatment of Important Human Actions Implementation Plan	Tecnatom	000984	Rev 1	XE00-R-R1ZZ-RDZZ-X	Yes
[17]	Functional Requirements Analysis and Function Allocation Implementation Plan	Tecnatom	000985	Rev 1	XE00-R-R1ZZ-RDZZ-X	Yes
[18]	Task Analysis Implementation Plan	Tecnatom	000986	Rev 1	XE00-R-R1ZZ-RDZZ-X	Yes
[19]	Human Factors Verification and Validation Implementation Plan	Tecnatom	000989	Rev 1	XE00-R-R1ZZ-RDZZ-X	Yes
[20]	Xe-100 Plant Staffing Report	X-energy	000077	Rev 3	XE-01-P-X-Z-D	Yes

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3. DEVELOPMENT

The overall role of the HFE design team in the S&Q development activity is illustrated in Figure 2. The HFE design team provides input to the development of the staffing level and qualification requirements. It analyzes the functions and tasks of operations personnel necessary for safe performance of all required plant operations, maintenance, and technical support for each operating mode. It also recommends the staffing numbers and minimum qualifications of plant personnel in terms of education and training, skill, knowledge, and experience. Although this S&Q is focused on the operations staff, activities related to maintenance may have an effect on the operations personnel tasks and qualifications.

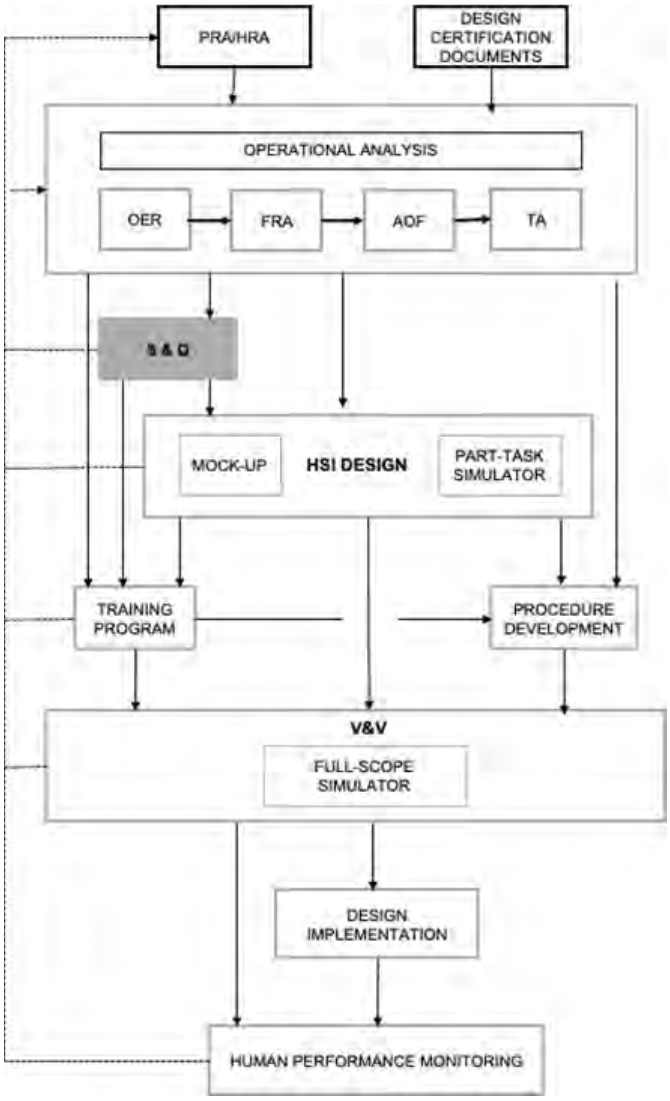

Figure 2: HFE relationship to S&Q development

This section includes a description of main documents required to perform the analysis, followed by a systematic process definition for further developing the element and a collection of the outputs expected.

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3.1. INPUTS

Inputs can be categorized as regulatory documents, HFE Program related elements, and Xe-100 plant documentation. All these are intended to contribute to achieving the purpose of this IP.

3.1.1. Regulatory Inputs

Regulatory criteria applicable to the S&Q element has already been considered to develop this IP but some of them are included in this input list as they might support the literature required to develop the S&Q element.

- NUREG-0800, Chapter 13 “Conduct of Operations” [6], Section 13.1.1, Management and Technical Support Organization. This chapter addresses staffing requirements.
- NUREG-0800, Chapter 18 “Human Factors Engineering” [7]. This chapter provides regulatory guidance, to the NRC, on the review of HFE criteria incorporation into the plant design process and incorporates, as Attachment B, “Methodology to Assess the Workload of Challenging Operational Condition in Support of Minimum Staffing Level Reviews”, a methodology to identify high-workload operational conditions and analyze the workload associated with them.

In terms of staffing level in the MCR, SMR operation deviates from the conventional. A workload evaluation focused on stage changes, simultaneous unit events, or other high workload potential scenarios is desired.

3.1.2. HFE Program Related Data

As S&Q is part of the Xe-100 plant HFE Program, data, results, and conclusions from other HFE elements of the HFE Program need to be considered while performing S&Q activities. Changes or assumptions made on the HFE elements during the performance of the HFE Program would result in a re-evaluation of the proposed staffing levels.

- Concept of Operations [13] and Plant Staffing Report [20] - Establish an initial staffing level in the MCR and provide information related to the operator´s tasks and key scenarios during the different operating conditions. They might address the basis for staffing and qualification levels.
- Operating Experience Review (OER) - Those operating experiences related to staffing level or qualification issues shall be considered during the S&Q development. Due to the technological features of the Xe-100 plant and its proposed reduced staffing levels, research based on workload, multitasking, multi-module plants, high degree of automation, and monitoring automatic actions are relevant as they might contribute to the staffing level validation. The set of operational conditions from OER data will be considered for the staffing plan.
- Functional Requirement Analysis and Function Allocation (FRA & FA) - Staffing level and their qualification shall be defined in accordance with the functions allocated to personnel for each job position.
- Task Analysis (TA) - Minimum staffing level defined shall be adequate to successfully perform all tasks assigned to the operators in the MCR and other facilities within the scope of the S&Q activity,

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including mentally and physically demanding tasks, multi-tasking or those included as part of challenging operational conditions. Detailed TA results shall be considered as a key input as it includes time needed to perform a task, the workload involved and personnel communication and coordination with other MCR crew members or even other location staff. It also specifies those operations that take place outside the MCR, acting as the basis to establish their location and personnel assigned to them. In relation to the MCR staff qualification, TA provides job requirements resulting from the sum of all tasks allocated to each individual inside and outside of the MCR.

- Treatment of Important Human Actions (TIHA) - This element identifies all Important Human Actions (IHAs), and how they should be treated, from an HFE point of view, in the rest of HFE Program elements. Attention shall be focused mainly on the effect that staffing levels might have on their performance and on personnel coordination for such IHAs. In addition, TIHA includes the overall set of important operating sequences covering all the relevant operational conditions inherent to the Xe-100 plant features.
- Human System Interface (HSI) Design - S&Q analysis considers the layouts proposed in the Concept of Operations[13] as a starting point, but the HSI final configuration shall support the staffing level recommended.
- Human Factors Verification and Validation (V&V) - Verification activities to other HFE Program elements such as HSI Task Support Verification and HSI Design Verification might also have an impact on the staffing level. The V&V results shall be reviewed for impact to the proposed staffing levels and qualifications. Prior to the availability of the full scope simulator, a part-task simulator and mock-up may be used to perform a preliminary evaluation of the proposed staffing level. At a later stage, the initially proposed staffing level will be validated using a simulator during the Human Factors Integrated System Validation (ISV) to ensure the staffing level established and qualifications are sufficiently enough to manage the plant during differing operating conditions. If required, staffing level shall be revaluated once V&V results are available.

3.1.3. Xe-100 Plant Specific Inputs

If required, to obtain more detailed information, specific plant documents may be consulted. These documents range, among many others, from control philosophy type to control room layouts or specific system logic diagrams.

3.2. METHODOLOGY

The methodology described in this section is aimed to support and guide the S&Q analysis. It is characterized by a systematic approach, namely the different stages of the methodology are intended to be followed in the order in which they are presented.

Figure 3 presents a high-level representation of the S&Q process to be followed during the S&Q analysis development. Each of the stages are further detailed in subsequent sections.

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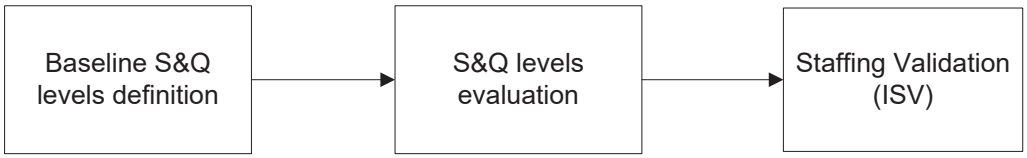

Figure 3: S&Q development process

Furthermore, as explained in the HFE PMP [12], to comply with NUREG-0711 [1] part of the analysis should be iterative; that is, the initial staffing goals are defined for the personnel in the MCR and then shall be re-evaluated as information from other HFE elements becomes available, until the ISV is completed and the staffing level is validated.

3.2.1. Baseline S&Q Levels Definition

The first stage defines preliminary S&Q level goals in the control room to be used as a starting point for the rest of the HFE Program elements development. The objective is to establish a baseline staffing level and associated qualifications for operations personnel performing tasks involving safety-related functions during the full range of plant operations, including:

- Startup
- Normal power operations
- Abnormal operations
- Low power operations
- Shutdown conditions
- Emergency operations
- Transient events included in the plant design basis
- Predefined maintenance of plant systems, including the HSI in the MCR; and
- Testing of plant systems, including Surveillance Testing

In addition to the expertise of the subject matter experts, baseline S&Q levels definition shall be based on previous SMR operating experience, the use of automation in the plant and the passive safety features incorporated into the Xe-100 plant design. The HFE team may also rely on information provided from experiences at oil and gas plants as they may have experience with automation as it relates to staffing, qualifications, and training.

3.2.2. S&Q Levels Evaluation and Refining

Initial S&Q levels will be used as a reference during the development of other HFE Program elements. Thus, the goal of this stage is to confirm the initial assumptions are valid or conversely, lead to an adjustment of the initial S&Q levels to satisfy the final goal, which is ensuring safe and reliable plant operation.

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The initial baseline staffing levels are based on the established staffing levels in the Concept of Operations [13]. Staffing levels and associated qualification requirements are evaluated through systematic examination of operating experience, identified functions, assigned tasks, and manual action risk-importance. Recommended staffing levels and qualification requirements are reflected in the HSI detailed design. Throughout the S&Q development process, staffing level and qualification requirements compliance with the requirements of 10 CFR 50.54 (m) [5] will be considered.

The evaluation process involves screening manual tasks for importance to plant safety. The focus of HFE Program activities, in support of the HSI design process, is management and control of plant safety for those key human actions allocated to operations personnel. Everyone who works in a nuclear power plant has a role in plant safety from a safety culture perspective. However, some operations personnel have a major role in protecting public safety when responding to events, while others must address their own personal safety.

The next step in the evaluation process is refinement of the staffing level and qualification requirements for the HSI design. The number and capabilities of operations personnel interacting with the HSIs must be adequate to provide safe operation under design basis and risk-important accident conditions. To meet this goal, consideration is given to the numbers and functions of the operations personnel needed to safely perform all required Xe-100 plant operations, and technical support for each operating mode, and to the minimum qualifications of plant personnel in terms of education and training, skill, knowledge, experience, and fitness for duty. This refinement includes verifying that information is easily available through the HSIs under various postulated accident conditions and potential plant situations and verifying feedback from corrective actions is available.

To support the evaluation and determine whether the initial S&Q levels are correct, at an early stage, the focus will be on the available HFE Program elements results. As soon as new plant information or staffing tests results become available, subsequent iterations of the evaluation shall be performed.

Adequacy of the recommended staffing levels and qualification requirements for successfully using the HSI design is demonstrated by confirming the following:

a. The staffing level is adequate to meet operations and accident demands resulting from the locations and use, especially concurrent use, of available controls and displays.

b. The HSI design supports coordinated actions between individuals at different strategic locations.

c. The HSI design provides timely information, accessible to and selected as needed by qualified personnel.

d. The physical configuration of the MCR and control consoles supports the organization and number of recommended shift operations personnel.

e. The Xe-100 plant information presented on both individual workstations and group-view interfaces are available during transient events to the shift operations personnel, as well as to the Technical Support Center and Emergency Operations Facility, if applicable.

As illustrated by Figure 4, adequacy of the recommended staffing level and qualification requirements are systematically evaluated during procedure and training program development. The evaluation of data collected may result in recommendations or changes to the initial staffing level, so that the new number

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of staff proposed shall be re-evaluated. The affected HFE Program elements will also be reviewed and revised accordingly.

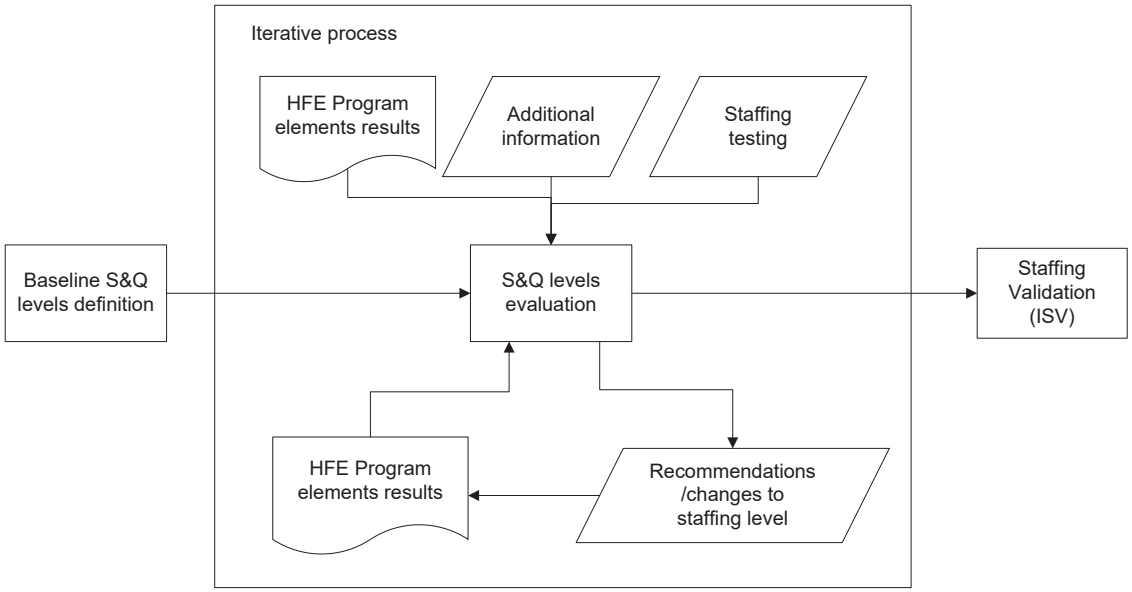

Figure 4: Detail of S&Q levels evaluation stage

The impact of alternative changes to the baseline staffing levels and qualification requirements are evaluated, and adjustments are made, where appropriate, to the Human Reliability Analysis (HRA) assumptions and quantification. Although this task is not part of the HFE Program, the HRA accident sequence models should be re-evaluated to assess associated changes in the risk importance of key human actions. If this assessment is positive, and changes to important human actions are identified, they shall be considered in the HFE Program through the TIHA element.

The output of this iterative stage is a final S&Q level which will be further validated once the simulator and qualified operators are available.

The following sections describe in greater detail how such inputs, HFE Program elements results, additional plant information, and staffing tests results shall be considered to evaluate the initial S&Q level established.

3.2.2.1. Results from HFE Program Elements

HFE Program elements results provide crew task performance related information required to evaluate the initial proposed S&Q level. This section describes, for each HFE Program related input, which information shall be analyzed to determine the number of personnel in the control room, their qualifications, roles, and responsibilities for the safe operation of the Xe-100 plant.

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3.2.2.1.1. Operating Experience Review

The innovative design of the Xe-100 plant implies a lack of a wide variety of predecessor plants with similar features. Therefore, as SMRs in operation do not represent an outstanding collection of operational matters, other industries with similar concept of operations might be considered for such purpose.

The evaluation of available operating experience and existing regulatory criteria have been considered as input in defining the initial Xe-100 S&Q levels. In addition to information gathered from applicable HTGR operating experience and commercial industries such as gas and oil, the operating experience takes into account the Xe-100 plant features, such as the implementation of a high degree of automation and inherently stable design. This stage will consolidate such basis and will include other relevant aspects that might have interfered on previous designs associated to the S&Q levels. As the Xe-100 plant design evolves, a bigger collection of applicable operating experience may be identified.

Operating experience shall be reviewed to ensure human performance errors detected at other plants, due to the staffing or qualification level, are properly addressed in the Xe-100 plant with the staffing number initially proposed and their corresponding qualification. This information will be factored into the preliminary design and become a part of the planned testing and evaluation.

Operating experiences based on terms related to the lack of personnel and inadequate communications between the plant staff and emergency response staff during emergency events are evaluated as appropriate.

In addition, initial S&Q level assumptions might be impacted by factors such as high workload, poor situational awareness, or, among others, inattention due to the high degree of automation of the Xe-100 plant.

In summation, operating experiences based on the search concepts for the items mentioned shall be considered. Additional details about the OER process can be found in the OER IP [15].

If the evaluation brings to light the applicable operating experience is not properly addressed during the HFE Program elements development, based on the S&Q levels initially proposed, a new iteration shall be done. That is, as HFE Program elements might be affected, once modified accordingly, the S&Q levels shall be revaluated until they satisfy the Xe-100 plant goals.

3.2.2.1.2. Treatment of Important Human Actions

TIHA provides a list with all the IHAs that will be later addressed in the TA. S&Q evaluation shall determine if the operator is able to conduct all the assigned IHAs in a reliable and feasible way and point out the existence of any issue affecting the performance of the IHAs due to the initial staffing level considered.

Details about the TIHA process can be found in TIHA IP [16].

3.2.2.1.3. Functional Requirement Analysis and Function Allocation

During the FA development, system functions and operating alignment changes will be performed automatically, manually, or as a combination of both. If human allocation is defined for certain functions, the operator assumes the overall control with no automatic support, unlike automatically based functions, where the operator performs a supportive role, monitoring the plant and systems, ready to intervene if

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required. The role of the operator in a monitoring and/or control role shall be clearly identified. Details about the FA process can be found in the FRA & FA IP [17].

During the S&Q levels evaluation, all allocations demanding human actions shall be in accordance with the corresponding operator qualification level. If mismatches are identified during this stage, both the staffing level and the operator's qualifications initial proposal shall be reviewed accordingly.

The roles and responsibilities of operations personnel depend on the selection of automatic versus manual operations during the allocation of functions. Increased automation results in reduced requirements for human decision-making and manual operation, while increased sophistication of advanced technologies can result in increased qualifications required of operations and maintenance personnel. Changes to the roles of personnel, due to Xe-100 plant system and HSI design modifications, can result in mismatches between functions and tasks allocated to personnel and the qualifications of those personnel. The S&Q development activity identifies and corrects such mismatches by conducting a review and reevaluation of the function allocation, or by adjusting the qualifications required of the personnel. It may be necessary to review the training program to see if the mismatch can be corrected through augmented training. The goal being to address the mismatch.

3.2.2.1.4. Task Analysis

The results obtained in the TA regarding the operating sequences related to safety-related operations shall be used as an input. In those operating sequences, the duration of tasks may be a critical factor for the later design of the interface as established in the TA IP [18], therefore, the analysis includes an assignation of operators to task, an estimation of task duration, and the relationship among tasks.

In the S&Q evaluation, the operating sequences from the TA shall be evaluated in terms of:

- Time available for sequences execution - determines if the duration of the operating sequences exceeds the time available
- Operator´s workload - identifies if an operator must perform a set of consecutive tasks that exceed the time in which he/she can maintain focused

In addition, S&Q input from the Task Analysis includes:

- Knowledge, skills, and abilities required to meet personnel task performance requirements
- Operations personnel response time requirements and workload assessments
- Personnel communication and coordination requirements, including interactions between personnel for diagnosis, planning, and control activities, and interactions between personnel for administrative, communications, and reporting activities
- Job requirements resulting from the sum of all tasks allocated to each individual, both inside and outside the MCR
- Ability of personnel to coordinate work activities through the HSIs: for example, directing local valve control from a remote display monitor and
- Availability of personnel, considering other ongoing activities operations personnel may take on as responsibilities outside the MCR.

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3.2.2.2. Additional information

As the Xe-100 plant design, including HSI design, evolves and new information is available, it shall be determined whether the S&Q levels are still appropriate, or a new iteration of the evaluation shall be performed. Below are examples of such information:

- New plant information might be available (e.g., new shared systems functionalities, description, etc.)
- Training Program Development might also face issues related to the coordination of the personnel. If so, they shall be considered during this stage, as its conclusions might impact the number of personnel initially established. In relation to personnel qualification, the Training Program provides staff qualification (in terms of knowledge, skills, and abilities) associated with each job position, obtained following a Systematic Approach to Training. This method uses task descriptions provided by TA. Such qualifications per each job position is validated during ISV, as illustrated on the V&V IP [19], and its conclusions shall determine whether the initial qualification level remains valid to fulfill all the tasks or conversely, if new requirements need to be considered to satisfy the overall set of the tasks assigned.
- Outputs from the HFE integration into the Procedure Development may impact S&Q results as well in terms of staffing demands resulting from requirements to concurrently use multiple procedures, or different personnel knowledge and abilities identified in the procedures.

All S&Q HFE-related issues, including HEDs, are a result of the evaluation of any of the aforementioned data and results and shall be tracked in the HFE Issues Tracking System (HFEITS) for a later resolution during successive iterations.

3.2.2.3. Staffing Testing: Partial Validation

In addition to the staffing validation presented in the next stage of this methodology, supportive tests may be performed on Xe-100 MCR mockup and/or part-task simulators to provide a more accurate preliminary staffing level proposal at an early stage of the design phase.

The staff used to perform the S&Q partial validation should comprise of operators that have experience at conventional plants and some staff that may have at least a working knowledge of the Xe-100 plant design.

The performance of the S&Q partial validation is subject to the fidelity of the mockup and other limiting conditions, such as the use of preliminary HSIs. In addition, S&Q partial validation is limited by personnel training and availability. It may be beneficial to use preliminary testbeds in gathering data demonstrating the time and timing of events, available control personnel response times, and identifying any human performance limitations requiring further evaluation in terms of staffing level. This includes any identified IHA.

Unlike the formal V&V activities, which are performed by an independent HFE team, the S&Q partial validation, at this stage, may be performed by the HFE design team in charge of defining the initial S&Q levels.

A set of sampling scenarios shall be reproduced in the S&Q partial validation, identified using the methods described in the V&V IP [19]. Sampling scenarios shall cover, but are not limited to, quite restrictive and

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challenging operational conditions for the operators of the Xe-100 plant. These include among others, multitasking, high workload, multiunit events, common systems failure, and high degree of coordination.

3.2.3. Staffing Validation: Integrated System Validation

The ISV, unlike the S&Q partial validation, is carried out over a consolidated design once the complete simulation environment is ready, including the control room crew.

The staffing validation takes part of the overall set of activities within the ISV framework, and its assessment shall demonstrate that the Xe-100 plant proposed crew level satisfies the plant and human performance requirements identified in the FRA, FA, and TA. This assessment shall include a wide range of operational conditions identified as relevant in terms of human performance.

Therefore, the demonstration is done through simulations that involve the operators and operating experience contribution. The process and methodology for the human-in-the-loop simulations will be described further in the V&V IP [19].

3.3. OUTPUTS

The main output, and thus the goal after the methodology implementation, is the determination of a minimum staffing and the qualification levels required for a safe and reliable Xe-100 plant operation.

