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Use Case Analysis for Designing an Integrated Monitoring Center for Nuclear Power Plants

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ABSTRACT

This study defines use cases for an integrated monitoring center for nuclear power plants (NPPs). The center receives operating and safety information from multiple plants and provides a common view of their conditions. It supports information review, coordination, and reporting while authorized staff at each plant remain responsible for plant operation. The use cases were designed around four goals: presenting a common view of plant conditions; supporting early detection and information review; supporting information sharing, response tracking, and reporting during emergencies or disasters; and managing the data, records, AI models, and security needed for these tasks. We defined 13 use cases and 51 top-level functions based on these goals. The functions cover monitoring, analysis, procedure support, response tracking, reporting, and supporting management tasks. They also link information produced by one task to related tasks, allowing monitoring information to support later review, response, and reporting. These links can reduce repeated searches, data entry, and report preparation. The proposed use cases and functions provide a basis for defining system functions when an integrated monitoring center for NPPs is developed.

Keywords: Nuclear power plants, Integrated monitoring center, Use case design, Operator support

INTRODUCTION

Centralized monitoring and coordination are established practices in aviation and space operations. EUROCONTROL's Network Manager Operations Centre exchanges information and coordinates with aviation stakeholders to support network operations (EUROCONTROL, 2020). NASA's Artemis I mission control brings together specialists who monitor different vehicle systems and coordinate mission activities (Kraft, 2022). These examples show how a common center can connect information and expertise across operational roles.

For NPPs, an integrated monitoring center is a system that remotely receives operating and safety information from multiple plants and provides a common view of their conditions. NPPs have connected systems, strict safety limits, and large amounts of operating data. The center should help users understand changes, share information, and follow responses. Its role is to

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support these tasks while authorized staff at each plant retain responsibility for plant operation.

Related nuclear human factors research provides design guidance but addresses a different level of the problem. Braseth and Fernandes (2024) examined good practices for overview displays within nuclear control rooms, while Boring (2023) discussed the need to consider human factors early in advanced-reactor design. These studies support attention to users and information presentation; their focus is not the task and function specification of the multi-plant center considered here. This study addresses that design need by defining 13 use cases and 51 top-level functions and linking them to four goals.

METHOD

Definition of the Center Goals

The four goals were defined from the intended responsibilities of the center. A common view of several plants requires integrated status monitoring. Recognizing and reviewing developing problems requires early detection and analysis support. Coordinating during emergencies requires shared information, response tracking, and reporting. These activities also depend on managed data, records, AI models, and security. The four goals therefore connect the purpose of the center to the work it should support, as summarized in Table 1.

Table 1: Center responsibilities and corresponding design goals.

Intended Responsibility	Design goal
Understand conditions across plants	G1: Provide a common view of plant conditions.
Find and review early signs of problems	G2: Support early detection and information review.
Coordinate information and follow responses	G3: Support emergency and disaster sharing, tracking, and reporting.
Maintain the resources needed for these tasks	G4: Manage data, records, AI models, and security.

Definition of Use Cases and Functions

The use cases were defined by grouping the main tasks needed to meet the four goals. Each use case describes one main task, such as reviewing trends or preparing a situation report. Monitoring, review, and response tasks are assigned to the first three goals, while record keeping and management tasks form a common foundation under the fourth. This grouping makes the intended scope of each use case explicit.

The top-level functions describe the information task and its result at a consistent level of detail. Displaying current values, comparing them with normal ranges, and reviewing their trends are separate functions within the same review use case. Each has a distinct purpose for the user even when it uses the same plant data. Inputs describe the information received, and

outputs describe the information presented or produced. The specification leaves software algorithms and interface layouts for detailed design. This approach connects each task to an identifiable information requirement.

USE CASE SPECIFICATION

The proposed specification contains 13 use cases arranged under the four goals. Figure 1 presents the overall structure, and Table 2 specifies all 51 functions with their inputs and outputs. Function identifiers combine the use case number and a local function number. This structure connects each task to the information it uses and produces.

