Enclosure 8

Technical Report MPWR-TECR-005004 (Redacted)

babcock & wilcox nuclear energy

Functional Requirements Analysis and Function Allocation
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a progressive energy solution

B&W mPower™ Reactor Program
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ABSTRACT

A functional requirements analysis (FRA) is the beginning of the operational analysis. The FRA is a human factors engineering (HFE) element that provides the basis for all plant and system functions. The functional requirements mapping provides the ability to link all structures, systems, and components to regulatory requirements for plant safety and power generation objectives. Function allocation (FA) element of HFE establishes the criteria, guidance, and methods for determination of control requirements for plant equipment at the system and component levels between man-machine interfaces. This technical report describes the process of FRA and FA from a human factors engineering perspective. The output of this process provides the basis for task analysis.

RECORD OF REVISION

Revision No.	Date	Preparer	Description of Changes
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1. INTRODUCTION

1.1 Applicability

This document is applicable to all human factors design activities for the Babcock & Wilcox (B&W) mPower™ reactor. This includes all B&W employees and contractors assigned to design activities of the B&W mPower reactor within the scope of the human factors engineering (HFE) program described in this report.

1.2 Scope and Objectives

The scope of this technical report is to describe the system design activities for the B&W mPower Modular reactor associated with the main control room (MCR), remote shutdown station (RSS), risk-important local control stations (LCS), technical support center (TSC), and the emergency operations facility.

This technical report applies to engineering aspects of the B&W mPower reactor design. Functional requirements analysis (FRA) and function allocation (FA) are performed in sequential order for individual tasks. This B&W mPower human factors engineering (HFE) FRA process is implemented to:

- Identify the performance requirements and constraints for the design functions
- Define the plant functions needed to meet the performance requirements and constraints (this includes both safety and power generation goals)
- Identify the relationships between plant functions and systems responsible for performing the function (e.g., plant configurations or success paths)
- Provide a framework for understanding the roles of automation, human-system interface (HSI), and the operating staff
- Utilize probabilistic risk analysis (PRA) insights to incorporate safety analysis throughout the plant design
- Provide a visual representation connecting plant functional requirements to system functional capabilities
- Structure the analysis of plant control and assign control functions to the machine, operator, or a shared responsibility
- Allocate control functions to provide the operator with logical, coherent, and meaningful tasks that are appropriate for the operator's abilities, workload, and situational awareness
- Provide input to the task analysis
- Provide a basis for the requirements management for the design

Table 1: HFE Elements Correlation with FRA/FA

HFE Elements/Inputs	Impact
HFE Program Management	The program management technical report describes the necessary program overview for the completion of the FRA/FA process.
Operating Experience (OE)	Operating experience reports (OER) are created in order to enable the process to mitigate design errors while maintaining positive aspects of the design. OE data is evaluated in the FRA/FA process and undergoes further analysis in the task analysis process.
Task Analysis (TA)	Task analysis uses the FRA/FA data to structure the detailed analysis of the following: • plant functions • system functions • system component functions • functional allocations • staffing and qualification assumptions
Probabilistic Risk Assessment / Human Reliability Assessment	Risk important human actions and their associated tasks and scenarios are addressed during FRA/FA, TA, HSI design, procedure development, and training.

1.3 Responsibilities

Work performed within the scope of this technical report is under the direction of the Unit Manager of the Integrated Design Process and Human Factors Engineering Program. The individuals performing the work are selected from the HFE design team. These HFE team members include, at a minimum, operations and systems engineering personnel. Engineers outside of the HFE team may be consulted on an as-needed basis. Other engineering personnel may be assigned to work within the bounds of the FRA/FA process and follow the direction of the HFE team members.

2. BACKGROUND

Inputs to FRA/FA come from PRA insights and the operating experience program (OEP). The FRA identifies functions that are dictated by regulatory requirements for plant safety and identifies power generation objectives. These functions follow the requirements needed to achieve safe and dependable electrical generation by the B&W mPower reactor design. Function allocation establishes the criteria, guidance, and methods for determination of control requirements for plant equipment at the system and component levels. The process uses the design information to develop the best possible interactions between the machine and operator. Providing the best possible interaction between man and machine maximizes the ability to create an environment that ensures proper situational awareness and control while minimizing operational errors. Function allocation divides the functions into those controlled by the machine

(full automation), the operator (fully manual), or a shared responsibility[

]This process provides personnel with logical, coherent, and meaningful tasks.