As the methodology process progresses, intermediate outputs, associated with its different stages are also expected. The following further explains some of the outputs in this process:

- Baseline S&Q levels definition
  - An initial minimum staffing and qualification levels that constituted the basis for the S&Q analysis
- S&Q levels evaluation and refining
  - An analysis of which HFE Program related inputs are used in the staffing evaluation
  - The assignment of tasks to control room personnel, gathered from the documents or tools that compile the TA data and results
  - A description of necessary qualifications of personnel
  - Final staffing and qualification levels achieved after this element’s implementation, including the required successive iterations.
- Staffing plan validation
  - Staffing plan validation results, that is, a validated minimum staffing number

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4. DOCUMENTATION

The S&Q Result Summary Report shall illustrate a brief description of the S&Q analysis process followed to determine initial and final staffing and qualification levels.

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5. APPENDICES

5.1. APPENDIX A: COMPLIANCE CHECKLIST

Table 1 details the specific requirements defined in NUREG-0711 [1] related to the criteria that the S&Q activities shall meet. It also provides the reference to this IP where the corresponding requirement is addressed and explained to facilitate the development of S&Q activities.

Table 1: NUREG-0711 compliance list

NUREG-0711 reference	Requirement	IP reference
6.4 (1)	The applicant should address the applicable staffing and qualifications guidance in NUREG-0800 Section 13.1.	3.1.1
6.4 (2)	The applicant should address the applicable staffing and qualifications guidance in 10 CFR 50.54.	3.1.1 (Note 1)
6.4 (3)	The applicant should use the results of the task analysis as an input to the staffing and qualification analyses. Personnel tasks, addressed in task analysis, should be assigned to staffing positions to ensure that jobs are defined considering: • the task characteristics, such as the knowledge and abilities required, relationships among tasks, time required to perform the task, and estimated workload • the person's ability to maintain situation awareness within the area of assigned responsibility • teamwork and team processes, such as peer checking	3.1.2 3.2.2 (Note 2)
6.4 (4)	The applicant's staffing analysis should determine the number and qualifications of operations personnel for the full range of plant conditions and tasks, including operational tasks (under normal, abnormal, and emergency conditions), plant maintenance, plant surveillance, and testing.	3.2.2 3.2.3 (Note 3)
6.4 (5)	The applicant's staffing analysis should be iterative; that is, the initial staffing goals should be modified as information from the HFE analyses from other elements becomes available.	3.2
6.4 (6)	The applicant should address the basis for staffing and qualification levels considering the specific staffing-related issues noted below. These considerations may be identified in other HFE elements or in related source documents as follows:	3.2.2 (Note 4)

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NUREG-0711 reference	Requirement	IP reference
	• Operating Experience Review - operational problems and strengths resulting from staffing levels in predecessor designs - initial staffing goals and their bases, including staffing levels of predecessor designs and a description of significant similarities and differences between predecessor and current designs - staffing considerations described in NRC Information Notice 95-48, "Results of Shift Staffing Study" - possible impact on staffing of requirements of limits to work hours, required break times, and required days off, as specified in 10 CFR 26.205, Work Hours, as part of the Fitness for Duty Rule - Regulatory Issue Summary (RIS) 2009-10, Communications Between the NRC and Reactor Licensees During Emergencies and Significant Events • Functional Requirements Analysis and Function Allocation - potential mismatches between functions allocated to personnel and their qualifications - changes to the roles of personnel due to modifying the plant's systems and HFE aspects • Task Analysis - time needed to perform a task, and the workload involved - personnel communication and coordination, including interactions between individuals for diagnosing, planning, and controlling the plant, and interactions between personnel for administrative, communications, and reporting activities - the job requirements resulting from the sum of all tasks allocated to each individual inside and outside the control room - potential decreases in the ability of personnel to coordinate their work due to changes to the plant - availability of personnel considering other work that may be ongoing, and for which operators may be responsible outside the control room (e.g., fire brigade)	

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NUREG-0711 reference	Requirement	IP reference
	- actions identified in 10 CFR 50.47, NUREG-0654, and procedures to implement an initial accident response in key functional areas, as denoted in the emergency plan - staffing considerations described by the application of ANSI/ANS 58.8-1994, "Time Response Design Criteria for Safety-Related Operator Actions" (ANS, 1994), if used by the applicant • Treatment of Important Human Actions - the effect of staffing levels on the performance of the identified important HAs - the effect of staffing levels on personnel coordination for important HAs - NUREG/CR-6753, Review of Findings for Human Performance Contribution to Risk in Operating Events • Procedure Development - staffing demands resulting from requirements to concurrently use multiple procedures - personnel knowledge, abilities, and authorities identified in the procedures • Training Program Development - concerns about coordinating personnel that are identified during the development of training	

Note 1. This IP also refers to NUREG-1791 [9] as it guides the applicant to determine criteria to develop the S&Q level evaluation in accordance with the exemption request.

Note 2. Knowledge and abilities required are determined during the Training Program development following a Systematic Approach to Training, using the TA data and results as input. This ensures proper correspondence between Training Program development and the HFE Program.

Note 3. V&V IP [19] illustrates the methodology to determine the sampling scenarios to validate the staffing plan during the ISV.

Note 4. Procedure Development and Training Program Development are not part of the HFE Program, although information from these tasks are used in the S&Q process.

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Enclosure 7

Xe-100 Treatment of Important Human Actions Implementation Plan

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Xe-100

Treatment of Important Human Actions Implementation Plan

Configuration Classification	:	**XE00-R-R1ZZ-RDZZ-X**
Revision	:	**1**
Status	:	**Approved**
Issue Date	:	**23-Apr-2021**
Project	:	**Xe-100**
Project Phase	:	**Concept**

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SYNOPSIS

This document provides the methodology to be followed to perform the Treatment of Important Human Actions element of the Human Factors Engineering Program.

CONFIGURATION CONTROL

Document Change History

Rev.	Date	Preparer	Changes
0A	31-Mar-2021	Hector Martinez-Pinna	Initial issue
1	23-Apr-2021	Hector Martinez-Pinna	Typos correction and minor changes

Document Approval

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ABBREVIATIONS

This list contains the abbreviations used in this document.

Abbreviation or Acronym	Definition
CDF	Core Damage Frequency
CNSC	Canadian Nuclear Safety Commission
D3	Defense in Depth and Diversity
DIHA	Deterministic Important Human Actions
FA	Function Allocation
FRA	Function Requirements Analysis
HFE	Human Factors Engineering
HFEITS	HFE Issue Tracking System
HRA	Human Reliability Analysis
HSI	Human System Interface
IHA	Important Human Action
IOS	Important Operating Sequence
IP	Implementation Plan
I&C	Instrumentation and Control
MCR	Main Control Room
NRC	(United States) Nuclear Regulatory Commission
OER	Operating Experience Review
PIHA	Potential Important Human Action
PMP	Program Management Plan
PRA	Probabilistic Risk Assessment
RIHA	Risk Important Human Action
SAR	Safety Analysis Report
S&Q	Staffing & Qualifications
TA	Task Analysis
TIHA	Treatment of Important Human Actions
V&V	(Human Factors) Verification and Validation

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DEFINITIONS

This list contains the terms of glossary used in this document.

Term	Definition
Element	From NUREG-0711 [1] the four general activities are separated into the following twelve elements: • HFE Program Management • Operating Experience Review • Functional Requirements Analysis and Function Allocation • Task Analysis • Staffing & Qualification • Treatment of Important Human Actions • Human-System Interface Design • Procedure Development • Training Program Development • Human Factors Verification and Validation • Design Implementation • Human Performance Monitoring
Implementation Plan (IP)	Document that describes the proposed methodology for conducting an HFE element, which is reviewed by the NRC staff to reasonably assure that it will generate acceptable results that satisfy the staff's review criteria.
Results Summary Report	Document that summarizes the results of a completed HFE element and cites documents or files that contain the complete results.
Important Human Action	Human action most important to safety that meets either risk or deterministic criteria.
Important Operating Sequence	Operating sequence that causes undue risk to the nuclear safety or plant availability.

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1. INTRODUCTION

The Xe-100 nuclear reactor is an innovative design that is categorized as a Small Modular Reactor due to its relatively low power, 200 MWt or 80 MWe. Its design allows for the fabrication and testing to be performed in a factory environment, so that it can be shipped to a site where it is installed as a single component. From a technological and regulatory point of view, the Xe-100 is a High Temperature Gas-cooled Reactor (HTGR) cooled by helium and moderated by graphite, implementing features that make the reactor inherently safe.

The plant configuration consists of four Xe-100 reactors, whose design is optimized since each unit shares like systems. The main purpose of a Xe-100 plant is to safely convert nuclear energy to electricity. In addition, the plant design accommodates multiple missions such as process heat applications.

As required for licensing, a Human Factors Engineering (HFE) Program shall be developed[1], with proven systematic analysis techniques to address human factors issues within the design process. The HFE Program and its products reflect state-of-the-art human factors principles.

As described in the HFE Program Management Plan [8], one of the first steps in the HFE Program is the preparation of Implementation Plans (IPs) that describe the proposed methodology for the performance of a specific HFE program element.

In accordance with NUREG-0711 [1], an IP provides an opportunity to obtain a review and concurrence from the regulatory staff of the proposed methodology before performing the work associated with the element. This early review is desirable because it offers the staff an opportunity to identify potential issues with the methodology and to provide the Xe-100 design team with early input to the analysis and design processes, when staff concerns can more easily be addressed, rather than when the element has been completed.

This is the Implementation Plan for the Treatment of Important Human Actions (TIHA), the sixth element of NUREG-0711 [1]. As stated in NUREG-0711 [1], the “Human Reliability Analysis” element was changed to “Treatment of Important Human Actions” and its scope was expanded to address human actions that are identified deterministically or using risk analysis.

1.1. PURPOSE

The purpose of this document is to describe the methodology to be followed in performance of the TIHA. When the work defined by the IP has been completed, a results summary report will be provided. Using the Probabilistic Risk Assessment (PRA), including its Human Reliability Analysis (HRA), risk-important human actions are identified. An HRA evaluates the potential for, and mechanisms of human error that might affect plant safety. It is an essential feature in assuring the HFE program goal of providing a design to minimize personnel errors, support their detection, and ensure recovery capability.

[1] Refer to 10 CFR 50.34 (f)(2)(ii), 10 CFR 50.34 (f)(2)(iii), and REGDOC-2.2.1**,** Human Factors.

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1.2. SCOPE

The scope of this IP is applicable to the human actions that are identified, the review and analysis process to be used in the treatment of the important human actions, and how they are related and interface with other HFE Program elements and for licensing of the Xe-100 plant design. This IP document is under the considerations and limitations established in the HFE Program Management Plan (HFE PMP [8]).

1.3. RELATIONSHIP TO OTHER DOCUMENTS

This IP is part of the HFE Program described in the HFE PMP [8], which includes high-level considerations that shall be known by the reader of this IP. Other HFE Program elements are related to the TIHA; therefore, the IPs of these elements are cross-referenced where needed. Figure 1 shows relationships between TIHA IP and other documents within the HFE Program.

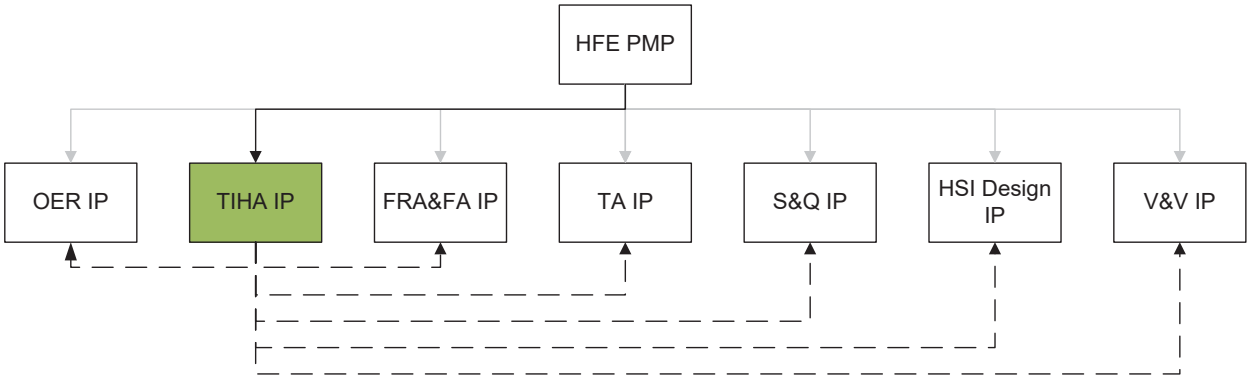

Figure 1: Relationship of TIHA IP to other documents within the HFE Program

1.4. DOCUMENT LAYOUT

This TIHA IP is formatted as follows. Section 1 addresses the document introduction, purpose, scope, and relationship to other documents. Section 2 identifies the references used in this IP. Section 3 describes the methodology, from the inputs, through the process and the expected outputs. Section 4 addresses how the outputs shall be documented. Section 5 includes, as an appendix, a checklist to verify compliance of this IP with the corresponding NUREG-0711 [1] review criteria.

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2. REFERENCES

The following documents are referenced within this document.

	Document Title	Preparer/Author	Document Number	Revision or Date of Issue	Classification	Applicable[2] (Yes/No)
[1]	NUREG-0711, Human Factors Engineering Program Review Model	NRC	N/A	Rev 3	N/A	Yes
[2]	REGDOC-2.2.1, Human performance management Human Factors	CNSC	N/A	2019	N/A	Yes
[3]	10 CFR 50.34, Contents of applications; technical information	NRC	N/A	2019	N/A	Yes
[4]	NUREG-0800, Standard Review Plan for the Review of Safety Analysis Reports for Nuclear Power Plants: LWR Edition, Chapter 7 “Instrumentation and Controls”	NRC	N/A	2016	N/A	Yes
[5]	NUREG-0800, Standard Review Plan for the Review of Safety Analysis Reports for Nuclear Power Plants: LWR Edition, Chapter 15, “Transient and Accident Analysis”	NRC	N/A	2007	N/A	Yes
[6]	NUREG-0800, Standard Review Plan for the Review of Safety Analysis Reports for Nuclear Power Plants: LWR Edition, Chapter 19 “Severe Accidents”	NRC	N/A	2015	N/A	Yes
[7]	NUREG-1791, Guidance for Assessing Exemption Requests from the Nuclear Power Plant Licensed Operator Staffing Requirements Specified in 10 CFR 50.54(m)	NRC	N/A	2005	N/A	Yes
[8]	TEC-XE100-HFE-PMP, HFE Services for the Xe-100 Plant Design – Human Factors Engineering Program Management Plan	Tecnatom	N/A	Rev 0	N/A	Yes

2 Applicable documents are applicable to the extent specified within this document and thus deemed to form part of this document.

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	Document Title	Preparer/Author	Document Number	Revision or Date of Issue	Classification	Applicable[2] (Yes/No)
[9]	Operating Experience Review Implementation Plan	Tecnatom	000982	Rev 0	XE00-R-R1ZZ-RDZZ-X	Yes
[10]	Functional Requirements Analysis and Function Allocation Implementation Plan	Tecnatom	000985	Rev 0	XE00-R-R1ZZ-RDZZ-X	Yes
[11]	Task Analysis Implementation Plan	Tecnatom	000986	Rev 0	XE00-R-R1ZZ-RDZZ-X	Yes
[12]	Staffing and Qualifications Implementation Plan	Tecnatom	000987	Rev 0	XE00-R-R1ZZ-RDZZ-X	Yes
[13]	Human-System Interface Design Implementation Plan	Tecnatom	000988	Rev 0	XE00-R-R1ZZ-RDZZ-X	Yes
[14]	Human Factors Verification and Validation Implementation Plan	Tecnatom	000989	Rev 0	XE00-R-R1ZZ-RDZZ-X	Yes
[15]	TEC-XE100-HFE-TRS, Control Room Staffing Analysis Methodology	Tecnatom	N/A	Rev 0	N/A	Yes
[16]	TEC-XE100-HFE-COO, Concept of Operations	Tecnatom	N/A	Rev 0	N/A	Yes

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3. DEVELOPMENT

As stated in NUREG-0711 [1], TIHA is an element of the HFE Program whose main objective is to minimize the likelihood of personnel error and to help ensure that personnel can detect and recover from any errors that occur. The relationship between the TIHA and other HFE Program elements is clearly illustrated in Figure 2 from Figure 7-1 in NUREG-0711 [1]. As illustrated in Figure 2, identification, review, analysis, and implementation of identified important human actions (IHAs) is an iterative process that affects all elements of the HFE program.

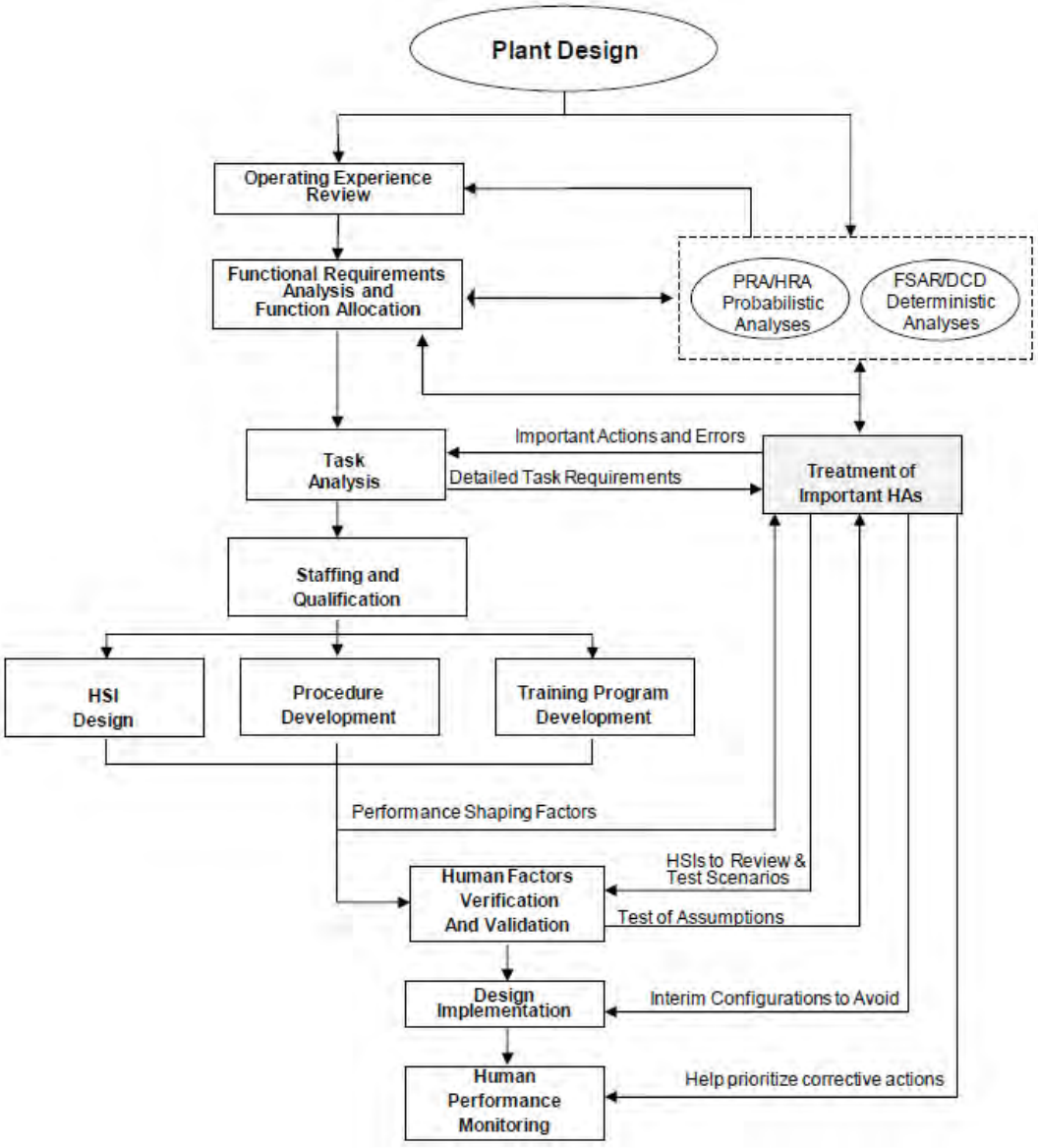

Figure 2: The role of TIHA in the HFE Program

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3.1. INPUTS

To perform the TIHA element, at a minimum, the following types of documents shall be reviewed and evaluated to extract the necessary input information:

- Probabilistic Risk Assessment and Human Reliability Analysis (PRA/HRA): This document identifies the risk-important human actions that may affect plant safety and reliability, and it is usually included in Chapter 19, Severe Accident, of the Safety Analysis Report (SAR). The contents of the PRA/HRA may be precursory but serve to provide a preliminary list of IHA. During the performance of other HFE Program elements, the IHA list will be finalized,
- Diversity and Defense in Depth (D3) analyses: This input provides human actions necessary for accomplishing the safety functions that may be affected by common cause failures of digital Instrumentation and Control (I&C). These analyses are usually included in Chapter 7, Instrumentation and Control, of the SAR. Those most relevant human actions shall be treated as IHAs in the HFE Program,
- Deterministic Analyses: These analyses will identify deterministic IHAs performed to prevent or mitigate accidental or transient events. These analyses are usually included in Chapter 15, Accident and Transient Analyses, of the SAR,
- Documents and/or tools compiling the data of the Operating Experience Review (OER) element: This information is needed to identify the list of potential IHAs from those undesirable scenarios in predecessor designs in case they remain important during the current design,
- Documents and/or tools compiling the data and results of all other elements of the HFE Program: Other HFE activities may identify new IHAs and/or Important Operating Sequences (IOSs).

3.2. METHODOLOGY

This IP describes the methodology analysis used to identify the IHAs and IOSs for consideration in the HFE design. As previously mentioned, the TIHA is an iterative process, and the results and conclusions are reviewed with the other HFE Program elements, including Functional Requirements Analysis and Function Allocation (FA), Task Analysis, and Human System Interface (HSI) Design. The results and conclusions of the TIHA may identify specific HFE Program elements whose conclusions may need analysis and revision. Figure 2 identifies this relationship between the inputs to the TIHA and the output to the other elements of the HFE Program.

To perform this analysis, the following steps are considered:

a. Identification of the Important Human Actions. Refer to section 3.2.1,

b. Identification of the Important Operating Sequences. Refer to section 3.2.2,

c. Considering them in designing the HFE aspects to minimize the probability of human error and to help ensure that personnel can detect and recover from any errors. Refer to section 3.2.3.

A simplified flowchart of activities of the TIHA is shown in Figure 3.

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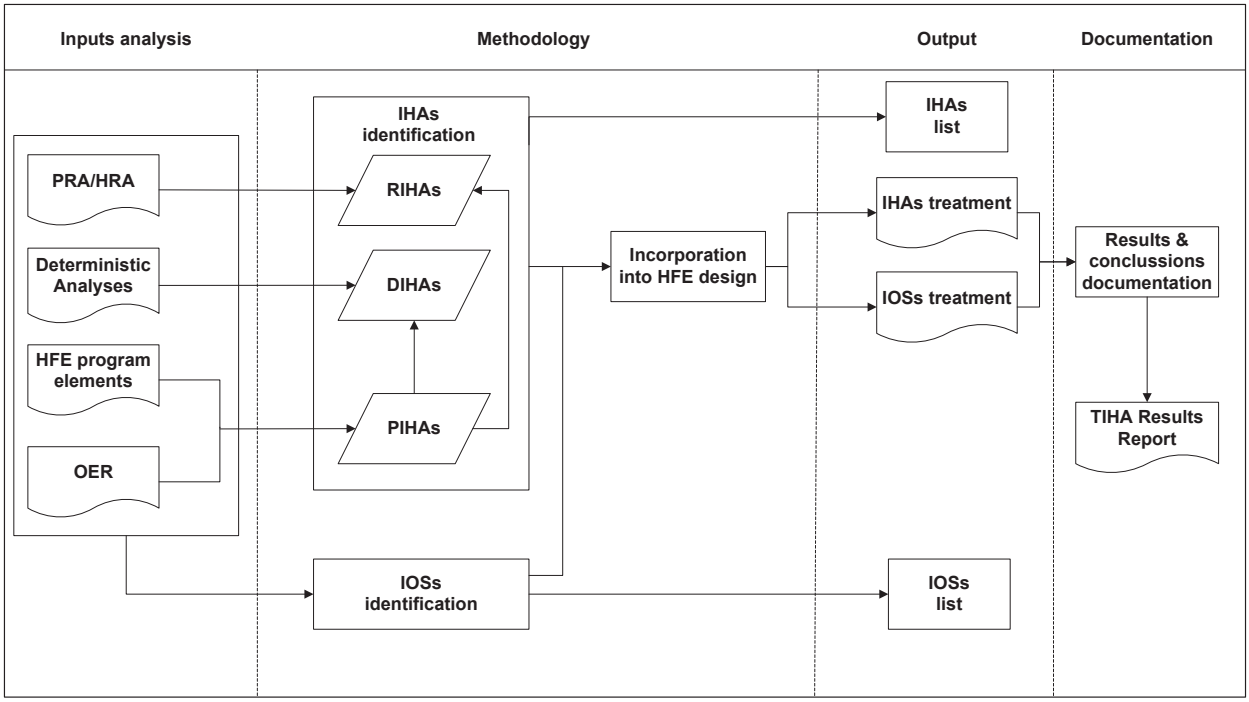

Figure 3 TIHA activities flowchart

3.2.1. Identification of Important Human Actions

IHAs are obtained via a combination of probabilistic and deterministic analyses, and categorized, according to their origin, as Risk-Important Human Actions (RIHA) or Deterministically-Identified Important Human Actions (DIHA), respectively.

RIHAs shall be identified using the PRA and HRA which are developed to evaluate human errors that might affect plant safety. PRA analyzes given scenarios and events in terms of probability based on the nominal Core Damage Frequency (CDF) using complex mathematical models. Additionally, HRA is included to study the contribution of each human action as part of those scenarios and events which may increase or decrease the resulting CDF. These human actions, namely RIHAs, are essential inputs in assuring the HFE Program goal of providing a design to minimize personnel errors. At least, a first version of the PRA/HRA (depending of the amount of design information available) shall be used to identify the RIHAs, so they can be considered in the early HFE Program elements.

DIHAs are identified as part of the deterministic analyses performed to evaluate the plant response under certain transients and postulated accidents, such as the D3 coping analyses and the transient and accident analyses performed in Chapters 7 and 15 of the SAR. Some human actions are credited in these analyses to prevent or mitigate the transients and postulated accidents; therefore they are categorized as important, namely DIHAs.

Note that the IHAs given on those probabilistic and deterministic analyses might be defined at the plant level, so that RIHAs and DIHAs selected in this step shall be those relevant to the design of the main control room (MCR).

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Besides IHAs identified by plant documents, there may appear others resulting from the HFE Program elements performance that might have passed unnoticed on the previous probabilistic or deterministic analyses. Those are called Potential Important Human Actions (PIHA), and they shall also be considered to analyze their potential impact in the rest of the HFE Program elements. A list of these particular types of actions will be provided to the appropriate Xe-100 team to consider updating those analyses.

The identification process should be updated iteratively as the design evolves to ensure the actual IHAs are captured and considered. At the very least, the set of IHAs should be finalized when the design of the plant and the rest of the elements of HFE Program are completed.

All the IHAs identified will constitute the set of IHAs that will be analyzed for their consideration and inclusion in the applicable elements of the HFE Program.

Each identified IHA will be categorized by the following coding and descriptions:

- Identification code: A unique code assigned to each IHA by numbering each category correlatively (i.e., RIHA01, DIHA01, DIHA02, PIHA01, etc.), to make the information more readily available,
- IHA name: Brief description of the human action,
- Detailed description: Context in which the IHA was identified. It may refer to specific plant conditions and/or events,
- Source: Input from where IHA was identified (e.g.: PRA/HRA, D3 analysis, etc.).

3.2.2. Identification of Important Operating Sequences

The Important Operating Sequences (IOS) are those that cause undue risk to nuclear safety or plant availability. Like the IHAs, the IOSs are identified using the probabilistic and deterministic analyses. For the purposes of the HFE Program, some events will be categorized as IOS, even though the source analysis may not identify the event as an IOS. The methodology for identifying these sequences includes analyzing the following events under a subject matter experts review:

- The sequences whose contribution to the core damage frequency is greater according to the most current PRA/HRA of the plant,
- Plant design-basis accident defined in Chapter 15 of the SAR or in other equivalent engineering document,
- Sequences containing any of the IHAs defined in section 3.2.1 from this IP,
- Sequences that have caused any undesired and important event identified in the OER covering all the relevant operational conditions inherent to the Xe-100 plant features.

Additionally, the most relevant transient events during nuclear power plant operation defined in Chapter 15 of the SAR could be considered IOSs.

The analysis should be updated iteratively as the design evolves to ensure the actual IOSs are captured and considered. At the very least, the set of IOSs should be finalized when the design of the plant and the rest of the elements of HFE Program are complete.

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Each identified IOS will be categorized by the following coding and descriptions:

- Identification code: A unique code assigned to each IOS by numbering them correlatively (i.e., IOS01),
- IOS name: Brief description of the important operating sequence,
- Detailed description: Context in which the IOS was identified. It may refer to specific plant conditions and/or events,
- Source: Input from where IOS was identified (e.g.: PRA/HRA, D3 analysis, etc.).

3.2.3. Treatment in the HFE Program

The IHAs and IOSs identified in sections 3.2.1 and 3.2.2 will be evaluated with the conclusions of each of the HFE Program elements. The list of IHA and IOS may require that the conclusions and reports of specific HFE Program elements be reevaluated and revised. The inclusion of IHAs and IOSs into the HFE Program elements will ensure that the final HSI design supports these important human actions.

Figure 2 illustrates the relationship between the TIHA and the rest of HFE Program elements. This diagram is key to understanding how the treatment of IHAs and IOSs shall be addressed. As depicted in the diagram, the main HFE Program elements where IHAs and IOSs might be addressed are Functional Requirements Analysis and Function Allocation (FRA&FA), Task Analysis (TA), Staffing and Qualifications (S&Q), HSI Design, and Human Factors Verification and Validation (V&V) elements. Development of operating procedures and training programs may also be affected. Interaction between IHAs and IOSs and each of the HFE element is explained below:

a. Functional Requirement Analysis and Function Allocation: This element evaluates the functions that may contain IHAs and verifies that they are appropriately allocated. For example, an IHA may be reallocated to a certain level of automation, thus it would no longer be treated as an IHA. Refer to FRA&FA IP [10] for details. If the IHA has been allocated to automation, it will still be tracked for further verification to ensure when a physical action is instead a monitoring action it is supported by the HSI design.

b. Task Analysis: In this element, each IOS is fully analyzed in terms of tasks, human-system interface requirements, staffing level, and workload. Moreover, by definition, all operating sequences with at least one IHA are categorized as IOS; therefore, they will also be fully analyzed within TA. As a conclusion, TA provides additional assurance that all IHAs and IOSs identified can be carried out with the necessary task requirement in terms of control, indication, alarms, or additional operation aids, and with the adequate operator workload within the staffing level and time available. Refer to TA IP [11] for details.

c. Staffing & Qualifications: In this element, IHAs and IOSs are evaluated to ensure its proper execution by main control room personnel. Refer to S&Q IP [12] for details. Special attention is given to staffing levels during performance of scenarios.

d. Human-System Interface Design: This element shall consider IHAs in terms of facilitating their execution and describing the controls, indications, and alarms that ensure the reliable performance of identified IHAs in a safe manner. For these HSIs where the IHAs are executed, a thorough analysis should be performed. Refer to HSI Design IP [13] for details.

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e. Human Factors V&V. Any assumption considered on the HSI design, based on previous analyses regarding IHAs, shall be validated as part of the V&V process. For this reason, V&V related activities may modify previous treatment assumptions. The adequacy of the HSI design to support operator performance of IHAs is finally confirmed in the integrated system validation. Refer to V&V IP [14] for details.

HFE issues that arise during the treatment stage shall be recorded into the HFE Issue Tracking System (HFEITS) to ensure they are tracked, evaluated, and corrected in the performance of the applicable HFE Program element(s). See section 4, Documentation. HFE issues shall be documented into HFEITS following the process described in the HFE PMP [8].

Moreover, to achieve the second goal of the TIHA, information related to the treatment of each individual IHA and IOS should be included as follows:

- HFE element addressed: HFE element that is affected by the IHA and/or IOS assessment, and
- Treatment description: How the IHA/IOS is resolved within the applicable HFE element.

3.3. OUTPUTS

Considering the inputs in section 3.1 and following the methodology proposed in section 3.2, the main outputs of the TIHA are:

a. Descriptions of IHAs and IOSs to be considered in other elements of the HFE Program,

b. Explanation of how each IHA and IOS have been considered in other elements of the HFE Program,

c. Identification of open issues related to IHAs or IOSs, which need to be addressed in other elements of the HFE Program.

Although the treatment is performed in the other elements of HFE Program, the most relevant information is collected within the TIHA element with two important objectives. First, it will be helpful to follow up on IHAs and IOSs and identify what specific HFE Program element is affected by each of the IHAs and IOSs, and secondly, where in that specific HFE Program element the TIHA has been incorporated.

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4. DOCUMENTATION

All the information and data resulting from the development of the activities of this element shall be recorded in a software tool, which shall be shared among all activities within the HFE Program. Using this single tool enables the HFE team to share common information and reduces the likelihood of making mistakes while performing HFE activities.

The tool consists of a relational database with a user interface. The database is configured in such a way that data within the same element and from different ones are related as described in the corresponding IPs. Using the user-friendly interface, data can be entered or modified. The users can also perform queries to the database to extract pieces of information in a human-readable format. The tool will be under administrative control and any changes must be requested.

The TIHA activities are incorporated into the HFE Program for the Xe-100 plant design; therefore, results and conclusions obtained after the performance of the activities shall be documented in a result summary report. That report shall include the descriptive lists of IHAs and IOSs, and the conclusions obtained from treating all relevant IHAs and IOSs including identification of HFE program elements affected by the IHAs and IOSs, as applicable.

Finally, HFE-related issues identified during the development of the activities of this element shall be recorded in the HFEITS. Previously recorded issues that are resolved within the scope of the activities of this element shall also be updated in HFEITS. A software tool shall implement the HFEITS in a way that allows the HFE team members to follow the process detailed in the HFE PMP [8].

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5. APPENDICES

5.1. APPENDIX A: COMPLIANCE CHECKLIST

Table 1 details the specific requirements defined in NUREG-0711 [1] related to the criteria that the TIHA activities shall meet. It also provides the reference of this IP where the corresponding requirement is addressed and explained to facilitate the development of TIHA activities.

Table 1: NUREG-0711 compliance list

NUREG-0711 reference	Requirement	IP reference
7.4 (1)	The applicant should identify risk important HAs from the PRA/HRA.	3.1 3.2.1 3.2.2
7.4 (2)	Applicants should identify deterministically important HAs from the following licensing analyses: • operator actions credited in the DCD/FSAR Chapter 15 accident and transient analyses • operator actions identified in the D3 coping analyses performed for DCD/FSAR Chapter 7, as specified in Section 1 and 2 of Interim Staff Guidance DI&C-ISG-02, *Diversity and Defense in Depth (D3) Issues* (NRC, 2009)	3.1 3.2.1 3.2.2
7.4 (3)	The applicant should specify how important HAs are addressed by the HFE program, in Function Allocation, Task Analysis, HSI design, Procedural Development, and Training Program Development, to minimize the likelihood of human error and facilitate error-detection and recovery capability.	3.2.3 Note 1
7.4 (4)	Additional Considerations for Reviewing the HFE Aspects of Plant Modifications.	N/A

Note 1. Operating Procedures Development and Training Program development are not part of the HFE Program where this IP is integrated.

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Enclosure 8

Xe-100 Human-System Interface Design Implementation Plan

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Xe-100

Human-System Interface Design Implementation Plan

Configuration Classification	:	**XE00-R-R1ZZ-RDZZ-X**
Revision	:	**1**
Status	:	**Approved**
Issue Date	:	**1-Jun-2021**
Project	:	**Xe-100**
Project Phase	:	**Concept**

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SYNOPSIS

This document provides the methodology to be followed to perform the Human-System Interface Design element of the Human Factors Engineering Program.

CONFIGURATION CONTROL

Document Change History

Rev.	Date	Preparer	Changes
A	14-May-2021	Hector Martinez-Pinna	Initial issue
1	1-Jun-2021	Hector Martinez-Pinna	Typos correction and minor changes

Document Approval

Action	Designation	Name	Signature	Date
Preparer	Tecnatom, Senior Human Factors Engineer	Hector Martinez-Pinna	DocuSigned by: Héctor Martínez-Pinna 31F691A6CD5B488...	6/2/2021 | 11:57 AM EDT
Reviewer	Tecnatom, Human Factors Principal Engineer	Richard Gutierrez	DocuSigned by: Richard Gutierrez A36744F44A30427...	6/2/2021 | 12:02 PM EDT
Reviewer	Tecnatom, Project QA Engineer	Santiago Lucas	DocuSigned by: FAEE967DCC7F49D...	6/2/2021 | 11:58 AM EDT
Reviewer	Senior Operator Training Engineer	Gregg Crannick	DocuSigned by: Gregg Crannick 3FA08AA7EDBD4BC...	6/2/2021 | 1:47 PM EDT
Reviewer	Senior Human Factors Lead	Paul Hippely	DocuSigned by: Paul Hippely 1AAE19CE8E784BD...	6/2/2021 | 12:00 PM EDT
Approver	Operator Training Simulator Manager	Yvotte Brits	DocuSigned by: Yvotte Brits E24E75C19AFA4BB...	6/2/2021 | 10:49 AM PDT

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ABBREVIATIONS

This list contains the abbreviations used in this document.

Abbreviation or Acronym	Definition
CFR	Code of Federal Regulation
CNSC	Canadian Nuclear Safety Commission
ConOps	Concept of Operations
EOF	Emergency Operations Facility
EPP	Emergency Preparedness Plan
FA	Function Allocation
FRA	Functional Requirements Analysis
GVD	Group View Display
HFE	Human Factors Engineering
HFEITS	Human Factors Engineering Issue Tracking System
HSI	Human-System Interface
IP	Implementation Plan
ISG	Integration Style Guide
I&C	Instrumentation and Control
LCS	Local Control Station
NRC	(United States) Nuclear Regulatory Commission
OER	Operating Experience Review
PMP	Project Management Plan
PRA	Probabilistic Risk Assessment
RSR	Results Summary Report
RSS	Reserve Shutdown Station
S&Q	Staffing and Qualifications
TA	Task Analysis
TIHA	Treatment of Important Human Actions
TSC	Technical Support Center
VDU	Visual Display Unit
V&V	(Human Factors) Verification and Validation

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DEFINITIONS

This list contains the terms of glossary used in this document.

Term	Definition
Element	From NUREG-0711 [1] the four general activities are separated into the following twelve elements: • HFE Program Management • Operating Experience Review • Functional Requirements Analysis and Function Allocation • Task Analysis • Staffing & Qualification • Treatment of Important Human Actions • Human-System Interface Design • Procedure Development • Training Program Development • Human Factors Verification and Validation • Design Implementation • Human Performance Monitoring
Human-System Interface	Hardware and/or software components of a nuclear power plant with which personnel interact in performing their monitoring, control, and maintenance tasks. As a minimum, major HSIs may include alarms, information displays, controls, procedures, and manuals.
Implementation Plan	Document that describes the proposed methodology for conducting an HFE element and is reviewed by the NRC staff to reasonably assure that it will generate acceptable results that satisfy the staff's review criteria.
Results Summary Report	Document that summarizes the results of a completed HFE element and cites documents or files that contain the complete results.

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1. INTRODUCTION

The Xe-100 nuclear reactor is an innovative design that is categorized as a Small Modular Reactor (SMR) due to its relatively low power, 200 MWt or 80 MWe. Its design allows for the fabrication and testing to be performed in a factory environment, so that it can be shipped to a site where it is installed as a single component. From a technological and regulatory point of view, the Xe-100 is a High Temperature Gas-cooled Reactor (HTGR) cooled by helium and moderated by graphite, implementing features that make the reactor inherently safe.

The plant configuration consists of four Xe-100 reactors, whose design is optimized since each unit shares like systems. The main purpose of a Xe-100 plant is to safely convert nuclear energy to electricity, in addition, the plant design accommodates multiple missions such as process heat applications.

As required by the licensing process and NUREG-0711 [1], a Human Factors Engineering (HFE) Program shall be developed[1], with proven systematic analysis techniques to address human factors issues within the design process. The HFE program and its products reflect state-of-the-art human factors principles.

As described in the HFE Program Management Plan (HFE PMP) [4], one of the first steps in the HFE Program is the preparation of Implementation Plans (IPs) that describe the proposed methodology for the performance of a specific HFE program element.

In accordance with NUREG-0711 [1] and NUREG/CR-3371 [13], an IP provides an opportunity to obtain a review and concurrence from the regulatory staff of the proposed methodology before performing the work associated with the element. This early review is desirable because it offers the staff an opportunity to identify potential issues with the methodology and to provide the Xe-100 design team with early input to the analysis or design processes, when staff concerns can more easily be addressed, rather than when the element has been completed.

The Human-System Interface (HSI) Design IP establishes the HSI design process and requirements implemented by the coordinated efforts of the HFE Design Team, responsible Engineers, and suppliers. The HSI design process applies methods and criteria from accepted human factors engineering practices and principles to achieve a consistent, integrated design of the Xe-100 plant HSI. Figure 1 illustrates the relationship of the HSI design process to the overall HSI design implementation.

[1] Refer to 10 CFR 50.34 (f)(2)(ii), 10 CFR 50.34 (f)(2)(iii), and REGDOC-2.2.1, Human Factors

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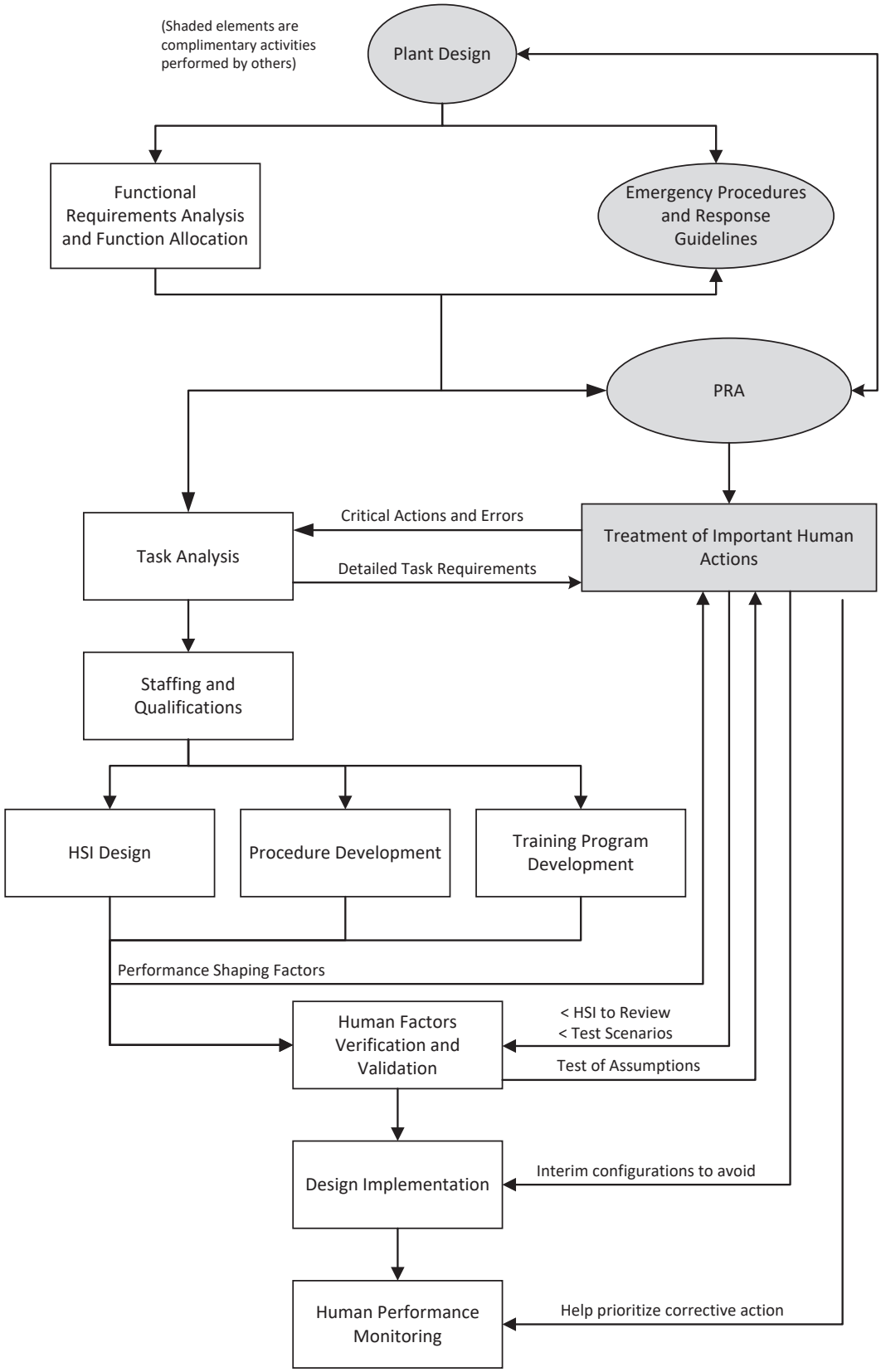

Figure 1: Human-System Interface Design process

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1.1. PURPOSE

The purpose of this document is to describe the methodology to be followed in the development of the seventh element of NUREG-0711 [1], HSI Design, and to establish the specific requirements for its Results Summary Report (RSR).

1.2. SCOPE

This IP applies to the HSI Design that will be performed as part of the HFE Program for the HFE licensing of the Xe-100 plant design. Therefore, this IP has been prepared in accordance with the criteria and guidelines as established in the HFE PMP [4].

The scope of HSI Design activities includes as a minimum:

a. Establishing the methods and criteria applied in the HSI design process, from concept of operations through specification of detailed design requirements, in accordance with accepted HFE guidelines, practices, and principles.

b. Implementing the HSI information, control, and alarm requirements which includes:

   i. Supporting tasks identified through the HFE analyses, for example, Operating Experience Review, Task Analysis, etc., particularly tasks identified as critical tasks.

   ii. Establishment of the minimum inventory of alarms, displays, and controls identified by the HFE analyses.

c. Establishing the methods for assuring consistency in the design of HSI components associated with human performance, including equipment design and associated workplace factors.

d. Establishing HSI design criteria and guidance for operations performed during periods of maintenance and testing, and for Xe-100 plant HSI maintainability.

e. Establishing test and evaluation methods and tools for identifying HFE/HSI design issues.

1.3. RELATIONSHIP TO OTHER DOCUMENTS

This IP is part of the HFE Program described in the HFE PMP [4], which includes high-level considerations that shall be known by the reader of this IP. Other HFE Program elements are related to the HSI Design; therefore, the IPs of these elements are cross-referenced where needed. Figure 2 shows relationships between the HSI Design IP and other documents within the HFE Program.

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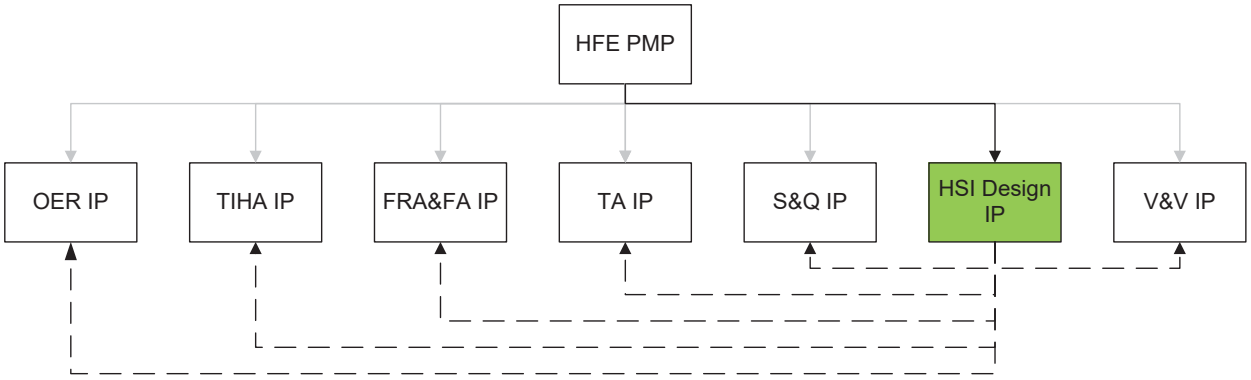

Figure 2: Relationship of HSI Design IP to other documents with the HFE Program

1.4. DOCUMENT LAYOUT

The HSI Design IP is formatted as follows. Section 1 addresses the document introduction, purpose, scope, and relationship to other documents. Section 2 identifies the references used in this IP. Section 3 describes the methodology, from the inputs, through the process and the expected outputs. Section 4 addresses how the outputs shall be documented. Section 5 includes as an appendix a checklist to verify compliance of this IP with the corresponding NUREG-0711 [1] review criteria.