[CCI per Affidavit 4(a)-(d)]

3. METHODOLOGY

The FRA and FA are performed in sequential order for each individual function; however, the steps of each type of analysis do not necessarily need to be performed in sequential order. The FRA is a top-down comprehensive analysis of the requirements for the B&W mPower reactor. The performance of the FRA consists of two general actions and is reconciled at the end of the analysis through the FRA gap analysis. The FA is performed on individual functions as they are developed and can therefore be done individually with an overall FA reconciliation. This process is outlined in Figure 1 (NUREG-0711).

3.1 Functional Requirements Analysis

The functional requirements analysis is a top-down process that addresses various levels of control for the B&W mPower reactor. The FRA describes the functional requirements from a general site scope down to the component level. This is illustrated in Figure 2. Each level has many of the same functional requirements as the higher level above it. This concept is the flow-down approach to requirements management where many of the same requirements apply to those levels below it. Future stakeholder's requirements would be considered in relation to the existing regulatory, technical, or functional requirements.

Functions analyzed include those related to safety and power generation. Safety functions include those functions needed to prevent or mitigate the consequences of postulated events as specified by the B&W mPower Reactor safety analysis. These requirements are documented in the functional requirements management (FRM) database and are provided as input to the other elements of the HFE design process. The FRM provides the physical (via database) and visual (printable format) requirements linkages.

General site requirements focus on the general site design and licensing basis. Emergency planning is considered from an HFE perspective when designing the site TSC.

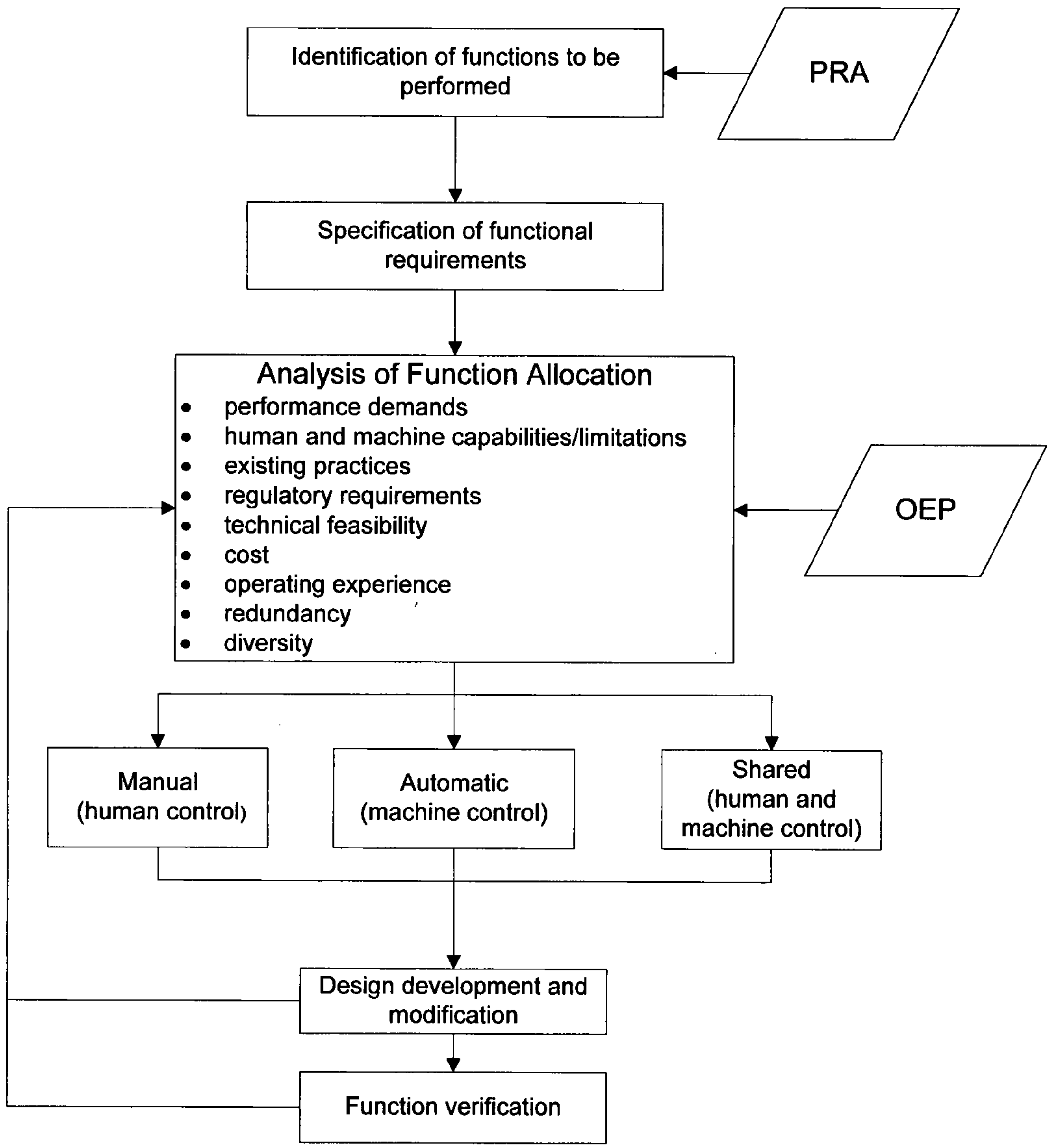

Figure 1: FRA/FA Process Overview

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Figure 2: Top-Down Requirements Management **[CCI per Affidavit 4(a)-(d)]**

The requirements breakdown starts with the high level functions and includes all critical safety functions. The FRA process defines the following for each function:

- Purpose of function
- When the function is needed (conditions)
- Availability of the needed function
- Operating indication necessary for the function
- Monitoring capability to determine effectiveness of function
- Termination criteria and parameters for securing function

All parameters are described in a qualitative manner for the purposes of the FRA (e.g., high, low, etc.).

The FRA is performed in two parts that are reconciled after completion. The plant level FRA is performed from the plant level down to the system level. This is the framework for the entire plant and is placed in the FRM tool.[

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[CCI per Affidavit 4(a)-(d)]

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Figure 3: Functional Requirements Relations

[CCI per Affidavit 4(a)-(d)]

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] **[CCI per Affidavit 4(a)-(d)]**

3.1.1 Plant-Level Overview

The FRA ensures two main requirements are met:

- All safety objectives are met by plant functions.
- All generation requirements are met by plant functions.

The plant is expected to operate under all conditions (i.e., normal, abnormal, and emergency). The identification of those requirements is defined by applicable parts of the following documents:

- Design and licensing basis
  - Federal regulations include
    - 10 CFR Part 20, "Standards for Protection Against Radiation"
    - 10 CFR Part 50, "Appendix A, General Design Criteria for Nuclear Power Plants"
    - 10 CFR Part 100, "Dose Limits"
    - 10 CFR Part 52, "Licenses, Certifications, and Approvals for Nuclear Power Plants
  - Licensing commitment requirements
    - Combined License Application requirements (if known)
    - Final Safety Analysis Report (if available)
    - Technical Specifications
    - Design Control Document requirements
    - Inspections, Tests, Analyses, and Acceptance Criteria (if known)
    - Design Acceptance Criteria (if known)
  - PRA assessments that relate to functional requirements or regulatory issues
- Industry codes and standards
- Applicable sections of the Electric Power Research Institute (EPRI) Utility Requirements Document

3.1.2 Functional Requirements Analysis Top-Down Structure

The top-down structure starts at the top and compliments the top-down approach. The requirements are determined at each level. High-level requirements lead to the establishment of more detailed (and more numerous) system-level and component-level requirements. When these system- and component-level requirements are satisfied by system and component capabilities, compliance with associated high-level requirements is also demonstrated. The FRM tool allows for effective use and distribution of this

information. This overall structure follows the layout of the NRC general design criteria from 10 CFR 50 Appendix A.