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2. REFERENCES

The following documents are referenced within this document.

	Document Title	Preparer/Author	Document Number	Revision or Date of Issue	Classification	Applicable[2] (Yes/No)
[1]	NUREG-0711, Human Factors Engineering Program Review Model	NRC	N/A	Rev 3	N/A	Yes
[2]	10 CFR 50.34, Contents of applications; technical information	NRC	N/A	2019	N/A	Yes
[3]	REGDOC-2.2.1, Human performance management Human Factors	CNSC	N/A	2019	N/A	Yes
[4]	TEC-XE100-HFE-PMP, Human Factors Engineering Program Management Plan	Tecnatom	N/A	Rev 0	N/A	Yes
[5]	TEC-XE100-HFE-COO, Concept of Operations	Tecnatom	N/A	Rev 0	N/A	Yes
[6]	NUREG/CR-7126, Human-Performance Issues Related to the Design and Operation of Small Modular Reactors	NRC	N/A	2012	N/A	Yes
[7]	NUREG-0700, Human-System Interface Design Review Guidelines	NRC	N/A	Rev 3	N/A	Yes
[8]	Human Factors Verification and Validation Implementation Plan	Tecnatom	000989	Rev 1	XE00-R-R1ZZ-RDZZ-X	Yes
[9]	TEC-XE100-HFE-ISG, Human-System Interface Integration Style Guide for Xe-100 Reactor	Tecnatom	N/A	Rev 0	N/A	Yes
[10]	Xe-100 Plant Alarm Philosophy	X-energy	0000678	Rev 1	XE00-P-DZZ-JZZ-D	Yes

2 Applicable documents are applicable to the extent specified within this document and thus deemed to form part of this document.

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	Document Title	Preparer/Author	Document Number	Revision or Date of Issue	Classification	Applicable[2] (Yes/No)
[11]	NP-4350, Human Engineering Design Guidelines for Maintainability	EPRI	N/A	1985	N/A	Yes
[12]	IEEE 828, IEEE Standard for Configuration Management in Systems and Software Engineering	IEEE	N/A	2012	N/A	Yes
[13]	NUREG/CR-3371, Task Analysis of Nuclear Power Plant Control Room Crews	NRC	N/A	1983	N/A	Yes

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3. DEVELOPMENT

The primary goal of HSI Design is to design and implement an Xe-100 plant HSI design facilitating safe, efficient, and reliable human task performance during all phases of normal plant operation, abnormal events, and accident conditions, including maintenance, testing, and inspection activities. This goal is achieved, in part, by providing plant personnel with a human-engineered and user-tested HSI providing accurate, complete, and timely information and control of equipment, systems, and environments necessary for human task performance.

Objectives of HSI Design include:

a. Develop HSI detailed design requirements supporting system functional and task performance requirements.

b. Identify applicable HFE guidelines, tailored to the Xe-100 plant HSI design requirements, and issued as detailed design specifications, such as the Integration Style Guide and other HFE specifications, to assure standardization and consistency in the HSI detailed design.

c. Establish a structured approach for development of any new designs not based on a predecessor design.

d. Iteratively refine the HSI design as needed, through progressive testing and evaluation.

e. Document the design basis and rationale for the HSI design, including the evaluation methods and tools.

Personnel use of HSIs is influenced directly by the organization of HSIs into workstations (including consoles and panels), the arrangement of workstations and supporting equipment into facilities, and the environmental conditions in which the HSIs are used; including temperature, humidity, ventilation, illumination, and noise.

This section includes a description of documents required to perform the analysis, followed by a systematic process definition to further develop the element and a collection of the outputs expected as a result of the methodology implementation.

3.1. INPUTS

Inputs are categorized according to their nature, as described in the following sub-sections.

3.1.1. HFE Program Related Requirements

Other HFE Program elements or documents provide inputs to the HSI design as follows:

- Concept of Operations [5]. This document defines the goals and expectations for the plant from the perspective of the users and includes a conceptual description of HSIs. An HFE-focused Concept of Operations serves as an initial step for the development of the HFE Program, because it contains the basic information and assumptions that will be further analyzed, verified and validated from a human factors perspective. This conceptual design shall be further developed into a detailed design under the HSI Design element.

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- Operating Experience Review (OER) - Lessons learned from other complex human-machine systems, especially predecessor designs and those involving similar HSI technology, should be considered, and encompassed in the HSI design process.
- Functional Requirements Analysis (FRA) and Function Allocation (FA) - The HSIs should support the roles of personnel in the plant. The HSI design should ensure the accomplishment of the plant goals and system functions. Also, the levels of automation must be in accordance with the allocation of functions.
- Task Analysis (TA) - The TA breaks down operator task into activities, where the analysis identifies interface requirement (control, indication, and/or alarm), communications necessities, and possible operation aids. All these requirements will be translated to an interface. As part of the iterative nature of the HFE Program elements, the levels of automation allocated in the previous iteration of the Function Allocation will be reviewed.
- Treatment of Important Human Actions (TIHA) - Important human actions and important operating sequences should be considered in the HSI design in terms of facilitating their execution. For important human actions, the HSI design should minimize the probability that errors will occur and maximize the probability that any error made will be detected. Any important human action related to HSI design will be identified in the HFEITS to facilitate its follow-up and tracking. The HFE design team will evaluate the allocation of important human actions to automation as an approach to reducing the potential for human error.
- Staffing and Qualifications (S&Q) - The findings from the S&Q analyses will provide input data for design decisions for the arrangement of the HSIs and the layout of the control rooms were these are located. Operator interfaces that present information, controls, or alarms will be provided on visual display units (VDUs), individual consoles, panels, or workstations within these areas. The S&Q analyses establish the basis for the minimum and maximum number of personnel to be accommodated, and requirements for coordinating activities between the areas that provide operator interfaces.
- Human Factors Verification and Validation (V&V) - This element comprises several evaluations that determine that the final HSI design conforms to design principles and allows the successful execution of personnel tasks.

3.1.2. Regulatory Requirements

NUREG-0711 [1] is the regulatory criteria basis for the development of this IP. Applicable NUREG-0700 [7] guidelines will be incorporated in the development of the Integrated Style Guide [9], and the guidelines will be translated into HSI design.

3.1.3. Xe-100 Plant Requirements

Xe-100 plant systems information (system descriptions, P&IDs, etc.), safety assessment analyses, applicable specifications, and/or instrumentation and control (I&C) system documents, especially those

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related to the digital HSI system, may be necessary to identify HSI design specific requirements or constraints.

3.2. METHODOLOGY

The HSIs with which personnel interact should be designed through a structured methodology guiding designers in identifying and selecting candidate HSI approaches, defining the detailed design, and performing HSI tests and evaluations.

The HSI will include a description of:

- Facility hardware and software layouts, including workstations and large screen displays.
- Working positions.
- Key HSI resources and their functionality, such as alarms, displays, controls, computer-based procedures (if any), and other support and job aids.
- Technologies to support teamwork and communication within the main control room and between other applicable monitoring and control facilities.
- Use of the interfaces for monitoring, interacting, and overriding automatic systems and for interacting with computerized procedures systems and other computerized operator support systems station, as applicable.

The HSIs are designed in a first approach taking as input the Concept of Operations [5], the existing Integration Style Guide (ISG) [9] and the results and conclusions from previous HFE Program elements. Figure 3 provides a block diagram that illustrates an overall view of the design inputs and the outputs as they are related to the overall HSI design, including the evaluations performed. The block diagram identifies the other key features of HSI, such as workspace, environmental, panel design, communications, etc.

The HSI design is an iterative process, with new inputs being provided as the Xe-100 plant design evolves and through the necessary V&V process, including the performance of Task Support Verification and Design Verification using very preliminary design inputs.

During the HSI design, any issues or discrepancies related to the HSI will be entered into the HFE Issues Tracking System, as described in the HFE PMP [4].

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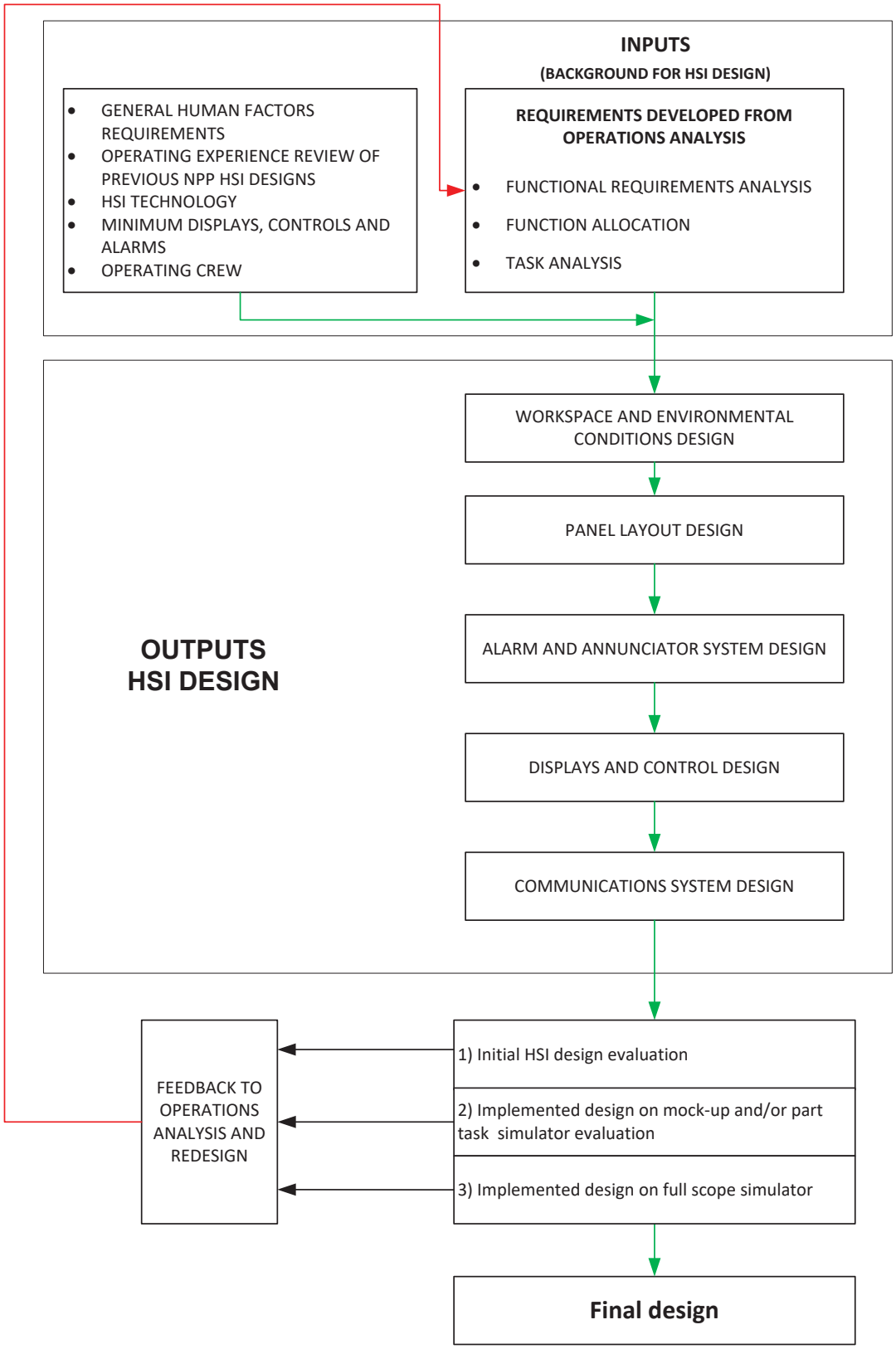

Figure 3: HSI Design process block diagram

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3.2.1. Interface Integration Style Guide

The ISG establishes the criteria for the design of all the HSIs that are included the Xe-100 plant design. The ISG ensures that the HSI is designed, developed, and implemented in a consistent manner by the Xe-100 design team, including deliverables from third party suppliers. The ISG uses the applicable criteria from NUREG-0700 [7] for implementation into the Xe-100 plant HSI design.

The ISG will remain a living document that is revised accordingly throughout the HSI design process as illustrated in Figure 2.

The ISG:

- Defines the scope of HSIs included in the design, and addresses their form, function, operations and environmental conditions in which they will be used that are relevant to human performance
- Defines the design-specific conventions (e.g., colors and symbols) that will be used in the HSI design.
- Will be sufficiently detailed so that design personnel can provide a consistent, verifiable design meeting the Xe-100 plant design guidelines.
- Will include procedures, written so that designers can readily understand them, for determining where and how HFE guidance will be used in the overall design process.
- Will be available in a format that is readily accessible and usable by designers and is easily modified and updated as the design matures.
- Will include references to the sources upon which the guidance is based.

Coding principles consistent with the guidelines of NUREG-0700 [7] will be established early in the HSI design process through the ISG. The coding system applied to location, information, color, and illumination will be consistent throughout the HSI detailed design in all applicable facilities (e.g., main control room and reserve shutdown stations).

Equipment shapes and symbols, abbreviations, and acronyms are defined and documented in the Xe-100 project design manuals or documents. Use of shapes and symbols for component coding, abbreviations, and acronyms conform to the requirements of the project. The coding method selected for application is determined by considering the relative advantages of the types of coding.

3.2.2. HSI Detail Design

Applicable criteria in sections 8.4.4.1 to 8.4.4.6 from NUREG-0711 [1] will be considered in the implementation of this methodology.

As a part of the TA and the HSI design, the HFE design team will need to perform an analysis regarding whether a function is assigned to a software parameter or alarm to be monitored, or a software switch or a hardware switch for control of a function. Their location in the plant arrangement will also be identified.

3.2.2.1. Software HSI Design

According to the Concept of Operations (ConOps) [5], the primary high-level responsibilities for the operating crew can be summarized as follows:

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- Operation of the plant by requesting the automated control system to actuate the plant systems and monitor its performance in accordance with relevant rules, operating procedures, established operational limits and conditions, and administrative procedures.
- Periodical monitoring of important parameters and analysis of trends should the parameters deviate from established limits.
- Identification of equipment in the plant to ensure that maintenance activities can be structured effectively.
- Management of alarms.
- Involvement in the development of surveillance programs for structures, systems, and components important to the safety and coordination of their implementation.
- Accurate maintenance of shift records and logs.

The Xe-100 plant is an entirely soft-controlled installation; all the activities listed above are accomplished through interaction using a software-based HSI (e.g., VDUs). One of the goals of the HFE Program is to provide an analysis that supports the software-based HSI.

The interaction between the user and the displayed information and controls on the VDU will be identified during the design of the HSI and consistent with the ISG. Interaction with the VDUs can be performed using a keyboard, mouse, or touchscreen technology. In all cases, applicable guidelines will be provided in the ISG.

It should be noted that in addition to the content and location of the display pages on a specific VDU or display panel, the proposed navigation between the display hierarchy, including proposed menu structures, need to be developed and evaluated.

Applicable normatives regarding physical and functional separation between safety- and non-safety-related systems will be considered. If needed, separate HSIs will be designed for each type and each safety train or division.

The details of the systems and functions to be assigned to safety-related VDUs will be determined during the HFE analysis as this may affect the design of the display pages on the VDUs and, more importantly, may also affect the number and location of the VDUs in the main control room (MCR) and other facilities.

One of the challenges of the software-based control system is the quantity of information and display pages that are managed by the operator. The activities to control the plant are supplemented with the activities necessary to navigate through the hardware interfaces (e.g., VDUs on desks, displayed on screens for unit supervision, etc.). In this aspect, the interface management should be conceived to minimize its impact in operator workload. The display pages will be designed and organized in a hierarchical structure, that will facilitate navigation and its comprehension.

The preliminary design for the Xe-100 MCR foresees using a set of workstations with software-based means of control and monitoring for individual use, and several group view displays (GVDs) which shall be at visual range of any MCR crew member. System-specific and plant monitoring information to be displayed on the GVDs will be identified as a part of the HFE analysis.

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3.2.2.1.1. Workstation Display Pages Design

The objective of the workstation display pages design is to define a set of interfaces that addresses the supervision and control activities of the plant, as well as the interface management. Figure 4 illustrates the process to be followed to accomplish this objective.

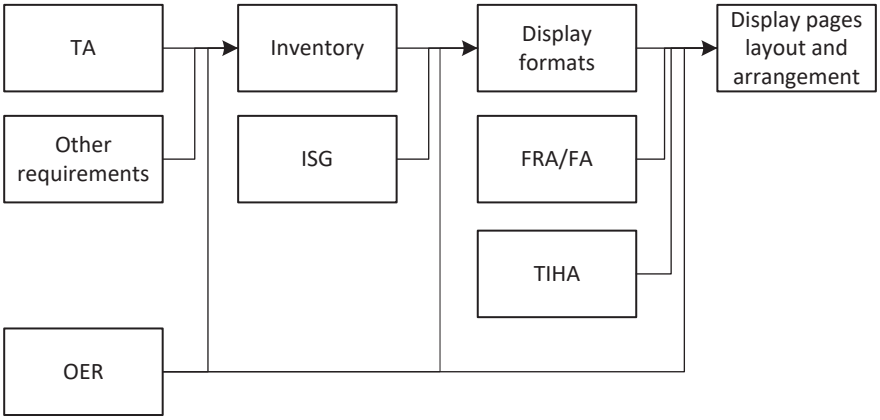

Figure 4: HSI display pages design process

The TA will identify a set of indications, controls and alarms that represent a minimum inventory to be represented in the HSI. Other requirements derived from regulatory requirements, I&C systems, plant requirements and other type of analysis will complete the inventory. The HSI design will relate each component of the inventory with a display format, according to the criteria described in the ISG.

The distribution and arrangement of these formats in the interface will be consistent with the TA and FRA, and will consider their importance, and frequency and sequence of use. The HSI design should facilitate the execution of the personnel task and the follow-up of functions and plant goals (i.e., nuclear safety and production goals).

The FA will identify the automatic actions, manual actions, and combination of the two that will be incorporated into the HSI. Considering that the Xe-100 plant control philosophy relies on a higher level of automation than current nuclear operating units, including adaptive automation of tasks, the HSI will incorporate features that perform many of the system functions or operator tasks while enabling operators to better understand the automation's processes and increase their transparency.

Every important human action, as identified in the TIHA, will be assigned to one or several activities in the TA. The display pages related to these important human actions will also be identified, to ensure their follow-up.

Also, communication requirements and operational aids extracted from the TA will be translated into the HSI design.

OER findings will be included in the HSI design and regulatory compliance will guarantee the HSI constitutes a the state-of-the-art HSI design supporting personnel performance.

The design of the HSI will take into consideration the Xe-100 plant operation philosophy, and that the MCR is monitoring and controlling four reactor units. The ISG criteria will be translated into HSI features that allow the MCR operators to effectively monitor multiple VDUs and maintain the necessary level of

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situation awareness. The HSI design will also support the management of the workload for coordinating and controlling four reactors. Using data gathered from the TA, the necessary level of automation will be implemented to perform monitoring, control, and diagnostics of plant systems to support operator workload. The HSI display hierarchy will be organized to address monitoring, control, and diagnostics tasks, whether automated or performed manually.

3.2.2.1.2. Group View Display Design

The GVDs are large-screen display devices located in the MCR with the objective of providing an overview or high-level summary of the plant status and supporting crew coordination, awareness, and collaboration. According to the ConOps [5], the eight large-screen display devices planned to be installed in the MCR cover the following functions:

- Two screens for safety important systems.
- Two screens for plant production.
- One screen for supervision of each unit, four in total.

The structured analysis of these functions and plant goals, as well as the TA will lead to a design of a set of displays, which may include plant, system and component alarms, always in concordance with ISG and OER, as shown in Figure 4 (in section 3.2.2.1.1). The output design will be verified and validated in an iterative process.

An important activity will be the design of the display pages and the assignment of display pages to a specific VDU and/or GVD. As stated previously, the GVD presents safety system information, plant production, and supervisory information for each of the four reactors. The HFE design team, as part of the analysis, will establish a criterion to allocate parameters to the VDU, the GVD, or both. The functionality of the GVDs and their role during normal, abnormal, and emergency conditions will also be included in the HFE analysis.

Additionally, the functionality of the GVD shall be specified, as they may affect HSI design, such as:

- Can a display on the VDU be displayed on a specific GVD?
- Can the information from one GVD be moved to another GVD if a GVD fails?
- What action does the MCR staff take in the event of a VDU or GVD failure?

3.2.2.1.3. Electronically Displayed Plant Operations Procedures

The display of plant procedures on the VDUs and GVDs in the MCR will be evaluated during the HSI design process. The electronically displayed procedures, sometimes referred to as *computerized procedures*, may also be provided at other facilities, such as the Reserve Shutdown Stations.

Normal and emergency procedures provided initially in hard copy format will be considered for inclusion as electronic files viewable on the VDU and GVD, enabling selection of the most up-to-date procedures electronically.

The level of functionality of the procedures will be determined during the HFE design process. Functionality of the displayed procedure pages may be as simple as displayed dynamic information to the

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ability of the user taking control actions from the displayed procedure page. The level of functionality will be determined by the Xe-100 design team, and the design will be evaluated as a part of the V&V process using both static and dynamic simulations.

The following criteria will be considered in the development of the electronically displayed procedures:

- Procedures are presented in the form of logic, flow charts, or text instructions.
- Procedures are provided on the same display as the parameters necessary for operations personnel to make each required decision.
- Procedures provide the capability for operations personnel to access those controls necessary for carrying out the tasks directly from the procedure display.
- Procedures include checklists of prerequisites and interlocks to steps necessary for completing an action, where applicable.
- Procedures provide for feedback and verification of operations personnel decisions, with operations personnel retaining final control and authority whether to proceed with specific actions. Automatic logging of event management decisions includes variance from any computer recommended decisions.
- Plant parameters and component status, presented as part of the procedures displays, are continuously updated.
- Procedures displayed electronically conform to industry and regulatory guidelines regarding HFE principles for computer displayed controls and procedures.

Electronically displayed procedures will be developed in accordance with the procedures development process and the Procedures Writer's Guide.

3.2.2.2. Workplace Design and Configurations

This section refers to the HSI design for the MCR. Additional facilities, covered by the Xe-100 HFE Program as specified in the HFE PMP [4], are addressed in section 3.2.2.3.

The conceptual design of the MCR layout and the workstations is described in the ConOps [5] and will be further developed under the HSI element to a detailed design oriented to support teamwork and task performance. The workplace detail design includes the definition of the layout and dimensioning of the MCR elements, number and size of large screen display devices, number of workstations, layout, disposition and dimensioning of the hard panels, and environmental conditions.

The detail design of the proposed workstation will include dimensions, assuming a potential user population. Using the criteria from NUREG-0700 [7], an HFE design will be prepared and applied to the MCR (and extended to other facilities and for use by third party vendors for systems that are provided out in the plant). The intent of the HFE design is to review the NUREG-0700 [7] anthropometric data and compare it to the user population planned for the Xe-100. The Xe-100 plant is monitored and controlled using both sit-down and standing workstations. Bounding measurements for seated and standing females and men will be identified and included in the HFE design. The information prepared should be of sufficient detail that preliminary mock-ups using soft materials can be constructed.

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The preliminary design will consider desktop and work surfaces, definition of devices (VDUs, computer input devices, etc.), and the determination of the number of screens at each workstation. In addition to the VDUs located on the workstations, consideration will also be given for the surface space necessary for plant procedures during normal, abnormal, and emergency conditions. The arrangement and location of communication devices such as telephones and plant pagers will be reviewed according to data collected in the TA.