3.1.2.1 Plant-Level Overall Functional Requirements

The objectives of the FRA fulfill two main functional requirements:

- Safety objectives are met by plant functions.
- Generation requirements are met by plant functions.

3.1.2.2 Plant-Level Objectives

Plant-level objectives are comprised of general categories of the two functional requirements. The safety objectives are found within the general design criteria in 10 CFR 50 Appendix A. The safety objectives are divided into the following categories:

- Overall requirements
- Multiple fission product barriers
- Protection and reactivity control
- Fluid systems
- Reactor containment
- Fuel and radioactivity control

The economic and power generation objectives are divided into the following categories:

- Heat generation
- Steam production
- Electricity production
- Electricity distribution

3.1.2.3 Plant-Level Design Criteria

Plant-level design criteria follow the breakdown for the general design criteria and also from the B&W mPower standard plant requirements document.

3.1.2.4 Plant-Level Functions

Analysts identify and document the plant-level functions required to satisfy plant-level design criteria and critical safety functions. Additional considerations considered when determining plant-level functions include:

- Applicable Plant Modes – Many plant-level processes are mode-dependent. This is the breakdown documenting the mode-dependent applications of the individual plant systems. Analysts document any mode dependency/limitations associated with plant-level functions.
- Plant Diversity Requirements – Diversity requirements for plant functions can be documented at this level by indicating the function that is needed to be diverse (e.g., reactivity control diversity). Diverse systems are documented during system-level FRA discussed in Section 3.1.2.5.

All plant-level functions describe:

- Purpose of the plant-level function
- Conditions that indicate the need for the plant-level function
- Parameters that indicate the availability of the plant-level function
- Parameters that indicate the operating status of the plant-level function
- Parameters that indicate whether the plant-level function is achieving its purpose(s)
- Parameters that indicate whether the operation of the plant-level function can or should be terminated

3.1.2.5 System Process Functions

System level process functional capabilities fulfill the plant-level process functional requirements. Redundancies in system processes, divisions, or channels are described at this level. Once the systems list is available, individual HFE analysts start the system level FRA process. Any inconsistency at this level is reconciled through the FRA gap analysis.

- Applicable Plant Modes – Many system-level processes are mode-dependent. This is the breakdown documenting the mode-dependent applications of the individual plant systems. Analysts document any mode dependency/limitations associated with system-level functions.
- System-Level Diversity – Diversity requirements for plant functions are documented for system-level requirements.

All system-level functions describe:

- Purpose of the system-level function
- Conditions that indicate the need for the system-level function
- Parameters that indicate the availability of the system-level function
- Parameters that indicate the operating status of the system-level function

- Parameters that indicate whether the system-level function is achieving its purpose(s)
- Parameters that indicate whether the operation of the system-level function can or should be terminated

3.1.2.6 Subsystem Process Functions

Subsystem level requirements are comprised of supporting functions that can be easily described at the component level. The functions described at this level form the supports of the system level functions. Independently they are not the actual system functions, but together they form the actual system level functions. For example, the system level function of water purification has several subsystem process functions of cool water, filter water, preheat water, and pump water. Together these subsystem functions form the system functions.

3.1.3 Functional Requirements Analysis Gap Analysis

The purpose of the FRA gap analysis is to link the plant level functional requirements to the system-level functional requirements. The FRM tool accurately documents all pathways through the entire analysis structure. This is performed by the plant-level FRA and system FRA analysts. The FRA gap analysis concludes with each system function being properly documented showing that all functional requirements are satisfied by the correct type and amount of systems. This also proves that all systems fulfill a functional requirement. When all links are properly made, the FRM functions as described in Section 3.3.