The MCR layout and workstation design process is iterative and will consider the current existing simulator design as the initial baseline. The layout and workstations will be verified according to V&V activities of the HFE Program to evaluate the accomplishment of NUREG-0700 [7] guidelines.

S&Q analysis findings will provide the minimum, normal and maximum staff capable of operating the plant in all plant conditions (normal operation, incident, accident, refueling, etc.). This analysis will establish the basis for the minimum and maximum number of personnel to be accommodated. S&Q also establishes requirements for coordinating activities between personnel, which will be translated to the HSI design.

3.2.2.2.1. Control Room Configuration

The following aspects of the control room configuration will be addressed in the design:

- Architectural Features - Architectural features of the control room, including its shape, entrances and exits, and windows.
- Furniture, Instrumentation, and Equipment Layout - The layout of the control room to support staffing levels, observation of information from the primary work locations, crew communication, movement within the control room, and equipment access.
- Group View Display Devices - The physical characteristics of group view display (GVD) devices, including viewing characteristics (such as viewing distance and angle), information display, and integration of GVDs into the control room environment.
- Document Organization and Storage - Provisions for storing documents such as procedures so they - can be easily located, retrieved, and used.
- Emergency Equipment - Emergency equipment including personnel protective equipment, radiation and rescue equipment, and equipment storage will be addressed.
- Supervisor Access - Provide for the supervisor’s access to the control room and communication with the crew, including a separate office area.
- Visitor Viewing Areas and Security - If planned in the design, address the protection of confidential information from being observed from visitor areas.
- Spare Parts, Operating Expendables, and Tools - Provide in the MCR, the availability of storage, and accessibility of spare parts, operating expendables, and tools needed by personnel. Identified during the analysis if there needs to be access to stationary, extra batteries, etc.
- Maintenance - Addresses the control and accommodation of maintenance activities in the control room. If the operating crew is to review and approve work packages, MCR access and access control will be addressed as well.

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- Ambience and Comfort - Addresses the general control room décor and accommodations for crew comfort, such as eating, restroom, lounge, and personnel storage facilities.
- Multiunit Control Rooms - Addresses considerations when a site has multiple control rooms, each for a different unit. The considerations include equipment arrangement, distinguishing between units, and shared equipment. In the Xe-100 plant, four units are controlled from one MCR. Review the impact if one unit is down for maintenance or undergoing an anomaly, and what is the workload impact to the operators when monitoring and controlling the other three units. Also review the impact if one unit is built and operating while other units are being constructed/commissioned to see the impact of the workload to the operators when monitoring and controlling the operating unit(s).
- Communication - The MCR staff may need to communicate with other staff in the office areas and in the plant. Communication with agencies offsite from the plant may be necessary. The number of and location of these communication devices will be part of the TA.

3.2.2.2.2. Control Room Environment

Environmental factors can affect operators' performance. The following aspects of the control room environment will be addressed in the design:

- Temperature and Humidity - Temperature and humidity factors, including ambient and effective temperature, humidity, and temperature differences throughout the control room. Review dissipation of heat by any processors located in the MCR.
- Ventilation and Air Quality - Air exchange and movement in the control room, as well as air quality, such as minimizing pollutants.
- Illumination - General illumination levels and specific local levels for locations (such as workstations, individual control and display devices, and areas used for reading and writing), glare, and reflectance.
- Emergency Lighting. -Lighting considerations when the primary lighting fails.
- Auditory Environment - Auditory environment, including background noise level, reverberation, and the sound absorption characteristics of the workplace.

3.2.2.2.3. Number of Workstation Screens

During the HFE analysis, as previously described, the allocation of information and/or controls to a display page or display screen will be identified using defined criteria (e.g., frequency of use, regulatory criteria, etc.). A predetermined location will be selected by the design team.

The HSI design will ensure that the operators are able to access the necessary display pages and information required in each situation within the criteria as specified in the ISG. As part of the HSI design, the number of screens necessary to perform a task should be determined considering different operation conditions. Navigation through a set of display pages will be addressed as a part of the display page design.

The methodology for carrying out this analysis will use the four-screen configuration as a starting point. Different scenarios from the TA will be evaluated, considering complex situations or concurrent events (i.e. one operator controlling more than one reactor). This evaluation will be based on job analysis,

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frequency and sequence of use, and the roles of operators. The analysis of these scenarios will consider the display pages required for its execution. This evaluation allows for drawing a conclusion as to whether or not the initial assumption of four screens is an adequate HSI or otherwise, a new iteration of the analysis should be carried out with a different number of screens.

3.2.2.2.4. Number of Large-Screen Display Devices

As defined in the ConOps [5], the preliminary MCR design includes devices for supervising overall plant operation for safety important systems (two screens), plant production (two screens) and supervision of the four units (one screen per unit, four in total). These are referred to as GVDs. In accordance with NUREG-0700 [7] and the ISG, the HFE analysis will identify the information to be provided on each of the GVDs.

The set of display pages proposed for the GVDs will be evaluated to determine if the proposed number of GVDs is consistent with the needs of the MCR staff. The functionality of the GVDs will also be evaluated. For example, the ability to present information from the desktop VDU onto the large-screen displays will be reviewed.

Other features to evaluated for the use of a GVD, is its ability to display:

- Plant, system and component alarms.
- Post-accident monitoring parameters.
- Safety parameter display system (refer to NUREG-0711 [1], section 8.4.4.2, and NUREG-0700 [7], section 5).

Section 3.2.2.1.2 identifies some of the features of the GVD and how they will be managed by the MCR staff.

3.2.2.3. Other Control and Monitoring Centers

In accordance with the applicable NUREGs and HFE principles, HSIs for operator and plant staff will be consistent across the plant design. As described in HFE PMP [4], the HFE Program addresses the HSI in control rooms and stations other than the MCR, such as the Reserve Shutdown Stations (RSS), Technical Support Center (TSC) if applicable, Emergency Operations Facility (EOF) if applicable, and any Local Control Station (LCS) monitored, operated or maintained by the MCR operating staff. The allocation of HSI to these control centers will be based upon the conceptual Xe-100 plant design and allocations identified during the HFE analysis.

3.2.2.3.1. Local Control Stations

LCSs may include multifunction workstations and panels, as well as operator interfaces. Areas outside of the control room present a completely different work environment. There may be more noise, some caused by loudspeakers and some by the equipment. In addition to the noise environment, the temperature conditions are different due to a lack of heaters and/or cooling air. An LCS typically uses many of the same HSIs as the MCR workstations and control boards. Thus, the design of the alarms, displays, and controls of LCSs will be consistent with the ISG and NUREG-0700 [7].

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The configuration and environmental features considered for the MCR will also be applied to the LCS as applicable.

3.2.2.3.2. Reserve Shutdown Station

As described in the ConOps [5], the Xe-100 plant design includes four RSSs, one for each reactor, to be used if the MCR becomes uninhabitable. The RSS HSI is in a room in each of the separate reactor buildings. As stated in the preliminary design, the HSIs in the RSS may include workstations, group-view displays and possibly a hard panel with no control capabilities except for reactor trip. The actual number of panels, VDUs and other HSIs located in the RSS room will be determined as a part of the HFE analysis.

The configuration and environmental features considered for the MCR will also be applied to the RSS as applicable.

3.2.2.3.3. Technical Support Center - (if applicable)

The TSC is a separate room and will be defined as part of the HSI design process. The room is activated in response to the plant emergency preparedness plan (EPP). The workstations, HSIs, communications equipment, etc. will be provided in accordance with the plant EPP.

The configuration and environmental features considered for the MCR will also be applied to the TSC as applicable.

3.2.2.3.4. Emergency Operations Facility – (if applicable)

Like the TSC, the EOF is activated in accordance with the plant EPP. The location and design of the EOF will be in accordance with the EPP.

3.2.3. Degraded I&C and HSI Conditions

The HSI design shall include the different interfaces used for the main subsystems of I&C (sensor, monitoring, automation and control, and communications), as well as consideration for the potential failures which may occur (automation failures and degraded conditions). Consistent with NUREG-0711 [1], the HSI design will address the manual initiation of protective actions at the system level for safety systems, otherwise initiated automatically.

The I&C architecture, including the capabilities and limitations of the I&C systems, the HSI subsystem, and the I&C system failure mode analysis will all be included in the inputs during the design process. The HSI design will consider the following as a minimum:

- Alarms, indications and controls required to detect the degradation and their management.
- Back-up systems.
- Actions to manage these conditions and transition to back-up systems.

The Xe-100 alarm system will be designed in accordance with the criteria defined in the Xe-100 Plant Alarm Philosophy [10]. According to this Alarm Philosophy, the Xe-100 alarm system to be developed will present alarms on the MCR VDUs and other devices as determined during the HSI design process. The

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planned alarm system will provide prioritized alarms, based upon relative importance and time urgency of the operations personnel response. Prioritization of alarms will be evaluated to ensure that alarms are valid for the appropriate plant mode and system state.

A consistent approach and philosophy are applied in selecting plant conditions to be alarmed, applying criteria like the following for the selection of alarmed conditions:

a. Each alarm is associated with a predefined action for operations personnel to take in response to system, component, or parameter anomaly.

b. Alarmed conditions are selected using a “dark board” concept, that is, no alarms are present when the plant is operating normally, in any plant operating modes with all systems in their normal configuration for that mode of operation.

c. Each alarm set point is defined such that operations personnel will be alerted early enough to have time to take the appropriate action, but not close enough to the normal operating range to produce unnecessary or nuisance alarms.

d. Alarms provide alerts before a major system or component problem results in a condition causing a loss of availability.

e. Alarms for process deviations are based, where possible, on validated process signals rather than individual sensor indications.

3.2.4. HSI Tests and Evaluations

Issues related to the detailed design of specific aspects of the HSIs will be resolved during the development of the HSI design, to minimize the impact on downstream decisions or modifications in the design process.

Trade-off evaluations based on aspects of human performance that are important to successful task performance and to other design considerations, will be performed to improve and refine the HSI design. The results of these evaluations will be substantiated and documented as part of the design process documentation.

Performance based testing will be carried out and documented as part of the partial validation activities, as described in the V&V IP [8]. Partial validation activities are accomplished during the design process (prior to Integration System Validation); therefore, these tests do not require a final and complete HSI, enabling a more agile process.

3.2.5. Maintainability

The Xe-100 HSI will be designed to facilitate maintenance in accordance with accepted human factors engineering principles. NP-4350 [11] provides the bases for a program to assist in placing proper emphasis on maintainability, and provides the following important maintainability features:

a. The HSI design simplifies and reduces the amount, and difficulty of, maintenance, testing, and surveillance activities required over the lifetime of the plant.

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b. Repair and replacement of HSI equipment can normally be accomplished by modular replacement in the field.

c. The HSI design provides access to HSI component physical locations, either within a panel or on a panel, and provides indication to operations personnel when the equipment is under repair.

d. Labeling and coding of components, inside and outside of cabinets, is unambiguous, legible, and consistent with other plant labeling practices.

e. A software maintenance plan complying with IEEE Std.828 will be established for the HSI software.

f. Operation and Maintenance Manual preparation conforms to the requirements of the Procedures Development Plan.

3.3. OUTPUTS

The output of the implementation of this methodology will be a verified and validated HSI design (including software interfaces, workstations, and workplaces) that has been designed to reduce the potential for human error and support personnel situation awareness.

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4. DOCUMENTATION

The results of the HSI design will be documented in a set of diagrams, drawings and/or reports as necessary. When possible, drawings will allow the implementation of the HSI design into the digital HSI system.

The ISG will remain a living document during the HFE design development and its content will be revised when needed according to section 3.2.1.

In addition, a Results Summary Report will summarize the results of the HSI design process, including or referring, as a minimum:

a. A description and/or representation of the MCR, and other applicable facilities, arrangements necessary to support normal, abnormal, emergency and maintenance operations.

b. A description of the number of VDUs and GVDs necessary in the MCR, and other applicable facilities, necessary to support normal, abnormal, emergency and maintenance operations.

c. A description of the display screens necessary as identified by the TA, to support normal, abnormal, emergency and maintenance operations.

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5. APPENDICES

5.1. APPENDIX A: COMPLIANCE CHECKLIST

Table 1 details the specific requirements defined in NUREG-0711 [1] related to the criteria that the HSI Design activities shall meet. It also provides the reference to this IP where the corresponding requirement is addressed and explained to facilitate the development of HSI Design activities.

Table 1: NUREG-0711 compliance list

NUREG-0711 reference	Requirement	IP reference
8.4.1 (1)	Analysis of Personnel Task Requirements – The applicant should use the following analyses, performed in earlier stages of the design process, to identify requirements for the HSIs: • Operational Experience Review – An input to the HSI design should encompass lessons learned from other complex human-machine systems, especially predecessor designs and those involving similar HSI technology. • Functional Requirements Analysis and Function Allocation – The HSIs should support the roles of personnel in the plant. • Task Analysis – The set of requirements to support the role of personnel is provided by task analyses that should identify: - Tasks needed to control the plant during a range of operating conditions from normal through accident conditions - Detailed information and control requirements - Task support requirements - Important Has that should be given special attention in the HSI design process • Staffing and Qualifications – The findings from analyses of staffing/qualifications should provide input for deciding upon the layout of the overall control room and allocating controls and displays to individual consoles, panels, and workstations. The staffing/qualifications analyses establish the basis for the minimum and maximum number of personnel to be accommodated, and requirements for coordinating activities between them.	3.1
8.4.1 (2)	System Requirements – The applicant should identify any constraints on the HSI design imposed by the overall I&C system.	3.1

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NUREG-0711 reference	Requirement	IP reference
8.4.1 (3)	Regulatory Requirements – The applicant should identify the applicable regulatory requirements as inputs to the HSI design process.	3.1
8.4.1 (4)	Other Requirements – The applicant should identify any other requirements that are inputs to the HSI design.	3.1
8.4.2 (1)	The applicant should develop a concept of use stating the roles and responsibilities of operations personnel based upon anticipated staffing levels. The concept of use should: • Provide a high-level description of how personnel will work with HSI resources. • Address the coordination of personnel activities, such as interactions with auxiliary operators and the coordination of maintenance and operations.	Note 1
8.4.2 (2)	The applicant should provide an overview of the HSI, covering the technical bases demonstrating that they constitute a state-of-the-art HSI design supporting personnel performance. These bases may include analyses of operating experience and the literature, tradeoff studies simultaneously considering multiple alternatives, and engineering tests and evaluations. The overview should include a description of: • Facility layouts, including workstations, large screen displays, and the nominal staff working positions. • Key HSI resources and their functionality, such as alarms, displays, controls, computer-based procedures, and other support and job aids. • Technologies to support teamwork and communication within the main control room and between the main control room, the remote shutdown facility, the TSC, EOF, and local control stations. • The responsibilities of the crew for monitoring, interacting, and overriding automatic systems and for interacting with computerized procedures systems and other computerized operator support systems.	3.2
8.4.3 (1)	The topics in the applicant's style guide(s) should address the scope of HSIs included in the design, and address their form, function, and operation, as well as the environmental conditions in which they will be used that are relevant to human performance.	3.2.1

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NUREG-0711 reference	Requirement	IP reference
8.4.3 (2)	The guidance in the applicant's style guide(s) should be developed from generic HFE guidance and HSI design-related analyses. It should be tailored to reflect the applicant's design decisions in addressing specific goals of the HSI design.	3.2.1
8.4.3 (3)	The individual guidelines in the applicant's style guide(s) should be expressed precisely and describe easily observable HSI characteristics, such as "Priority 1 alarms are shown in red." The guidelines in the style guide(s) should be sufficiently detailed so that design personnel can deliver a consistent, verifiable design meeting the applicant's guidelines.	3.2.1
8.4.3 (4)	The applicant's style guide(s) should contain procedures for determining where and how HFE guidance will be used in the overall design process. They should be written so designers can readily understand them; the text should be supplemented with graphical examples, figures, and tables to facilitate comprehension.	3.2.1
8.4.3 (5)	The applicant should maintain the style guide(s) in a form that is readily accessible and usable by designers and is easily modified and updated as the design matures. The guidance should include a reference(s) to the source upon which it is based.	3.2.1
8.4.4	8.4.4.1, General 8.4.4.2, Main Control Room 8.4.4.3, Technical Support Center 8.4.4.4, Emergency Operations Facility 8.4.4.5, Remote Shutdown Facility 8.4.4.6, Local Control Stations	3.2.2
8.4.5 (1)	The applicant should identify: • The effects of automation failures and degraded conditions on personnel and plant the performance. • HFE-significant I&C degradations, i.e., the failure modes and degraded conditions of the I&C system that might adversely affect the HSIs personnel use to accomplish important HAs.	3.2.3
8.4.5 (2)	The applicant should specify the alarms and other information personnel need to detect degraded I&C and HSI conditions in a timely manner, and to identify their extent and significance.	3.2.3

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NUREG-0711 reference	Requirement	IP reference
8.4.5 (3)	The applicant should determine any needed back-up systems to ensure that important personnel tasks can be completed under degraded I&C and HSI conditions.	3.2.3
8.4.5 (4)	The applicant should determine the necessary compensatory actions and supporting procedures to ensure that personnel effectively manage degraded I&C and HSI conditions, and the transition to back-up systems.	3.2.3
8.4.6.1 (1)	In comparing design approaches, the applicant should consider those aspects of human performance important to performing tasks. The applicant should take into account the following factors when developing criteria to apply in selecting one design approach over another: • Personnel-task requirements • Human-performance capabilities and limitations • HSI-system performance requirements • Inspection and testing needs • Maintenance demands • Use of proven technology and the operating experience of predecessor designs	3.2.4
8.4.6.1 (2)	The applicant should state explicitly the relative benefits of design alternatives and the basis for the design approach selected.	3.2.4
8.4.6.2 (1)	The applicant should identify the specific objectives of the tests.	3.2.4 Note 2
8.4.6.2 (2)	The applicant should base the general approach to testing on the test's objective(s). The following aspects of the tests should be described (note that not all items are applicable to every type of test): • Participants • Testbed • Design features or characteristics of the HSI being tested • Tasks or scenarios used • Performance measures • Test procedures • Data analyses	3.2.4 Note 2

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NUREG-0711 reference	Requirement	IP reference
8.4.6.2 (3)	The conclusions from the tests and their impact on design decisions should be described.	3.2.4

Note 1. The concept of use of the HSIs is described in the ConOps [5], which addresses this criterion.

Note 2. Details on how to perform tests and evaluations can be found in V&V IP [8].

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Enclosure 9

Xe-100 Human Factors Verification and Validation Implementation Plan

Xe-100

Human Factors Verification and Validation Implementation Plan

Configuration Classification	:	**XE00-R-R1ZZ-RDZZ-X**
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SYNOPSIS

This document provides the methodology to be followed to perform the Verification and Validation element of the Human Factors Engineering Program.

CONFIGURATION CONTROL

Document Change History

Rev.	Date	Preparer	Changes
A	04-May-2021	Hector Martinez-Pinna	Initial issue
1	21-May-2021	Hector Martinez-Pinna	Typos correction and minor changes

Document Approval

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ABBREVIATIONS

This list contains the abbreviations used in this document.

Abbreviation or Acronym	Definition
BARS	Behaviorally Anchored Rating Scale
CNSC	Canadian Nuclear Safety Commission
DI	Design Implementation
DV	Design Verification
FA	Function Allocation
FRA	Functional Requirements Analysis
FSS	Full Scope Simulator
HED	Human Engineering Discrepancy
HFE	Human Factors Engineering
HFEITS	Human Factors Engineering Issue Tracking System
HSI	Human-System Interface
HTGR	High-Temperature Gas-cooled Reactor
I&C	Instrumentation and Control
IP	Implementation Plan
ISV	Integrated System Validation
LWR	Light Water Reactor
NRC	(United States) Nuclear Regulatory Commission
NASA-TLX	NASA-Task Load Index
OER	Operating Experience Review
PMP	Program Management Plan
PV	Partial Validation
S&Q	Staffing and Qualifications
SART	Situation Awareness Rating Technique
SMR	Small Modular Reactor
TA	Task Analysis
TIHA	Treatment of Important Human Actions
TSV	Task Support Verification
V&V	(Human Factors) Verification and Validation

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DEFINITIONS

This list contains the terms of glossary used in this document.

Term	Definition
Element	From NUREG-0711 [1] the four general activities are separated into the following twelve elements: • HFE Program Management Plan • Operating Experience Review • Functional Requirements Analysis and Function Allocation • Task Analysis • Staffing & Qualification • Treatment of Important Human Actions • Human-System Interface Design • Procedure Development • Training Program Development • Human Factors Verification and Validation • Design Implementation • Human Performance Monitoring
Human Engineering Discrepancy	Human factor issue, which based upon human factors criteria identified for the Human Factors Engineering Program is identified during the execution of verification and validation activities and managed through the HFEITS, which tracks the issue to closure.
Implementation Plan	Document that describes the proposed methodology for conducting an HFE element and is reviewed by the NRC staff to reasonably assure that it will generate acceptable results that satisfy the staff's review criteria.
Integrated System Validation	Evaluation using performance-based tests to determine whether an integrated system design (i.e., hardware, software, and personnel elements) meets performance requirements and supports the plant's safe operation.
Mock-up	A static representation of a human-system interface. This may be examples of proposed graphical user interfaces, control room panels, or remote shutdown system panels. Typically, though realistic in representation, mock-ups may have limited dynamic capabilities.
Performance-based test	Test that involve assessing personnel performance, including subjective opinions, to evaluate a design.
Primary tasks management	Monitoring and detection, situation assessment, response planning and response implementation of the main tasks.
Results Summary Report	Document that summarizes the results of a completed HFE element and cites documents or files that contain the complete results.

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Term	Definition
Secondary tasks management	Ease of completion of those tasks performed on displays or other devices which requires different kinds of actions such as navigation and recording.
Simulator	A facility that physically represents the HSI configuration, and dynamically represents the operating characteristics and responses of the plant in real time. The functions and capabilities presented are determined by the phase of the design being verified and validated. The full functions and capabilities planned for the design may not be available until later in the design process. In the early phases of HSI design, a prototype simulator, not linked to a process model or simulator, may be used to perform design and verification activities.
Situation Awareness	The degree to which personnel's perception of plant parameters and understanding of the plant's condition corresponds to its actual condition at any given time and influences predictions about future states (per NUREG-0711 [1]).
Testbed	The environment or facility in which human performance is measured. The testbed typically includes a representation of the human-system interface and may include a process model that can be used for testing human and integrated human-system performance (per NUREG-0711 [1])
Verification	The process by which the design is evaluated to determine whether it provides the information, controls, and task-support needed to accomplish tasks; and conforms to the HFE design guidance.
Validation	A set of activities to ensure that a system can accomplish its intended use, goals, and objectives in the operational environment.

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1. INTRODUCTION

The Xe-100 nuclear reactor is an innovative design that is categorized as a Small Modular Reactor (SMR) due to its relatively low power, 200 MWt or 80 MWe. Its design allows for the fabrication and testing to be performed in a factory environment, so that it can be shipped to a site where it is installed as a single component. From a technological and regulatory point of view, the Xe-100 is a High Temperature Gas-cooled Reactor (HTGR) cooled by helium and moderated by graphite, implementing features that make the reactor inherently safe.

The plant configuration consists of four Xe-100 reactors, whose design is optimized since each unit shares like systems. The main purpose of a Xe-100 plant is to safely convert nuclear energy to electricity, in addition, the plant design accommodates multiple missions such as process heat applications.

As required by the licensing process and NUREG-0711 [1], a Human Factors Engineering (HFE) Program shall be developed[1], with proven systematic analysis techniques to address human factors issues within the design process. The HFE program and its products reflect state-of-the-art human factors principles.

As described in the HFE Program Management Plan (HFE PMP) [3], one of the first steps in the HFE Program is the preparation of Implementation Plans (IPs) that describe the proposed methodology for the performance of a specific HFE program element.

In accordance with NUREG-0711 [1] and NUREG/CR-3371 [9], an IP provides an opportunity to obtain a review and concurrence from the regulatory staff of the proposed methodology before performing the work associated with the element. This early review is desirable because it offers the staff an opportunity to identify potential issues with the methodology and to provide the Xe-100 design team with early input to the analysis or design processes, when staff concerns can more easily be addressed, rather than when the element has been completed.

As presented in NUREG-0711 [1], the twelve elements have been arranged in four general activities: planning and analysis, design, verification and validation, and implementation and operation. This is the IP related to human factors verification and validation (V&V), the tenth element of the HFE Program, per NUREG-0711 [1].

1.1. PURPOSE

The purpose of this document is to describe the methodology to be followed in the development of the V&V and to establish the specific requirements of the corresponding Results Summary Report. In accordance with the HFE PMP [3], the V&V element encompasses several activities[2] which can be organized as follows:

- Major activities:

[1] Refer to 10 CFR 50.34 (f)(2)(ii), 10 CFR 50.34 (f)(2)(iii) [10], and REGDOC-2.2.1, Human Factors [10].

[2] The HFE Program execution is an iterative process. Therefore, this organization of V&V activities does not imply that they are performed sequentially.

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i. HSI Task Support Verification (TSV)

ii. HFE Design Verification (DV)

iii. Integrated System Validation (ISV)

- Advanced added value activities:

iv. Partial Validations (PVs)[3]

- Human Factors Issues Management Activity:

v. Human Engineering Discrepancy (HED) Management via the Human Factors Engineering Issue Tracking System (HFEITS)

The above-mentioned major activities are supported by a context activity to select the applicable interfaces and scenarios following sampling criteria.

- Supporting activity:

vi. Sampling of operational conditions

The detailed information about the specific objectives and scope of each of them is included in Section 3.

1.2. SCOPE

This IP applies to the V&V to be performed in accordance with the criteria as defined in the HFE Program for the HFE licensing of the Xe-100 plant design. Therefore, this IP has been tailored to address the licensing process as established in the HFE PMP [3].

1.3. RELATIONSHIP TO OTHER DOCUMENTS

This IP is part of the HFE Program described in the HFE PMP [3], which includes high-level considerations that shall be known by the reader of this IP. Other HFE Program elements are related to the V&V; therefore, the IPs of these elements are cross-referenced where needed. Figure 1 shows the relationship between the V&V IP and other documents within the HFE Program.

[3] Partial Validations, which are not included as part of NUREG-0711 specific requirements in the V&V element, are proposed as advanced high-value tests and evaluations, and prior to the ISV execution. See section 3.2.3.2 for details.

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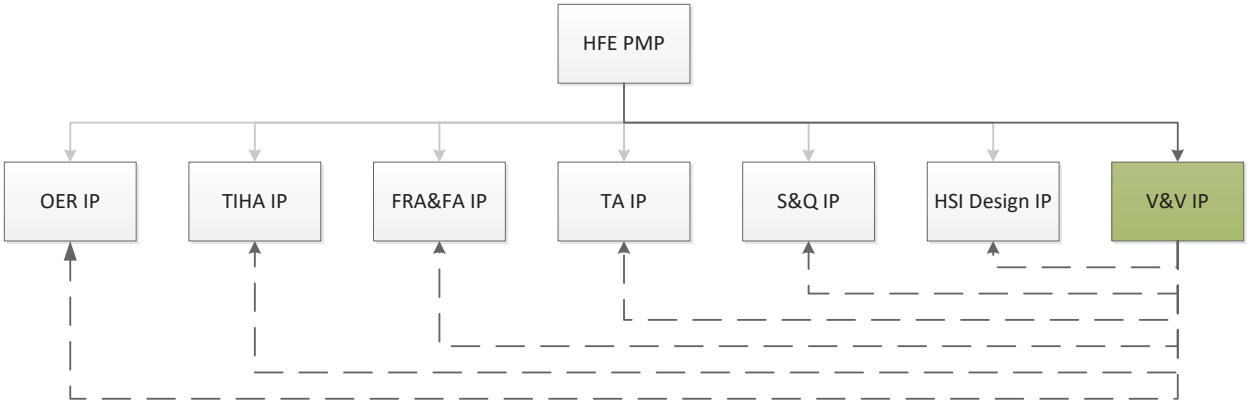

Figure 1: Relationship of V&V IP to other documents within the HFE Program

1.4. DOCUMENT LAYOUT

The V&V IP is formatted as follows. Section 1 addresses the document introduction, purpose, scope and relationship to other documents. Section 2 identifies the references used in this IP. Section 3 describes the methodology, from the inputs, through the process and the expected outputs. Section 4 addresses how the outputs shall be documented. Section 5 includes as an appendix a checklist to verify compliance of this IP with the corresponding NUREG-0711 [1] review criteria.

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2. REFERENCES

The following documents are referenced within this document.

	Document Title	Preparer/Author	Document Number	Revision or Date of Issue	Classification	Applicable[4] (Yes/No)
[1]	NUREG-0711, Human Factors Engineering Program Review Model	NRC	N/A	Rev 3	N/A	Yes
[2]	REGDOC-2.2.1, Human performance management Human Factors	CNSC	N/A	2019	N/A	Yes
[3]	TEC-XE100-HFE-PMP, Human Factors Engineering Program Management Plan	Tecnatom	N/A	Rev 0	N/A	Yes
[4]	TEC-XE100-HFE-COO, Concept of Operations	Tecnatom	N/A	Rev 0	N/A	Yes
[5]	NUREG-0700, Human-System Interface Design Review Guidelines	NRC	N/A	Rev 3	N/A	Yes
[6]	NUREG/CR-7126, Human-Performance Issues Related to the Design and Operation of Small Modular Reactors	NRC	N/A	2012	N/A	Yes
[7]	NUREG/CR-7202, NRC Reviewer Aid for Evaluating the Human-Performance Aspects Related to the Design and Operation of Small Modular Reactors	NRC	N/A	2015	N/A	Yes
[8]	NUREG/CR-7190, Workload, Situation Awareness, and Teamwork	NRC	N/A	2015	N/A	Yes
[9]	NUREG/CR-3371, Task Analysis of Nuclear Power Plant Control Room Crews	NRC	N/A	1983	N/A	Yes
[10]	10 CFR 50.34, Contents of applications; technical information	NRC	N/A	2019	N/A	Yes

[4] Applicable documents are applicable to the extent specified within this document and thus deemed to form part of this document.

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3. DEVELOPMENT

This section includes a description of main documents or sources required to perform the V&V activities, followed by a systematic process definition to further develop the element, and a collection of the outputs expected due to the methodology implementation.

It should be noted that the V&V element is tightly related to the rest of the elements of the HFE Program (see Figure 2); therefore, its development shall consider the processes and outputs from all other elements.

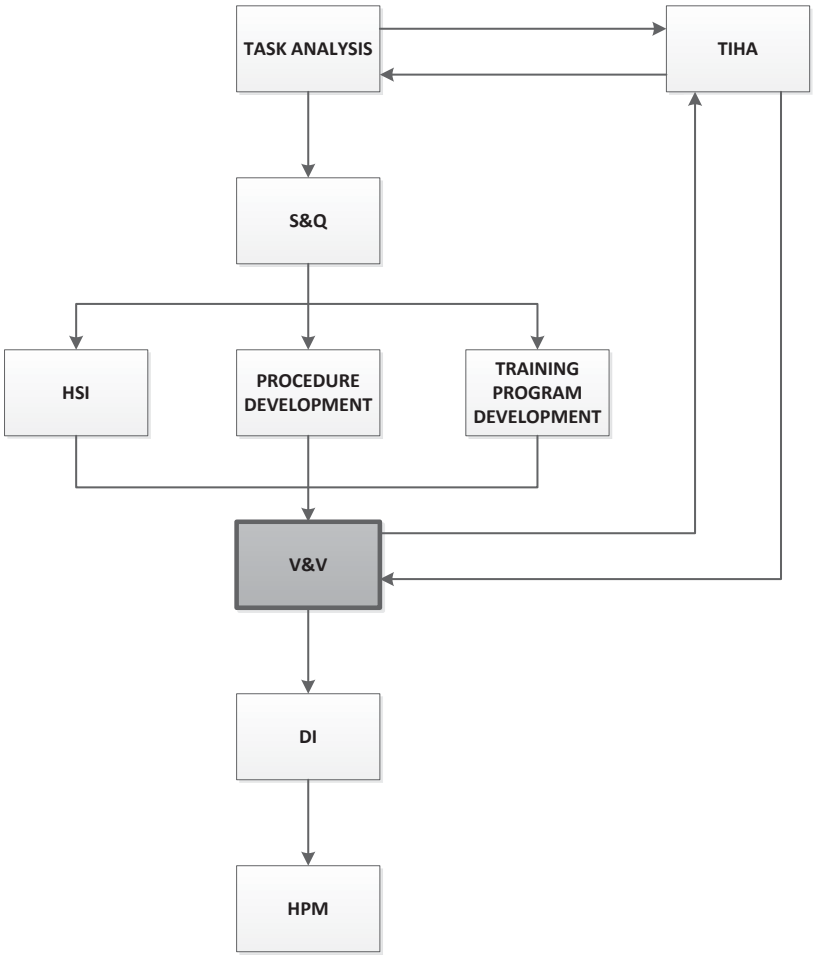

Figure 2: V&V and general relations with the rest of HFE elements (adapted from NUREG-0711 Rev. 3)

3.1. INPUTS

The inputs to be considered for the entire V&V element are divided into the following categories:

- General design bases inputs: International standards, normative and/or guidelines, engineering design documents, and applicable plant operation and training procedures are used as inputs, as applicable, in each phase of the V&V activity. This set of documents includes, but is not limited to the following:

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i. Entire V&V element:

a) NUREG-0711, Human Factors Engineering Program Review Model, revision 3, NRC

b) IEC 1771, Nuclear Power Plants Main Control Rooms-Verification and Validation of Design, International Electrotechnical Commission, 1995

ii. HFE Design Verification:

a) NUREG-0700, Human-System Interface Design Review Guidelines, revision 3, NRC

b) IEC 60964, Nuclear Power Plants – Control Rooms – Design, International Electrochemical Commission, 2009

c) ISO 11064-7 Ergonomic Design of Control Centres: Part 7: Principles for the Evaluation of Control Centres, 2006

iii. Integrated System Validation:

a) NUREG/CR-6393, Integrated System Validation: Methodology and Review Criteria, NRC, 1997

b) ANSI/AIAA G-035A-2000, Guide to Human Performance Measurements, AIAA, 2001

c) ANSI/ANS 3.5-2009, Nuclear Power Plant Simulators for Use in Operator Training, American Nuclear Society, 2009

d) IEEE Std. 845-1999, IEEE Guide to the Evaluation of Human-System Performance in Nuclear Power Generating Stations, Institute of Electrical and Electronics Engineers, 1999

e) NUREG/CR-7190, Workload, Situation Awareness and Teamwork, NRC, 2015

f) NUREG-0800, “Standard Review Plan for the Review of Safety Analysis Reports for Nuclear Power Plants: LWR Edition”, Chapter 18, “Human Factors Engineering”, Attachment B, “Methodology to Assess the Workload of Challenging Operational Conditions”, revision 3, NRC

- Inputs from prior HFE program elements:
  i. HFE PMP [3]
  ii. Xe-100 Plant Concept of Operations [4]
  iii. Operating Experience Review (OER)
  iv. Task Analysis (TA)
  v. Integration Style Guide
  vi. HSI Design (for all the interfaces, either software or hardware based)
  vii. Treatment of Important Human Actions (TIHA)
  viii. Staffing & Qualifications (S&Q)
- Specific X-Energy inputs (revisions in force):
  i. XE-P1-PL-G0-D24-100483, Preliminary Xe-100 Plant Control Philosophy

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ii. XE00-B-G1ZZ-GLZZ-E, Systems Engineering Management Plant

iii. XE00-B-G1ZZ-GLZZ-D, Xe-100 Nuclear Power Plant Modes & States

- X-Energy Engineering controlled design input documents:

  i. Xe-100 plant engineering documents used in the preparation of HFE Functional Requirements Analysis and Function Allocation, TA and HSI Design elements

  ii. Plant operating procedures that may be completed

  iii. Applicable operator training materials

The inputs used in the V&V activities will be under the Configuration Control of the project. The procedures used for the performance of the V&V activities will be based on design inputs provided by the project and may include, but are not limited to: HFE reports, plant system drawings, plant system procedures, etc. The procedures prepared for the performance of the V&V activities shall identify the design input documents and revisions.

The HEDs prepared during the performance of the V&V activities will identify the affected HSI, documents, etc. The revision control between the inputs and outputs allows for analysis and resolution of the HEDs using controlled documents.

3.2. METHODOLOGY

This section presents the details of the methodology to be followed for the performance of the V&V activities. An overview is shown in Figure 3.

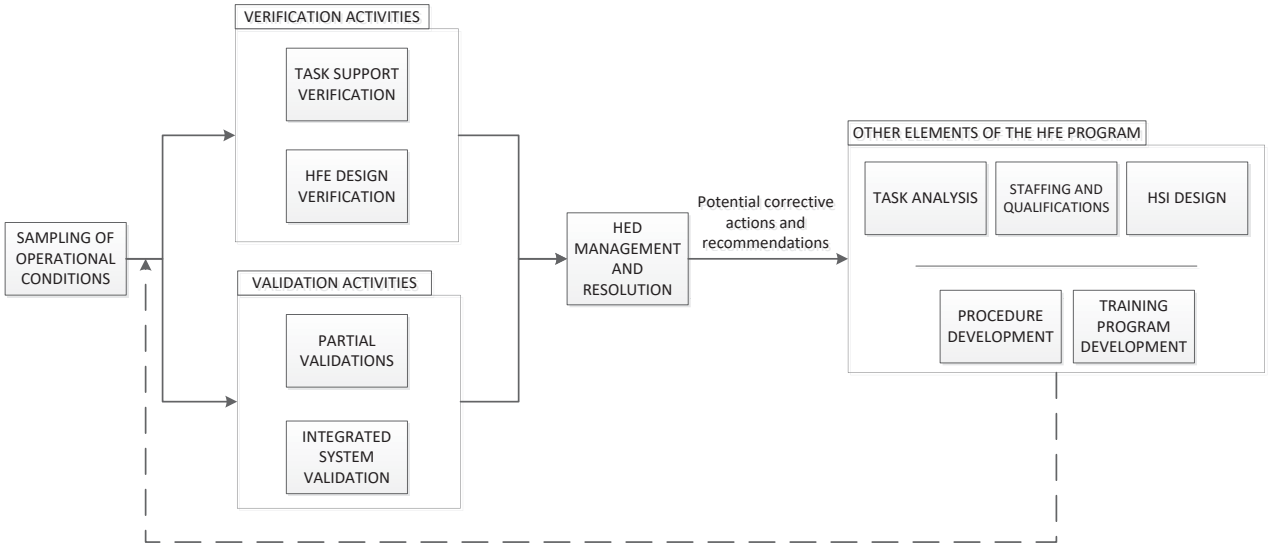

Figure 3: Overview of V&V activities

It is worth noting that members of the team performing the V&V activities shall be independent from the design being verified or validated.

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3.2.1. Sampling of Operational Conditions

As presented in Section 1.1, the sampling of operational conditions activity supports and provides context to the major V&V activities. The HFE tests and evaluations of a new plant design can involve thousands of individual HSIs, so following a sampling strategy is important to select those HSI that:

- Include conditions representative of the range of events that could be encountered during the operation of the Xe-100 plant.
- Reflects the characteristics expected to contribute to variations in the system's performance.
- Considers the safety significance of the HSI.

The sampling dimensions to identify the conditions to be addressed (refer to NUREG/CR-7126 [6] and NUREG/CR-7202 [7]) are:

a. *Plant conditions*: among the plant conditions to be considered for the Xe-100 plant V&V activities, the following shall be included:
    - Normal operations
        - Non-LWR processes and reactivity effects
        - Novel refueling methods
        - Load-following operations
        - Control room configuration and workstation design
        - HSI design for multi-unit monitoring and control
        - Normal events – plant modes changes
    - Instrumentation and control (I&C) system and HSI failures
        - Automation failures
        - Degraded conditions (e.g., of one unit while the others are operating normally)
    - Off-normal conditions and emergencies
        - Safety Function Monitoring
        - Unplanned shutdowns
        - Handling off-normal conditions at multiple sites
        - Design of emergency operating procedures for multi-unit disturbances
        - New hazards (e.g., new SMRs that use graphite in the core, such as the HTGR design, may present a potential flammability event)
        - Passive safety systems (how personnel interact with the monitoring systems, verification of the initiation and success, and back them up should they fail)
        - Loss of HSIs and control room habitability

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- Transients (abnormal operational events) and accidents (emergency operational events), such as:
  - Reactor trip
  - Turbine trip
  - Loss of offsite power
  - Stuck-open primary relief valve
  - Loss of coolant accident (LOCA)
- Maintenance
  - HSI maintenance activities (e.g., main control room HSI maintainability)

b. *Personnel tasks*: among the different operation personnel tasks to be considered, the following shall be included:

- Risk Important human actions (extracted from the TIHA element execution[5])
- Manual initiation of protective actions
- Automatic System Monitoring (special attention to Safety Parameter Display System monitoring)
- OER identified risk important tasks (extracted from the OER element execution[6])
- Procedure guided tasks
- Knowledge based tasks
- Human cognitive activities (specially to be observed during the ISV)
- Human interactions

c. *Error-forcing contexts*: to evaluate how the HSIs support the operators under challenges of performance, the following situations shall be considered:

- High-workload situations (multi-unit operations and teamwork)
- Varying workload situations (e.g., from normal operation to specific situation of higher workload during refueling monitoring)
- Fatigue situations (e.g., continuous monitoring with minimum staff)

This sampling strategy shall give context to each of the V&V activities, providing the necessary inputs for verification and validation:

- Task Support Verification: Using the HSIs and TA developed as part of the HFE program

[5] Important human action results from the TIHA analysis shall be included in the sampling to treat them in the V&V element to validate that the HSI supports safe performance when executing risk important human actions.

[6] Those issues identified during the OER execution, related to personnel tasks and applicable to Xe-100 plant, shall be incorporated into the V&V element to be addressed in the corresponding tests and evaluations.

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- HFE Design Verification: Using the HSIs selected (from main control room and/or other facilities[7]) and constituting the HSI inventory and characterization
- Integrated System Validation: Using a set of scenarios based on the sampling strategy to address the relevant plant conditions[8]

3.2.2. Verification activities

The two main verification activities to be considered are Task Support Verification and HFE Design Verification, with the objective of verifying that the inventory and characterization accurately describes all HSI displays, controls, and related equipment necessary to complete the tasks identified in the scenarios identified and as a part of the sampling of operational conditions.

An inventory of the HSI is prepared to describe the characteristics of each HSI within the scope of the verification. The following information will be provided for each HSI, at a minimum:

- a unique identification code number or name
- associated plant system and subsystem
- associated personnel functions and tasks
- type of HSI, for example:
  - computer-based control (e.g., touch screen or cursor-operated button and keyboard input)
  - hardwired control (e.g., J-handle controller, button, and automatic controller)
  - hardwired display (e.g., dial, gauge, and strip-chart recorder)
- display characteristics and functionality, for example:
  - plant variables/parameters
  - units of measure
  - accuracy of variable/parameter
  - precision of display
  - dynamic response
  - display format (e.g., bar chart or trend plot)

Other examples of characterization are provided in NUREG-0711 [1] and may be used as applicable to the HSI.

[7] See the HFE PMP [3] for details about the applicable facilities.

[8] Note that the list of final scenarios applicable to the test and evaluation (e.g., ISV) will be included in the specific ISV procedure prior to the execution of the activity, in which they will be widely described for all the participants.

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3.2.2.1. Task Support Verification

The objective of the HSI Task Support Verification is to ensure that the HSIs provide the necessary information, controls, alarms, and procedures to support the tasks to be performed by the personnel as defined by the task analysis criteria as part of the HFE program. Therefore, this analysis will be performed with the following inputs from the HFE program:

a. HSI Design

b. Task Analysis

c. Operational conditions and scenarios identified from the sampling of operational conditions analysis

Using the identified scenarios and operational conditions, the TSV will be based on a comparison between the HSIs under the scope of V&V (those selected following the sampling strategy indicated in previous Section 3.2.1), and the tasks being performed by the personnel. Verification that the identified tasks can be performed with the available HSIs (defined by the HSI Design) will be documented using a checklist format.

3.2.2.2. HFE Design Verification

The objective and scope of the HFE Design Verification (DV) is to verify that the design of the HSI Design (for all the selected interfaces either software or hardware based on the Sampling of Operational Conditions) conforms to the applicable HFE guidelines, addressing the suitability of the HSI regarding human capabilities and limitations.

The following sections from NUREG-0700 [5] are related to HSI design and will be used in the performance of the DV:

Part 1. Basic HSI Elements

1. Information Display
2. User-Interface Interaction and Management
3. Analog Display and Control Devices

Part 2. HSI Systems

1. Alarm System
2. Safety Parameter Display System
3. Group-View Display System
4. Soft Control System
5. Computer-Based Procedure System
6. Automation System
7. Communication System

Part 3. Workstations and Workplaces

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1. Workstation Design
2. Workplace Design

Part 4. HSI Support

1. Maintainability of Digital Systems
2. Degraded HSI and I&C Conditions

For each of the HSIs, a verification checklist shall be prepared, including reference numbers to the applicable criteria in NUREG-0700 [5]. The selection of applicable criteria from NUREG-0700 [5] will be based on the characteristics of the HSI being evaluated.

A checkbox will be included, and marked as appropriate, to indicate whether the HSI is acceptable or not in accordance with the applicable HFE criteria required for the corresponding task being evaluated:

- Yes/Acceptable - the HSI conforms to the selected guideline and the compliance is total.
- No (but acceptable) - the HSI does not conform to the applicable guideline, but there is a reasonable justification and an analysis that justifies it is available.
- N/A - the overall NUREG-0700 selected section is applicable, but not the specific guideline because it addresses features not found on the HSI being evaluated.
- Discrepancy - the HSI does not conform to the applicable guideline and upon initial review a bases for the design cannot be identified. Therefore, a HED is prepared and logged into HFEITS for further review and disposition within the HFE program.
- Pending - the HSI cannot be evaluated at the time the HFE Design Verification was performed due to lack of HSI capability (e.g. the dynamic features of a component of the HSI cannot be verified due to development process or simulation capability). Therefore, it is a pending guideline to be verified in future revisions of the iterative HSI cycle when the applicable information is available. An HED is prepared and entered in the HFEITS so that this HSI can be verified at a later point in the project.

The completion of the verification checklists with the applicable guidelines and their annotated compliance checkboxes form the basis for results of the HFE Design Verification of each of the HSIs included in the corresponding report.

3.2.3. Validation activities

The main HFE validations to be considered are the Integrated System Validation and the Partial Validations, described in the following subsections.

3.2.3.1. Integrated System Validation

Using performance-based tests, the integrated system (hardware, software, procedures, and personnel elements) validation is performed to verify that safe operation of the plant is supported.

The ISV uses the scenarios identified (based on the Sampling of Operational Conditions, refer to section 3.2.1) and is performed using the full scope simulator (FSS) or a similar suitable representation of the

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integrated system, that allows for verification of the design's ability to support the safe operation of the plant. The validation will be performed after the resolution of all significant HEDs identified in the verification reviews.

The necessary elements to be considered for the planning, execution and documentation of the ISV are the following:

- Validation team
- Test objectives
- Validation testbed
- Plant personnel
- Selected scenario
- Performance measurement
- ISV design
- Data analysis and HED identification
- ISV conclusions

3.2.3.1.1. Validation Team

The personnel responsible in the preparation, executing and recording of the ISV shall be an independent team. Although the V&V team members may work for the same organization, their responsibilities should only include V&V and not participation in the design.

The HFEITS designed for the HFE Program and described in the HFE PMP [3] will be used by the V&V team to prepare, resolve, and close HEDs identified during the V&V activities. The HFEITS will be managed through the project life cycle with clear traceability of all the personnel involved.

As a minimum, the ISV team will consist of personnel qualifications and expertise in the following areas:

- Human Factors Engineering
- Plant operations
- Plant procedures
- System engineers, as necessary
- Psychology experts, specifically in the area of human behavior and evaluations of human actuation
- Hardware and/or software experts, with knowledge of the HSI Design being evaluated
- Plant simulator

The personnel who conduct the validation tests will be trained on the use and importance of test procedures; errors that may be introduced due to failure to follow the test procedures or improper interaction between participants; and the importance of accurately documenting problems arising during testing (even if they were due to an oversight or error of those conducting the test).