3.2 Function Allocation

The function allocation process receives input from the FRA. System operating experience is also considered for the initial allocations. PRA/human reliability analysis (HRA) assumptions are considered for all risk-important human actions. Vendor constraints on physical operation of any component are considered on a case-by-case basis. These functions are assigned according to the control necessary to ensure proper operation of plant systems. These assignments are either human (manual), machine (automatic), or shared responsibility

Function allocation determines the correct means of control for the functions (and allowed transitions between functions) identified in the systems FRA process. The technical bases for allocation decisions include one or more of the following:

- Performance demands
- Human and machine capabilities/limitations
- Existing practices
- Regulatory requirements
- Technical feasibilities

- Cost
- Operating experience
- PRA/HRA considerations
- Redundancy
- Diversity

Function allocation determines the best means of control for a given function. The particular control mechanism may be automatic (machine controlled), manual (operator controlled), or shared (both operator and machine function). The allocation of a function to automatic or machine control does not negate the human involvement in this function. For all automated functions, consideration is given for the degree of human involvement necessary for monitoring and control of those automated actions. This allows the operator to assume control in the event of an automatic system failure.

Operating experience plays a vital role in establishing and modifying initial function allocations. Since OE incorporation is applicable to all stages of the design, it is established as a continuous process. When applicable OE is identified, the FA is reviewed in order to:

- Justify the original analysis of the function
- Justify the original human-machine allocation
- Identify alternative solutions to a change in FA (e.g., training, qualifications, or procedure design)
- Serve as a basis for changing the original allocation if warranted

The output of the FA process is a listing of allocated functions and allowed transitions between functions that serve as input to the task analysis process. The allocation of functions applies from the plant level to the system and subsystem level. The FRA/FA outcomes are maintained throughout the lifecycle of the plant. The FRM provides the basis for analysis and comparison of future plant modifications. This is critical to ensure that the proposed changes consider the established requirements.

Figure 4 depicts the overall FA process. FA is an iterative process and initial assignment may be modified when necessary. This is expected since the initial task analysis is made using this data. Workload analysis is performed as part of the design assessment portion of task analysis and may provide feedback leading to allocation changes.

Other reasons for changes after the initial allocation include new operating experience data that signals the needs for reallocation, changes to the functional requirements, or changes to PRA/HRA data. Modifications made to the plant after the plant has been licensed, constructed, and operated are expected to be processed using the data within the FRM tool with regards to the function allocation and will be based on NRC regulations and regulatory guidance. Further, modifications will use initial FA data as well as proposed changes to the design and/or operation of the plant to determine if the allocation changes are necessary.

Operations can be fully assigned to:

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Figure 4: Function Allocation Process Flow **[CCI per Affidavit 4(a)-(d)]**

Function allocation also involves the placement of controls. The controls are distributed between the MCR, RSS, TSC, and LCSs as appropriate. This is done in order to maintain a coherent structure of information for control of all system processes. If all functions that could be automated are automated and the remaining functions are left for human control, the result may

not form a coherent picture that matches the operator's conceptual model of the systems. By providing controls that form a natural mapping of functions consistent with appropriate information, ease of use during subsequent encounters is elevated and operator errors are reduced.

The FRA determines whether there is a requirement that establishes if a particular function belongs in a certain category. If there is no clear direction of how the function has to be assigned, then the analysis of the function addresses the following questions to determine the appropriate assignment:

- Is automation preferred as a result of environmental conditions?
- Is automation necessary due to operator limitations?
- Is automation technically feasible?
- Is automation cost effective?
- Is automation necessary for partial performance of the task?
- Is manual operation preferable due to performance requirements?
- Is manual operation preferable to create a coherent operator task?
- Is manual operation preferable due to technical or cost effectiveness reasons?
- Are shared functions necessary for cost control or technical feasibility reasons?
- Are shared functions necessary due to workload analysis adjustments?
- Can function be redesigned if no method seems appropriate?

Logical constraints are the relationship between the spatial or functional layout of components and the objects that affect them. This starts with the development of the functional requirements top-down process. This is a major factor in the development of natural mapping by correctly allocating the functions for the task.

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] **[CCI per Affidavit 4(a)-(d)]**

Operating experience is considered throughout the design process and may drive changes to the FRA or cause new regulations to be put into effect, thereby changing the initial FA. Examples of this are Three Mile Island, Chernobyl, and the Fukushima Daiichi nuclear reactor events.

3.3 Functional Requirements Mapping

Functional requirements mapping documents plant-level functional requirements, the system-level functional capabilities that satisfy them, and how these functions (and allowed transitions between functions) are allocated. These allocated functions form part of the design basis for the plant and are maintained throughout the design life-cycle of the plant. The information repository is maintained up-to-date with the plant design and provides the ability to link plant functions to system and component functions and supports the life-cycle configuration management of the facility.

3.4 Modifications

After the design is completed and certified, there may be reasons for making modifications to the initial FA. These modifications can be the result of changes to initial data by the licensee or future applicant. The functional requirements analysis and subsequent function allocation analysis should be limited to the change induced by the modification considering:

- Changes to existing safety functions
- Introduction of new safety features
- Changes to the degree of integration between systems (e.g., placing two systems under the same controller that were previously independent)
- Changes to the degree in which systems share common resources such as power supplies, cooling systems, or data-transmission
- Changes that are likely to change the function allocation for those functions important to safety
- Changes in operator roles in context of the operators' overall responsibilities
- OE induced changes
- Regulatory-induced modifications

4. SUMMARY/CONCLUSIONS

The primary documentation for FRA/FA consists of the FRM tool output, which produces a results summary report for NRC submittal. This output provides the ability to verify and validate:

- All plant- and system-level functions necessary for safe operations
- All requirements of each function
- Basis for all function allocation to the operator
- A logical, coherent, and meaningful role of the operator

5. DEFINITIONS, ABBREVIATIONS, AND ACRONYMS

5.1 Definitions

Term	**Definition**
Configuration Management	The systematic approach for identifying, documenting, and changing the characteristics of a facility's structures, systems and components (SSCs), to ensure that the conformance is maintained between the requirements, the physical configuration and configuration information.
Design Basis	The high-level functional requirements, interfaces, and expectations of a facility's SSCs that are based on regulatory requirements or facility analysis. Individual bases are contained in design information and may be reflected in any combination of criteria, codes, standards, specifications, computations, or analyses identifying pertinent constraints, qualifications, or limitations. The design basis identifies and supports the reasons a design requirement is established.
Function Allocation (FA)	The process of assigning responsibility for function accomplishment to human or machine resources, or to a combination of human and machine resources.
Functional Requirements Analysis (FRA)	The examination of system goals to determine what functions are needed to achieve them.
Human-System Interface (HSI)	A human-system interface (HSI) is that part of the system through which personnel interact to perform their functions and tasks. This interaction includes the alarms, displays, controls, and job performance aids (e.g., procedures, instructions, etc.).
Local Control Station (LCS)	An operator interface related to local plant process control that is not located in the control room. This includes multifunction panels, as well as, single function LCSs such as controls (e.g., valves, switches, and breakers) and displays (e.g., meters) that are operated or observed during normal, abnormal, or emergency operations.

Term	**Definition**
Logical constraint	The relationship between the spatial or functional layout of components and the objects that they are affected by. This starts with the development of the functional requirements flow-down process. This is a major factor in the development of natural mapping for the task analysis
Main Control Room (MCR)	The room within the plant control building that houses and protects control room personnel and the human-system interface equipment provided for command and control of plant equipment to support the safe and efficient operation of the plant.
Modification	Any type of change or modernization made to HSI components or plant systems that may influence personnel performance. This is defined as an action that can only occur after the original design certification is completed.
Plant	For the B&W mPower reactor design, a plant is one set of standard reactors and corresponding secondary systems. This twin-pack arrangement is the basic unit marketed as one plant.
Probabilistic Risk Assessment (PRA)	A qualitative and quantitative analysis of the risk associated with plant operation under normal, abnormal, and emergency conditions. This assessment measures frequency of occurrence of adverse outcomes such as core damage or the release of radioactive material and the effects of these adverse outcomes on the health and safety of the public.
Risk-Important Human Actions	Actions that are performed by plant personnel to provide reasonable assurance of plant safety. Actions may be made up of one or more tasks. There are both absolute and relative criteria for defining risk-important actions. From an absolute standpoint, a risk-important action is any action whose successful performance is needed to provide reasonable assurance that probabilistic design objectives are met. From a relative standpoint, the risk-important actions may be defined as those with the greatest risk contribution in comparison to all risk contributors.
Safety Functions	Functions that serve to verify high-level objectives and are often defined in terms of a boundary or entity that is important to plant integrity and the prevention of the release of radioactive materials. A typical safety function is "reactivity control." A high-level objective, such as preventing the release of radioactive material to the environment, is one that designers strive to achieve through the design of the plant and that plant operators strive to achieve through proper operation of the plant.