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3.2.3.1.2. Test Objectives

The following detailed test objectives and considerations will be addressed to provide evidence that the integrated system adequately supports plant personnel in safely operating the plant:

- Validate the acceptability of the shift staffing level(s), the assignment of tasks to crew members, and crew coordination within the control room between the control room and local control stations and support centers, and with individuals performing tasks locally.
- Validate that the design has adequate capability for alerting, informing, controlling, and providing feedback such that personnel tasks selected are successfully completed during normal plant evolutions, transients, design-basis accidents, and also under selected, risk significant events beyond-design basis, as defined by sampling operational conditions.
- Validate that specific personnel tasks can be accomplished within the time and performance criteria, with effective situational awareness, and acceptable workload levels that balance vigilance and personnel burden.
- Validate that the HSIs minimize personnel error and assure error detection and recovery capability when errors occur.
- Validate the assumptions about performance on identified important human actions.

3.2.3.1.3. Validation Testbed

The ISV for the Xe-100 project will be performed when the FSS becomes available. The use of the FSS for this activity assures that the integrated system clearly represents with a high functional and physical fidelity to the Xe-100 plant design. In addition to representing the completed integrated system, the fidelity of the FSS will include:

- Interface physical fidelity
- Interface functional fidelity
- Environmental fidelity
- Data completeness fidelity
- Data content fidelity
- Data dynamics fidelity

The FSS may not be available until a later stage in the project and it may become necessary to perform partial phased validations (see Section 3.2.3.2). Mock-ups, virtual reality, and other acceptable testing tools may be used to verify the requirements for human performance.

Prior to the availability of the FSS, test beds with the necessary functionality and physical fidelity may be used as necessary. Within the limits of the test bed, the HSI and procedure functionality should be represented with high fidelity to the reference design that allows performance of the planned ISV activities. The functionality and procedures will be evaluated so that the HSI represented can be used for the selected scenarios and the validation.

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The results of any validation (ISV or partial) will be part of validation activities and, as such, identified HED will be included in the HFEITS.

3.2.3.1.4. Plant Personnel

The operation personnel to participate in the ISV shall be representative of the final plant staffing (e.g. licensed operators or experienced operation personnel), considering human variability, the shift levels involved in the plant operation, and avoiding end users with previous participation in the HSI Design and/or with negative effects on the independent validations. Additionally, they should be appropriately trained according to the training program with the HSIs (including procedures) under evaluation. Therefore, at least an initial version of the procedures shall be ready in advance.

The final operation personnel for the ISV shall be selected paying attention to:

- Address all the positions/composition of the staff proposed (as indicated after the S&Q is performed)
- Consider the minimum shift staffing levels, nominal levels, and maximum levels, including shift supervisors, reactor operators, shift technical advisors, etc.
- Prevent bias in the sample of participants by avoiding the use of participants who:
  - are members of the design organization.
  - participated in prior evaluations.
  - were selected for some specific characteristic, such as crews identified as good performers or more experienced.

Due to the new design of the Xe-100, the personnel selected may be licensed on other plant designs. During the performance of any of the V&V phases, it is understood that the personnel may have been trained using a test bed that does not have the complete integrated design of the reference plant.

3.2.3.1.5. Selected scenarios

Based on the sampling of operational conditions (see Section 3.2.1), the ISV shall contain the selected scenarios, detailing among others:

- Scenario overview
- Scenario goals
- Identification of tasks
  - Primary tasks
  - Secondary tasks
- Expected operator actions
- Communication/interaction expected from operators
- Relevant data/parameter information

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The scenarios selected for the V&V may be adjusted for the fidelity of the test bed being used. The test bed may not have the functionality and fidelity to allow for the performance of all the scenarios. The specific ISV procedure will identify the characteristics of the test bed and what scenarios will be performed.

3.2.3.1.6. Performance Measurement

The specific plant performance measures applicable to each ISV scenario are identified.

The measures chosen to evaluate personnel task performance will reflect those aspects of the task that are important to system performance.

Objective measures - To be collected during the scenario execution by the V&V team according to objective parameters:

- Time
- Accuracy
- Frequency
- Amount accomplished
- Consumption or quantity used

The analysis of primary tasks will support the identification of errors of omission (primary tasks not performed). Also, any actions and tasks that operators perform that deviate from the primary tasks should be identified and noted. These actions should be used to identify errors of commission.

Subjective measures - to be collected by the V&V team according to the observations made during the scenario execution include**:**

- Subjective reports of participants
- Annotations by observers related to human actuation

In addition to the above-mentioned measures, the following three constructs (workload, situation awareness, and teamwork) shall be measured to evaluate the *cognitive factors* (refer to NUREG/CR-7190 [8]), especially relevant when operating a SMR.

Workload - The high levels of automation in a SMR are expected to significantly lower physical and mental workload. However, it creates other human-performance difficulties (loss of vigilance, other human errors, etc.).

In the Xe-100 plant main control room, it is planned that one or two reactor operators will be monitoring and controlling four units. In addition to monitoring and control, there will be communication dynamics between the operators that will be evaluated. This staffing configuration may create human-performance issues related to multi-module interactions.

The schema illustrated in Table 1 is proposed to use the appropriate metric, assuring that it is non-intrusive, reliable, valid, sensitive and diagnostic.

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Table 1: Workload measurement

Factor	Workload
Proposed metric	NASA-TLX
Measurement Plan	In individuals
Administration	Post task
Responsible for completing the metric	Participant/Operator

The corresponding report for the ISV will include the results of the administration of this NASA-TLX metric for each of the scenarios selected, detailing the results for the six sub-scales in which it is divided:

- Mental demand
- Physical demand
- Temporal demand
- Performance
- Effort
- Frustration

Situation awareness - The HSI design for multi-unit monitoring and control will aid the operators in maintaining a high-level of awareness of the status of the four units. The specific HSI for one unit is designed to prevent confusion with any other unit.

The schema illustrated in Table 2 is proposed to use the appropriate metric, assuring that it is non-intrusive, reliable, valid, sensitive, and diagnostic.

Table 2: Situation Awareness measurement

Factor	Situation Awareness
Proposed metric	SART
Measurement Plan	In individuals
Administration	Post task
Responsible for completing the metric	Participant/Operator

The corresponding report for the ISV will include the results of the administration of this SART metric for each of the scenarios selected, detailing the results for the three dimensions in which it is divided:

- Demand

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- Supply
- Understanding

Teamwork - When accomplishing the task of multi-unit monitoring and control, teamwork becomes a key issue. Based upon the function allocation, the HSI design assists the operator in monitoring overall plant performance and safety. Confirming that the suitable information is accessed and monitored by individuals or teams in their task performance, is evaluated during the ISV.

The personnel performance involves not only performance of the necessary tasks (identified by the task analysis), but also how well all the individuals work as a team in coordinating activities and communicating together.

The schema illustrated in Table 3 is proposed to use the appropriate metric, assuring that it is non-intrusive, reliable, valid, sensitive, and diagnostic.

Table 3: Teamwork measurement

Factor	Teamwork
Proposed metric	Behaviorally Anchored Rating Scale (BARS)
Measurement Plan	In teams
Administration	Post task
Responsible for completing the metric	Participant/Operator

The corresponding report for the ISV will include the results of the administration of this BARS metric for each of the scenarios selected, detailing the results for several behavioral categories, such as:

- Communication
- Openness
- Coordination
- Team spirit
- Task focus and decision making

Anthropometric and physiological measures - Among other factors, the following shall be considered[9]:

- Visibility of displays
- Accessibility of control devices

[9] Note that most of these anthropometric factors are verified prior to the ISV performance. The HFE Design Verification and Partial Validation activities pay attention to them, using the ISV only for those aspects which may require the integrated system to be completely assessed.

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- Ease of manipulation of control devices
- Ability of personnel to effectively use workstations or consoles while performing their tasks

The basis for the performance criteria can be a combination of factors related to the corresponding measure that identifies the acceptability of performance. Therefore, the following shall be considered:

- Rating established in the different metrics used (e.g. for workload, situation awareness and teamwork with the minimum, maximum and intermediate scores)
- Requirements, if applicable (e.g. required time to complete a task according to engineering analyses)
- Expert judgement (e.g. recommendations based on V&V team experience and operation personnel knowledge)
- Norms, if applicable (e.g. specific performance required according to a predecessor system)

3.2.3.1.7. ISV Design

According to the HFE PMP [3], a specific ISV Procedure shall be prepared prior to performing the ISV to ensure that all the ISV participants understand the activity and the manner in which it is going to be performed.

Among the different aspects to be included in this procedure, the following are especially relevant:

- Scenarios and sequencing: list of scenarios for the test and the assignment to a crew and the order in which the scenarios should be presented.
- Methodology: the ISV procedure will contain the specific instructions for all the participants and the steps to be followed so everyone understand the objectives.
- Participants: The V&V team shall be independent and with sufficient experience to perform the test and clearly present it to the operation staff and other interested personnel. Additionally, the different operation crews should be representative and knowledgeable of the HSI, procedures and the integrated system.
- Potential pilots: if necessary, simple pilots may be executed prior to the ISV to assure the adequacy of the final ISV, performance measures and data collection methods. To ensure unbiased results, the participants used in the pilot will not be those who participate in the validation tests.
- Documentation: as applicable, to be used to capture the ISV performance including checklists, data gathering tables questionnaires, audio recording devices and the use of video.
- A staff identified to collect the results and to prepare the preliminary report.

3.2.3.1.8. Data Analysis and HED Identification

The following items shall be considered for the ISV results analysis:

- A combination of quantitative and qualitative methods will be used to analyze data. The analysis should reveal the relationship between the observed performance and the established performance criteria.

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- The methods by which data is analyzed across trials, including the criteria used to determine successful performance for a given scenario.
- The degree of convergence between related measures (i.e., consistency between measures expected to assess the same aspect of performance) will be evaluated as applicable.
- When interpreting test results, a margin of error will be allowed to reflect the fact that actual performance may be slightly more variable than observed validation-test performance.
- The correctness of the analyses of the data will be verified. This verification will be performed as part of the ISV results reports revision, by individuals or groups other than those who performed the original analysis but may be from the same organization.
- When an observed performance does not meet the performance criteria, an HED will be identified and logged into the HFEITS.
- HEDs identified by pass/fail measures will be resolved before the design is accepted.

3.2.3.1.9. ISV Conclusions

The analysis and acceptance of the ISV results for determining that performance of the integrated system is adequate will be documented. Any limitations identified in the ISV and their possible effects on the conclusions of the validation, and their impact on implementing the design will also be documented.

3.2.3.2. Partial Validations

The ISV is an important final test, performed after the resolution of all the significant HEDs identified during the verification process (TSV and DV activities) and it is executed when a full scope simulator is available, providing an integrated system identical to the final plant operation environment. The expected results, if the HFE process is properly implemented, should not identify significant discrepancies that require modifications to the already designed and manufactured HSIs.

For this reason, previously performed verifications and partial validations are highly recommended to ensure that the HSI Design delivered for ISV has been previously reviewed and identified HEDs have been closed. The main advantages of performing partial validations prior to the final ISV and in parallel with the HSI Design process are:

- Tests and evaluations in a less complex format than the ISV can be performed in advance to obtain added value feedback to improve the HSI design
- These validations are performed with sufficient time margin to detect potential modifications so they can be implemented in time and with lower cost and effort than waiting until the final ISV performance.
- These validations maximize the power of mock-ups and new technologies (virtual reality, graphic simulators, etc.) to test the different options and refine the HSI design as much as possible.
- These validations are a powerful tool that involve critical roles during the design and manufacturing processes (end-users, designers, V&V team, manufacturers, and implementation teams, etc.), achieve an integrated design and minimize potential difficulties in the future.

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- These validations provide an opportunity to obtain advanced acceptability of the proposed design by testing different design options if necessary.
- Performance of the validations act as training tools for the planned operating crews.

Based on project design schedules, several PVs may be developed and performed with the same philosophy as the ISV but limiting the scope consistent with the fidelity of the HSI being evaluated. The test and evaluation conditions of these PVs are typically checked prior to the performance to assure that they are appropriate for the validation objectives (design features to be validated).

Among the different design features that may be considered for validation are the following:

- Staffing levels - The different iterations described in the S&Q IP to determine the final staffing plan proposed can be validated through successive performance-based tests. The first staffing test is performed in a partial validation performance-based test, whereas the final staffing plan validation is performed during the ISV.
- Specific HSIs - The performance-based tests can be used to verify that a specific HSI meets the postulated performance criteria, or to evaluate different design options for it.
- Anthropometric features - Some characteristics (e.g. visibility, access to control devices, etc.) typically verified during the HFE DV in a static manner require additional validation using performance-based tests/mock-ups, so the test can confirm that the HSI Design proposed meets the HFE principles and recommendations.

3.2.4. Human Engineering Discrepancies Management

Human engineering discrepancies (HEDs) are the HFE issues identified during the performance of the V&V activities:

- Task Support Verification
- Design Verification (DV)
- HFE Design Verification
- Integrated System Validation
- Partial Validations

The management and resolution of HEDs is performed using the HFEITS, as described in the HFE PMP [3].

HED resolution may be performed iteratively throughout V&V. Thus, issues identified during one V&V activity can be addressed and resolved before starting another V&V activity.

The types of HEDs identified are dependent on the V&V activity being performed. For example, the HEDs may include the following:

a. Task Support Verification
    i. Unavailable HSIs for the task performance
    ii. HSI design features that do not match personnel requirements

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iii. Available HSIs not linked to a specific task

b. HFE Design Verification - All the HEDs identified and marked on the corresponding checklist during the performance of the DV.

c. Integrated System Validation- HEDs identified during the performance of the scenarios selected for ISV and those that may affect any of the elements of the integrated system.

d. Partial Validations - HEDs identified during the tests and evaluations that may have been performed in parallel to the design and prior to the ISV, so the necessary changes are identified and corrected in advance of other V&V activities.

HEDs identified during the performance of the V&V evaluations may affect several elements of the HFE program requiring corrective revisions to the applicable documentation, including:

- Task Analysis (e.g., possible modifications of tasks requirements)
- S&Q (e.g., modifications of the initial S&Q baseline)
- HSI Design (e.g., modifications of the verified design)
- TIHA (e.g., modifications of the HSI to facilitate the support to operation personnel during the execution of important human actions)

For each of the identified HEDs, sufficient information shall be provided to identify the affected element (task, HSI, etc.) and the basis for the identified discrepancy (aspect not met, discrepant HFE guideline, etc.).

An analysis and evaluation shall be performed to resolve HEDs identified during the performance of the other HFE program elements. As applicable, corrective changes will be made to the applicable HSI and any supporting documentation.

A full description of the HFEITS is provided in the HFE PMP [3].

3.3. OUTPUTS

The outputs from the V&V element are determined by the specific V&V activity being performed:

a. Sampling of operational conditions - A list of final operational conditions to be considered to serve as input to the rest of the V&V activities:

   i. HSI inventory to be verified and validated

   ii. Group of scenarios to be included under the scope of the final ISV

b. Task Support Verification - Verification checklist of tasks to be performed by operation personnel (as defined by the TA) and the confirmation that the inventory of controls, indications, and alarms of the HSI is correct to perform them. Unnecessary indications and controls may also be identified.

c. HFE Design Verification - For each of the HSIs subject to verification, a confirmation is made that they are designed according to the applicable HFE principles in accordance with NUREG-0700 [5] guides.

d. Integrated System Validation - Results of the final performance-based test with the integrated system, confirming that it supports the safe operation of the plant.

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e. Partial Validations - Results of the partial performance-based tests executed to obtain advanced feedback about specific objectives (staffing levels, HSI specific design selection, etc.).

f. HED Management - Collection of all the HEDs generated during the project lifecycle for all the V&V activities and according to the process described in the HFE PMP [3].

g. Any video or audio recordings as applicable will be identified and provided.

h. Any photographs or electronic copies as applicable will be identified and provided.

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4. DOCUMENTATION

The outputs and results described in the previous section will be documented separately for specific V&V activities. Therefore, the following reports[10] are expected from the V&V.

a. Task Support Verification and Design Verification Report. - The results of the TSV and the DV will be documented in tables and/or checklists with all the tasks identified by TA and the inventory of controls, indications, and alarms to perform them. The results of this activity are pass/fail type, addressing the availability of items needed to support task requirements. HEDs produced from this activity will also be included.

   i. Table with all the design input documents:

      a) HFE reports for each system used in the TSV and the DV.

      b) List of all engineering documents used by type and revision number.

      c) List of HSIs to be verified.

      d) Any video or audio recordings as applicable will be identified.

   ii. Analysis of NUREG-0700[5] applicable sections

   iii. List of HEDs prepared in the performance of the TSV and the DV

   iv. Conclusions and Recommendations

b. Partial Validation Report - Each of the individual PVs performed during the project lifecycle will have a report containing the results of the test.

   i. Table with all the design input documents:

      a) HFE reports used in the PV

      b) List of all engineering documents used by type and revision number, as applicable

      c) List of all plant procedures used by type and revision number, as applicable

   ii. HSIs subject to partial testing, as applicable

   iii. Logs of the scenarios performed

   iv. Measurements used

   v. Any video or audio recordings as applicable will be identified

   vi. A table identifying all the HEDs prepared in the performance of the PV

   vii. Conclusions, recommendations, and extracted information for decision making about the HSI Design or staffing configuration

[10] Note that the final number of reports and revisions corresponding to these four V&V activities will depend on the HSIs subject to be verified and validated (according to the sampling of operational conditions), the needs of an easy management of deliverables, and project necessity.

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c. Integrated System Validation Report - The final performance-based test of ISV will be documented in a report containing the results.

   i. A list of each of the scenarios performed - If a scenario was not performed due to an HED or other cause, it will be identified.

   ii. Results of the measurements according to the methodology exposed in Section 3.2.3.1.

   iii. Results of the constructs used for cognitive factors and evaluation of impact on human performance.

   iv. Validation conclusions with the bases for determining the acceptability of the performance of the integrated system.

   v. Limitations of the test (e.g., aspects out of control), if applicable.

   vi. Any video or audio recordings as applicable will be identified.

   vii. A list of the HEDs prepared during the activity.

   viii. Conclusions and recommendations.

All the V&V reports will include a specific *Test and Evaluation Conditions* section to provide information about the conditions under which the specific V&V activity was performed (e.g., facilities used for the test, participants, HSIs subject to verification and basis, HSIs current revision, etc.).

The other two V&V activities indicated in Section 1.1, Sampling of Operational Conditions and HED Management, do not have specific reports. The results of the Sampling of Operational Conditions are inputs to provide context to the remainder of the V&V activities, supporting them by the selection of HSIs for verification and scenarios for validations. Therefore, each of the corresponding reports of the V&V activities will include the HSI subject to be analyzed and the basis. The HEDs produced during the V&V activities are included in the HFEITS for management, tracking and reporting as necessary. Each HED will identify the HSI, the environment (e.g., design, testing, V&V, etc.) the applicable NUREG-0711 [1], NUREG-0700 [5], or other regulatory criteria, applicable design documents and software, analysis and resolution and a recommendation for its closure.

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5. APPENDICES

5.1. APPENDIX A: COMPLIANCE CHECKLIST

Table 4 details the specific requirements defined in NUREG-0711 [1] related to the criteria that the V&V activities shall meet. It also provides the reference to this IP where the corresponding requirement is addressed and explained to facilitate the development of V&V activities.

Table 4: NUREG-0711 compliance list

NUREG-0711 reference	Requirement	IP reference
11.4.1.1 (1)	The applicant should include the following plant conditions: normal operational events, I&C and HSI failures, degraded conditions and transient and accidents.	3.2.1
11.4.1.1 (2)	The applicant should include the following types of personnel tasks: IHAs, Systems and Accident Sequences; Manual Initiation of Protective Actions; Automatic System Monitoring; OER-Identified Problematic Tasks; Range of Procedure Guidance Tasks; Range of Knowledge-Based Tasks; Range of Human Cognitive Activities; Range of Human Interactions.	3.2.1
11.4.1.1 (3)	The applicant should include situational factors or error-forcing contexts known to challenge human performance. It also should include situations specifically designed to create human errors to assess the system's error tolerance, and the ability of personnel to recover from any errors, for example: High-workload situations, Varying-Workload Situations, Fatigue Situations and Environmental Factors.	3.2.1
11.4.1.2 (1)	The applicant should combine the results of the sampling to identify a set of V&V scenarios to guide subsequent analyses	3.2.1
11.4.1.2 (2)	The applicant should not bias the scenarios.	3.2.3.1
11.4.1.3 (1)	The applicant should identify operational conditions and scenarios to be used for HSI Task Support Verification, Design Verification, and ISV. The applicant should develop detailed scenarios suitable for use on a full-scope simulator.	3.2.1 and 3.2.3.1
11.4.1.3 (2)	The applicant's scenarios should realistically replicate operator tasks in the tests; then, the findings from the test can be generalized to the plant's actual operations.	3.2.3.1

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NUREG-0711 reference	Requirement	IP reference
11.4.1.3 (3)	When the applicant's scenarios include work associated with operations remote from the main control room, the effects on personnel performance due to potentially harsh environments (e.g., high radiation) should be realistically simulated.	3.2.3.1
11.4.1.4	Additional Considerations for Reviewing the HFE Aspects of Plant Modifications	N/A
11.4.2.1 (1)	Scope – The applicant should develop an inventory of all HSIs that personnel require to complete the tasks covered in the validation scenarios.	3.2.3.1 and 4
11.4.2.1 (2)	HSI Characterization – The applicant's inventory should describe the characteristics of each HSI within the scope of the verification.	3.2.2 and 4
11.4.2.1 (3)	Inventory Verification – The applicant should verify the inventory description of HSIs to ensure that it accurately reflects their current state.	3.2.2
11.4.2.2 (1)	The applicant should base the HSI task support criteria on the alarms, controls, displays, and task support needed by personnel to complete their tasks as identified by the applicant's task analysis.	3.2.2.1
11.4.2.2 (2)	The applicant should compare the HSIs and their characteristics (as defined in the HSI inventory and characterization) to the needs of personnel identified in the task analysis for the defined sampling of operational conditions.	3.2.2.1
11.4.2.2 (3)	HED Identification – The applicant should identify and document an HED.	3.2.4
11.4.2.2 (4)	HED Documentation – The applicant should document HEDs to identify the HSI, the tasks affected, and the basis for the deficiency (what aspect of the HSI was identified as not meeting task requirements).	3.2.4 and 4
11.4.2.2 (5)	Additional Methodology Considerations for Plant Modifications	N/A
11.4.2.3 (1)	The applicant should base the criteria used for HFE Design Verification on HFE guidelines.	3.2.2.2
11.4.2.3 (2)	General Methodology – The applicant's HFE Design Verification methodology should include procedures	3.2.2.2
11.4.2.3 (3)	HED Identification – The applicant should identify an HED	3.2.4

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NUREG-0711 reference	Requirement	IP reference
11.4.2.3 (4)	HED Documentation – The applicant should document HEDs in terms of the HSI involved, and how its characteristics depart from a particular guideline.	3.2.2.2 and 4
11.4.2.3 (5)	Additional Considerations for Reviewing the HFE Aspects of Plant Modifications	N/A
11.4.3.1 (1)	The applicant should describe how the team performing the validation has independence from the personnel responsible for the actual design.	3.2.3.1
11.4.3.2 (1)	The applicant should develop detailed test objectives.	3.2.3.1
11.4.3.2 (2)	Additional Considerations for Reviewing the HFE Aspects of Plant Modifications	N/A
11.4.3.3 (1)	Validation Testbeds: Interface Completeness	3.2.3.1
11.4.3.3 (2)	Validation Testbeds: Interface Physical Fidelity	3.2.3.1
11.4.3.3 (3)	Validation Testbeds: Interface Functional Fidelity	3.2.3.1
11.4.3.3 (4)	Validation Testbeds: Environmental Fidelity	3.2.3.1
11.4.3.3 (5)	Validation Testbeds: Data Completeness Fidelity	3.2.3.1
11.4.3.3 (6)	Validation Testbeds: Data Content Fidelity	3.2.3.1
11.4.3.3 (7)	Validation Testbeds: Data Dynamics Fidelity	3.2.3.1
11.4.3.3 (8)	For important HAs at complex HSIs remote from the main control room (e. g., a remote shutdown facility), where timely, precise actions are essential, the use of a simulator or mockup should be considered to verify that the requirements for human performance can be met.	3.2.3.1
11.4.3.3 (9)	The applicant should verify the conformance of the testbed to the testbed-required characteristics before validation tests are conducted.	3.2.3.1
11.4.3.4 (1)	Participants in the applicant's validation tests should be representative of plant personnel who will interact with the his.	3.2.3.1
11.4.3.4 (2)	To properly account for human variability, the applicant should use a sample of participants that reflects the characteristics of the population from which it is drawn.	3.2.3.1

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NUREG-0711 reference	Requirement	IP reference
11.4.3.4 (3)	In selecting personnel for participating in the tests, the applicant should consider the minimum shift staffing levels, nominal levels, and maximum levels, including shift supervisors, reactor operators, shift technical advisors, etc.	3.2.3.1
11.4.3.4 (4)	The applicant should prevent bias in the sample of participants	3.2.3.1
11.4.3.5.1 (1)	The applicant should identify the specific plant performance measures applicable to each ISV scenario.	3.2.3.1
11.4.3.5.1 (2)	The applicant should identify the primary task measures applicable to each ISV scenario.	3.2.3.1
11.4.3.5.1 (3)	The applicant should identify the secondary task measures applicable to each scenario.	3.2.3.1
11.4.3.5.1 (4)	The applicant should identify the measures of situation awareness applicable to each scenario.	3.2.3.1
11.4.3.5.1 (5)	The applicant should identify the workload measures obtained for each scenario.	3.2.3.1
11.4.3.5.1 (6)	The applicant should identify the anthropometric and physiological measures obtained for each scenario.	3.2.3.1
11.4.3.5.2 (1)	The applicant should describe the methods by which these measures are obtained, e.g., by simulator data recording, participant questionnaires, or observation by subject-matter experts.	3.2.3.1
11.4.3.5.2 (2)	The applicant should specify when each measure is obtained (recorded), such as continuously, at specific points during the scenario, or after the scenario ends.	3.2.3.1
11.4.3.5.2 (3)	The applicant should describe the characteristics of the performance measures.	3.2.3.1
11.4.3.5.2 (4)	The applicant should identify the specific criterion for each measure used to judge the acceptability of performance and describe its basis.	3.2.3.1
11.4.3.5.2 (5)	The applicant should identify whether each measure is a pass/fail one or a diagnostic one.	3.2.3.1
11.4.3.6.1 (1)	The applicant should balance scenarios across crews to provide each crew with a similar, representative range of scenarios.	3.2.3.1

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NUREG-0711 reference	Requirement	IP reference
11.4.3.6.1 (2)	The applicant should balance the order of presentation of scenarios to crews to provide reasonable assurance that the scenarios are not always presented in the same sequence (e.g., the easy scenario is not always used first).	3.2.3.1
11.4.3.6.2 (1)	The applicant should use detailed, unambiguous procedures to govern the conduct of the tests.	3.2.3.1
11.4.3.6.2 (2)	The applicant's test procedures should minimize the opportunity for bias in the test personnel's' expectations and in the participant's responses.	3.2.3.1
11.4.3.6.3 (1)	The applicant should train test personnel.	3.2.3.1
11.4.3.6.4 (1)	The applicant's training of participants should be very similar to the training plant personnel receive.	3.2.3.1
11.4.3.6.4 (2)	To assure that the participants' performance is representative of plant personnel, the applicant's training of participants should result in near asymptotic performance.	3.2.3.1
11.4.3.6.5 (1)	The applicant should conduct a pilot study before the validation tests begin to offer an opportunity for the applicant to assess the adequacy of the test design, performance measures, and data-collection methods.	3.2.3.1
11.4.3.6.5 (2)	The applicant should not use participants in the pilot testing who will then be participants in the validation tests.	3.2.3.1
11.4.3.7 (1)	The applicant should use a combination of quantitative and qualitative methods to analyze data.	3.2.3.1
11.4.3.7 (2)	The applicant should discuss the method by which data is analyzed across trials, and include the criteria used to determine successful performance for a given scenario.	3.2.3.1
11.4.3.7 (3)	The applicant should evaluate the degree of convergence between related measures.	3.2.3.1
11.4.3.7 (4)	When interpreting test results, the applicant should allow a margin of error to reflect the fact that actual performance may be slightly more variable than observed validation-test performance.	3.2.3.1
11.4.3.7 (5)	The applicant should verify the correctness of the analyses of the data.	3.2.3.1

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NUREG-0711 reference	Requirement	IP reference
11.4.3.7 (6)	The applicant should identify HEDs when the observed performance does not meet the performance criteria.	3.2.3.1 and 3.2.4
11.4.3.7 (7)	The applicant should resolve HEDs identified by pass/fail measures before the design is accepted.	3.2.4
11.4.3.8 (1)	The applicant should document the statistical and logical bases for determining that performance of the integrated system is and will be acceptable.	4
11.4.3.8 (2)	The applicant should document the limitations in the validation tests, their possible effects on the conclusions of the validation, and their impact on implementing the design.	4
11.4.4	HED Management	3.2.4

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Enclosure 10

Xe-100 Design Implementation Implementation Plan

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Xe-100

Design Implementation Implementation Plan

Configuration Classification	:	**XE00-R-R1ZZ-RDZZ-X**
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SYNOPSIS

This document provides the methodology to be followed to perform the Design Implementation element of the Human Factors Engineering Program model. Performing this element is not part of the Human Factors Engineering Program for the standard design of the Xe-100 plant.

CONFIGURATION CONTROL

Document Change History

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Document Approval

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ABBREVIATIONS

This list contains the abbreviations used in this document.

Abbreviation or Acronym	Definition
DI	Design Implementation
HA	Human Action
HED	Human Engineering Discrepancy
HFE	Human Factors Engineering
HFEITS	Human Factors Engineering Issues Tracking System
HSI	Human-System Interface
IHA	Important Human Action
IP	Implementation Plan
PMP	Program Management Plan
NRC	(United States) Nuclear Regulatory Commission
TIHA	Treatment of Important Human Actions
V&V	(Human Factors) Verification and Validation

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DEFINITIONS

This list contains the terms of glossary used in this document.

Term	Definition
Element	From NUREG-0711 [1] the four general activities are separated into the following twelve elements: • HFE Program Management Plan • Operating Experience Review • Functional Requirements Analysis and Function Allocation • Task Analysis • Staffing & Qualification • Treatment of Important Human Actions • Human-System Interface Design • Procedure Development • Training Program Development • Human Factors Verification and Validation • Design Implementation • Human Performance Monitoring
Human Engineering Discrepancy	Human factor issue, which based upon human factors criteria identified for the Human Factors Engineering Program is identified during the execution of verification and validation activities and managed through the HFEITS, which tracks the issue to closure.
Implementation Plan	Document that describes the proposed methodology for conducting an HFE element and is reviewed by the NRC staff to reasonably assure that it will generate acceptable results that satisfy the staff's review criteria.
Integrated System Validation	Evaluation using performance-based tests to determine whether an integrated system design (i.e., hardware, software, and personnel elements) meets performance requirements and supports the plant's safe operation.
Results Summary Report	Document that summarizes the results of a completed HFE element and cites documents or files that contain the complete results.
Verification	The process by which the design is evaluated to determine whether it provides the information, controls, and task-support needed to accomplish tasks; and conforms to the HFE design guidance.
Validation	The set of activities to ensure that a system can accomplish its intended use, goals, and objectives in the operational environment.

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1. INTRODUCTION

The Xe-100 nuclear reactor is an innovative design that is categorized as a Small Modular Reactor (SMR) due to its relatively low power, 200 MWt or 80 MWe. Its design allows for the fabrication and testing to be performed in a factory environment, so that it can be shipped to a site where it is installed as a single component. From a technological and regulatory point of view, the Xe-100 is a High Temperature Gas-cooled Reactor (HTGR) cooled by helium and moderated by graphite, implementing features that make the reactor inherently safe.

The plant configuration consists of four Xe-100 reactors, whose design is optimized since each unit shares like systems. The main purpose of a Xe-100 plant is to safely convert nuclear energy to electricity, in addition, the plant design accommodates multiple missions such as process heat applications.

As required by the licensing process and NUREG-0711 [1], a Human Factors Engineering (HFE) Program shall be developed[1], with proven systematic analysis techniques to address human factors issues within the design process. The HFE program and its products reflect state-of-the-art human factors principles.

As described in the HFE Program Management Plan (HFE PMP) [4], one of the first steps in the HFE Program is the preparation of Implementation Plans (IPs) that describe the proposed methodology for the performance of a specific HFE program element.

In accordance with NUREG-0711 [1] and NUREG/CR-3371 [8], an IP provides an opportunity to obtain a review and concurrence from the regulatory staff of the proposed methodology before performing the work associated with the element. This early review is desirable because it offers the staff an opportunity to identify potential issues with the methodology and to provide the Xe-100 design team with early input to the analysis or design processes, when staff concerns can more easily be addressed, rather than when the element has been completed.

1.1. PURPOSE

The purpose of this document is to describe the methodology to be followed in the development of the eleventh element of NUREG-0711 [1], Design Implementation. Note that DI activities are out of the scope of the HFE Program for the Xe-100 plant standard design.

The DI activity verifies that the "as-built" Human-System Interface (HSI) conforms to the approved HSI design specifications and validates elements of the HSI not completed before the Human Factors Verification and Validation (V&V). Elements not previously evaluated using the full-scope Simulator (e.g., lighting, environmental control, floor layout, sound powered communication, noise mitigation, display changes based on pre-operation and startup testing, access to plant areas for maintenance, etc.) are validated in the as-built facilities. DI confirms any open HFE issues entered in the HFE Issues Tracking System (HFEITS) have been adequately resolved.

[1] Refer to 10 CFR 50.34 (f)(2)(ii), 10 CFR 50.34 (f)(2)(iii) [3], and REGDOC-2.2.1, Human Factors [2].

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1.2. SCOPE

This IP applies to the DI that will be performed as part of the implementation of the Xe-100 plant standard design in an actual Xe-100 plant. This IP is provided within the HFE Program for licensing the Xe-100 plant design. Therefore, the document is under the considerations and limitations established in the HFE PMP [4].

In this document, the term *design* shall be understood as the part of the design within the scope of the HFE Program, that is, the HSI, the operating procedures, and the training program.

1.3. RELATIONSHIP TO OTHER DOCUMENTS

This IP is part of the HFE Program described in the HFE PMP, which includes high-level considerations that shall be known by the reader of this IP. Other HFE Program elements are related to the DI; therefore, the IPs of these elements are cross-referenced where needed. Figure 1 shows relationships between the DI IP and other documents within the HFE Program.

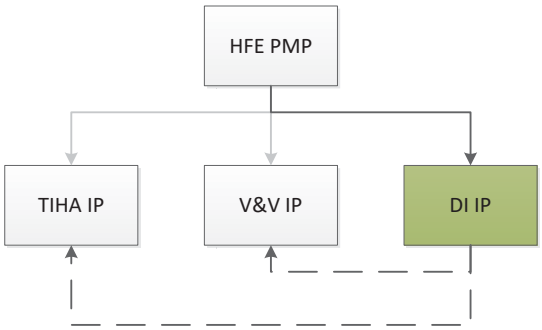

Figure 1: Relationship of DI IP to other documents within the HFE Program

1.4. DOCUMENT LAYOUT

The DI IP is formatted as follows. Section 1 addresses the document introduction, purpose, scope, and relationship to other documents. Section 2 identifies the references used in this IP. Section 3 describes the methodology, from the inputs, through the process and the expected outputs. Section 4 addresses how the outputs shall be documented. Section 5 includes as an appendix a checklist to verify compliance of this IP with the corresponding NUREG-0711 [1] review criteria.

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2. REFERENCES

The following documents are referenced within this document.

	Document Title	Preparer/Author	Document Number	Revision or Date of Issue	Classification	Applicable[2] (Yes/No)
[1]	NUREG-0711, Human Factors Engineering Program Review Model	NRC	N/A	Rev 3	N/A	Yes
[2]	REGDOC-2.2.1, Human performance management Human Factors	CNSC	N/A	2019	N/A	Yes
[3]	10 CFR 50.34, Contents of applications; technical information	NRC	N/A	2019	N/A	Yes
[4]	TEC-XE100-HFE-PMP, Human Factors Engineering Program Management Plan	Tecnatom	N/A	Rev 0	N/A	Yes
[5]	Human Factors Verification and Validation Implementation Plan	Tecnatom	000989	Rev 1	XE00-R-R1ZZ-RDZZ-X	Yes
[6]	Treatment of Important Human Actions Implementation Plan	Tecnatom	000984	Rev 1	XE00-R-R1ZZ-RDZZ-X	Yes
[7]	NUREG-0700, Human-System Interface Design Review Guidelines	NRC	N/A	Rev 3	N/A	Yes
[8]	NUREG/CR-3371, Task Analysis of Nuclear Power Plant Control Room Crews	NRC	N/A	1983	N/A	Yes

2 Applicable documents are applicable to the extent specified within this document and thus deemed to form part of this document.

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3. DEVELOPMENT

The DI is performed while the Xe-100 plant standard design is being implemented in a specific design for an actual Xe-100 plant. After this occurs, the responsibility of the HFE Program is transferred from X-energy to the Xe-100 plant licensee. Therefore, DI activities are executed by the Xe-100 plant licensee.

In summary, the objectives of the DI are:

- to evaluate all aspects of the design that were not addressed during the V&V activities of the HFE Program.
- to assess the conformity of the as-built design to the verified and validated design.
- to verify that all human engineering discrepancies (HEDs) and other HFE-related issues have been satisfactorily resolved.
- to verify that each important human action (IHA) has been appropriately addressed in the HFE Program.

3.1. INPUTS

During the development of the DI activities, the following list of inputs shall be considered:

- The documents and/or tools that compile the data and results of the V&V element performed within the HFE Program. This information includes those aspects of the Xe-100 plant standard design that could not be addressed in the V&V activities of the HFE Program and, thus, need to be addressed during the implementation process.
- The as-built design implemented in the actual Xe-100 plant, and the verified and validated design of the standard Xe-100 plant. These two designs shall be compared to assure conformity to an HFE design process established as part of the HFE Program.
- The HFEITS from the HFE Program, where all HFE-related issues, including HEDs, are recorded. The content of this system shall be reviewed to confirm that the most important issues have already been resolved in the standard design.
- The documents and/or tools that compile the data and results of the Treatment of Important Human Actions (TIHA) element of the HFE Program. This information needs to be reviewed to assure that the IHAs can be safely performed with the as-built design.

3.2. METHODOLOGY

The methodology described in this section ensures the fulfillment of the objectives of the DI, which are described above. It is divided into several stages, which shall be executed iteratively until all objectives of all stages are fulfilled. Figure 2 shows a process diagram of the methodology described in this section.

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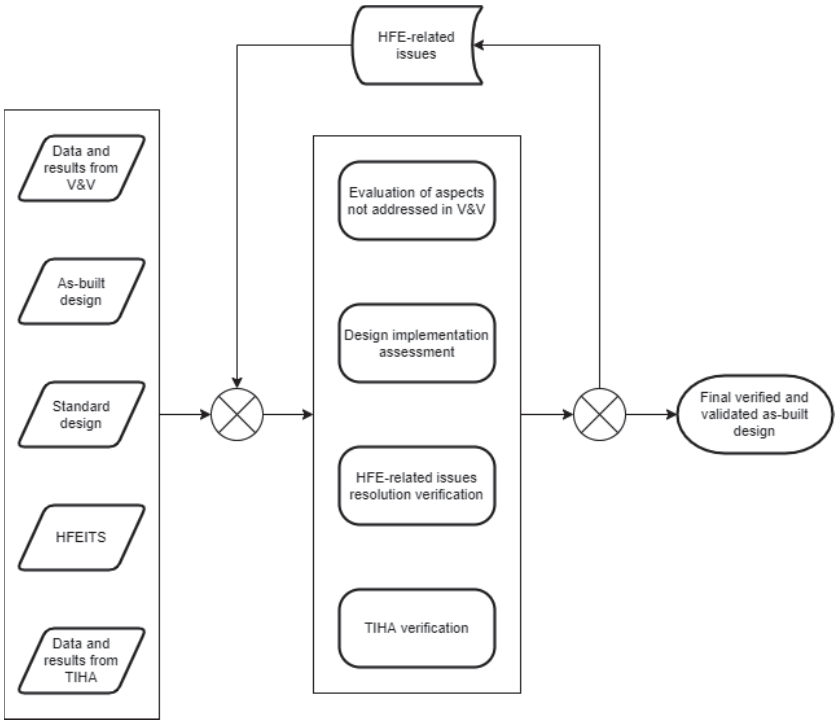

Figure 2: Design Implementation process diagram

3.2.1. Evaluation of Aspects not Addressed in V&V

Some aspects of the standard design may not have been addressed in the V&V activities of the HFE Program, due to the impossibility of accurately simulating them with the available tools. Examples of these kinds of aspects are environmental conditions, such as lighting and noise, and control means outside the main control room but within the HFE Program scope, such as the reserve shutdown station or other safety-related local control stations. Most of these issues have already been recorded in the HFEITS during the development of the HFE Program by the time the DI is performed; these may still be open, in a pending to be resolved state.

In addition, the as-built design may include design characteristics that are not part of the standard design, such as new or modified displays for plant-specific features. These design characteristics are not addressed in the V&V activities of the HFE Program.

The purpose of the DI at this stage is to evaluate all those aspects not addressed in the V&V activities, and to explain how they were covered in implementing the design. The methods and methodology described in the V&V IP [5] can be appropriately adapted and used for this stage of the DI.

The objective is accomplished when all HEDs that may arise in the evaluation process are addressed and resolved.

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3.2.2. Design Implementation Assessment

The as-built design of the actual Xe-100 plant shall be compared with the validated design of the standard Xe-100 plant. Since the latter results from the HFE design process and the V&V activities, any deviation in the as-built design shall be corrected or justified.

The assessment performed within this stage shall be done in two sequential steps. Firstly, the final design documentation, before being actually implemented, shall be compared with the validated design. Secondly, the actual HSIs, already manufactured and implemented in the actual plant, shall be compared with the final design documentation. This two-step approach allows addressing issues in the final design before its implementation, potentially reducing the effort needed to correct them.

If the as-built design does not conform, further HFE review is performed to determine whether the as-built design is acceptable or HEDs shall be generated, tracked, and resolved.

The methods to perform the conformance assessment include, but are not limited to:

- Review of specifications, drawings, and technical information recorded in the final design documents.
- Plant walkdowns, to assess the physical configuration and layout of the HSIs, including control rooms.
- Subject matter experts' evaluations

The scope of the DI activity includes verification and validation of the following aspects and elements of the HSI:

a. Final facility layout, floor design, and workstation arrangement.

b. Installed elements of the HSI, confirming conformance to the verified and validated Xe-100 design specifications:

   i. Controls, displays, alarms, and data processing, including use of the Safety Parameter Display System and display navigation, efficient information retrieval, and access to controls.

   ii. Automation features.

   iii. Panel layout, arrangement, and configuration.

   iv. Peripherals (e.g., printers, utility tables, etc.).

c. Anthropometrics of workstations, including panels and installed equipment such as phones and radios.

d. Work environments (e.g., normal and emergency lighting, open space, ventilation, conditioning of the air, noise mitigation features, avoidance of hazards).

e. Operations personnel communications, methods, and equipment (e.g., phones, radios, intercoms, etc.).

f. Provisions for routine tests and maintenance (e.g., cleaning touchscreen displays, testing alarms, replacing HSI components, etc.).

g. Operations and maintenance procedures, both hardcopy and electronically displayed.

h. Training manuals.

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i. Shift staffing, room occupancy, and rotation schedules.

j. Data and video interfaces necessary to link the Technical Support Center to the Main Control Room and the Plant Computer System to the Technical Support Center.

k. Equipment to duplicate or link the Emergency Operations Facility to the plant process database used to support the Main Control Room and the Technical Support Center.

To fulfil the objective of this stage, all aspects of the design shall be assessed, and potential deviations shall be justified.

3.2.3. HFE-Related Issues Resolution Verification

As described in the HFE PMP [4], an HFEITS is established at the beginning of the development of the HFE Program to assure that HFE-related issues are identified, tracked, evaluated, and corrected. Each issue recorded in the HFEITS is classified according to its importance in a 3-grade priority system and follows a process that ends by correcting (and validating) the issue or keeping it open for further evaluation, or eventual correction in the design implementation phase. Examples of the latter are those issues that cannot be addressed within the HFE Program (refer to section 3.2.1) and new ones that may be identified during the performance of DI activities.

When the HFE Program responsibility is transferred to the Xe-100 plant licensee, the HFEITS shall be reviewed to verify that all priority 1 and priority 2 issues are resolved; that is, either corrected or deemed non-verifiable with a justification. From then on, within the DI scope of work, all open HFE-related issues are tracked, evaluated, and corrected according to the applicable processes of the Xe-100 plant licensee.

This stage is completed when all HFE-related issues are resolved.

3.2.4. Treatment of Important Human Actions Verification

IHAs are identified and tracked as described in the TIHA IP [6], and addressed as described in the relevant IPs of the HFE Program. The Xe-100 plant standard design already implements all needed features to allow the operators to perform all IHAs with the HSIs in a safe manner.

The as-built design of the actual Xe-100 plant may differ from the standard design. In this stage of the DI, the list of IHAs identified and tracked within the HFE Program shall be reviewed to verify that the as-built design also adequately addresses all IHAs.

3.3. OUTPUTS

The output of the DI, after all stages are completed, is a final verified and validated as-built design.

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4. DOCUMENTATION

DI activities are not included in the HFE Program for the Xe-100 plant standard design, and as a result, a results summary report is not expected to be provided. Therefore, documentation of this element is not addressed by this IP.

Nevertheless, based upon past projects experience, such a DI scope would include, as a minimum, a DI results summary report that documents DI activities, addressing the following:

a. Objectives of the DI activity.

b. Participants' names, positions, experience/qualifications, relevant demographics.

c. Descriptions of the specific HSI components involved, or references to applicable documents.

d. Test conditions.

e. Personnel performance issues, if any, applicable to the DI activity.

f. Methods and procedures used.

g. Documentation and administration of issues and discrepancies, recorded, assessed for impact, resolved, and justified.

h. Presentation and discussion of test data (e.g., performance measurements, test results, and findings).

i. HFE issues, if any, including training-related issues to be examined with respect to learning objectives and post-training performance.

j. Conclusions and recommendations, such as design changes or corrective actions (e.g., by reference to the corresponding HFEITS record). Any proposed changes would be performed under the plant change control procedures.

In addition, separate reports may be issued for each major activity within the DI activity (e.g., measurement of environmental features for each individual facility, conformance of Procedures, etc.).

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5. APPENDICES

5.1. APPENDIX A: COMPLIANCE CHECKLIST

Table 1 details the specific requirements defined in NUREG-0711 [1] related to the criteria that the DI activities shall meet. It also provides the reference to this IP, where the corresponding requirement is addressed and explained, to facilitate the development of DI activities.

Table 1: NUREG-0711 compliance list

NUREG-0711 reference	Requirement	IP reference
12.4.1 (1)	The applicant should evaluate aspects of the design that were not addressed in V&V by an appropriate V&V method.	3.2.1
12.4.1 (2)	The applicant should compare the final HSIs, procedures, and training with the detailed description of the design to verify that they conform to the planned design resulting from the HFE design process and V&V activities. This verification should compare the actual HSI, procedures, and training materials to design descriptions and documents. Any identified discrepancies should be corrected or justified.	3.2.2
12.4.1 (3)	The applicant should verify that all HFE-related issues in the issue-tracking system are adequately addressed.	3.2.3
12.4.1 (4)	The applicant should provide a description of how the HFE program addressed each important HA.	3.2.4
12.4.2	Additional Considerations for Reviewing the HFE Aspects of Plant Modifications.	N/A

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