Term	**Definition**
Safety-related	A term applied to those nuclear structures, systems, and components that prevent or mitigate the consequences of postulated accidents that could cause undue risk to the health and safety of the public (see 10 CFR 50, Appendix B). These are the structures, systems, and components on which the design-basis analysis of the safety analysis report is performed. They also should be part of the full quality assurance program.
Situational Awareness	The relationship between the operator's understanding of the plant's condition and its actual condition at any given time.
Task Analysis	A method for determining and describing what plant personnel must do to achieve the purposes or goals of their tasks. The description can be in terms of cognitive activities, actions, and supporting equipment.
Validation	Also termed Integrated System Validation. This is 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.
Verification	The process by which the design is evaluated to determine whether it acceptably satisfies personnel task needs and HFE design guidance.

5.2 Abbreviations and Acronyms

B&W	Babcock and Wilcox
CM	configuration management
EPRI	Electric Power Research Institute
FA	function allocation
FRA	functional requirements analysis
FRM	functional requirements management
GmP	Generation mPower
HFE	human factors engineering
HRA	human reliability analysis
HSI	human-system interface
LCS	local control station
MCR	main control room
NRC	U.S. Nuclear Regulatory Commission
OE	operating experience
OER	operating experience review
OEP	operating experience program

PRA	probabilistic risk assessment
RSS	remote shutdown system
SSC	structures, systems, and components
TA	task analysis
TSC	technical support center

6. REFERENCES

6.1 Regulatory Requirements and Guidelines

6.1.1 10 CFR 50, Domestic Licensing of Production and Utilization Facilities, United States Nuclear Regulatory Commission

6.1.2 10 CFR 50, Appendix A – General Design Criteria for Nuclear Power Plants, United States Nuclear Regulatory Commission

6.1.3 10 CFR 50, Appendix B – Quality Assurance Criteria for Nuclear Power Plants and Fuel Reprocessing Plants, United States Nuclear Regulatory Commission

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6.1.7 NUREG-0800, Branch Technical Position 7-19, Guidance for Evaluation of Diversity and Defense-in-Depth in Digital Computer-Based Instrumentation and Control Systems, United States Nuclear Regulatory Commission

6.1.8 NUREG/CR-3331, A Method for Allocating Nuclear-Power-Plant Control Functions to Human or Automatic Control, United States Nuclear Regulatory Commission, 1983

6.1.9 NUREG/CR-6303, Method for Performing Diversity and Defense-in-Depth Analysis of Reactor Protection Systems, Lawrence Livermore National Laboratory, December 1994

6.2 Codes and Standards

6.2.1 IEEE-603-1998, Standard Criteria for Safety Systems for Nuclear Power Generating Stations, Institute of Electrical and Electronics Engineers, July 1998

6.2.2 IEEE-1023-2004, Recommended Practice for the Application of Human Factors Engineering to Systems, Components, and Facilities of Nuclear Power Generating

Stations and Other Nuclear Facilities, Institute of Electrical and Electronics Engineers, June 2005

6.2.3 EPRI-1008122, Human Factors Guidance for Control Room and Digital Human-System Interface Design and Modification: Guidelines for Planning, Specification, Design, Licensing, Implementation, Training, Operation and Maintenance, Electric Power Research Institute, Palo Alto, CA, the U.S. Department of Energy, Washington, DC, 2004

6.2.4 EPRI-1022684, Elements of Pre-operational and Operational Configuration Management for a New Nuclear Facility, Electric Power Research Institute, Palo Alto, CA