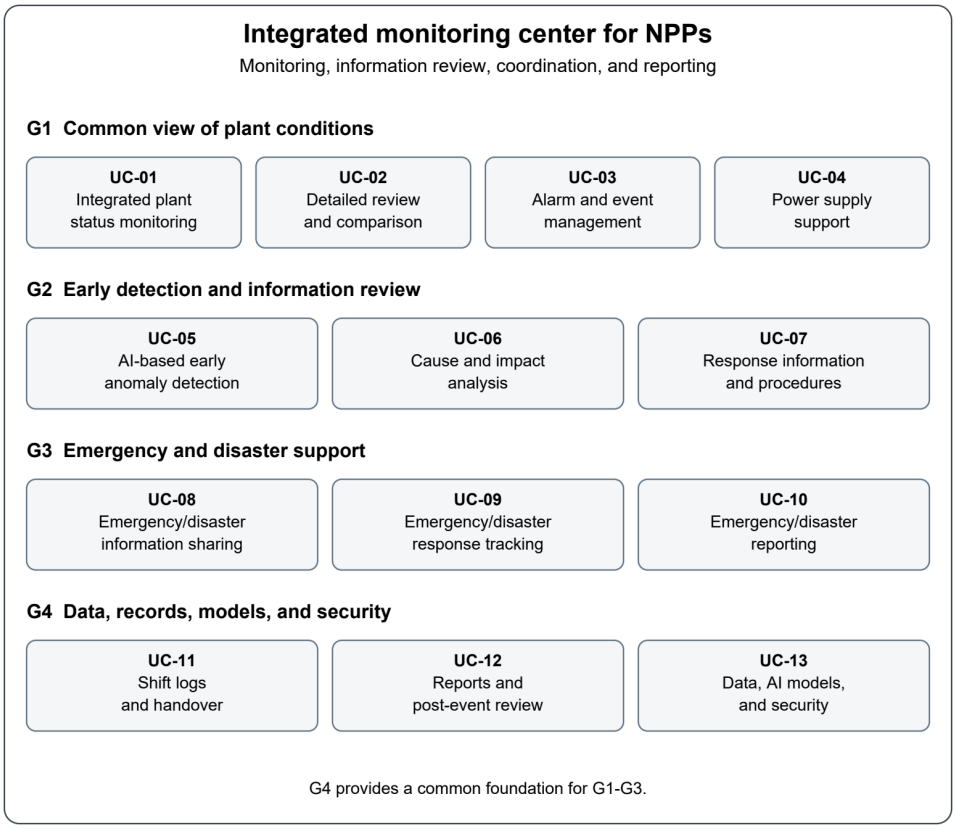


Figure 1: Thirteen use cases organized under four goals for an NPP integrated monitoring center.

The input and output columns distinguish information received from the result a function provides. Plant data denotes operating variables and state information. Where information is displayed without transformation, the input and output can describe the same information. These entries make the information needed for each function explicit.

Some input and output definitions remain open at this stage. Table 2 marks these entries as "Not specified"; this does not mean that the function needs no input or produces no output. Detailed interface design should resolve

these entries. The table therefore separates the defined information links from items requiring further specification.

Common View of Plant Conditions

G1 connects an overview of multiple plants to the information needed to examine a particular condition. UC-01 brings together plant states, safety indicators, alarm counts, emergency information, and communication status. UC-02 supports closer review through current values, normal ranges, trends, maintenance history, and comparisons across similar units. UC-03 allows alarms to be sorted and their histories reviewed. UC-04 adds power supply, reserve margin, and the history of responses to power system operator requests. Together, these use cases define the information available for moving from a common overview to a focused review.

Early Detection and Information Review

G2 connects an early indication of abnormal data to diagnosis and response information. UC-05 checks signal completeness before detecting anomalies, so the detection function receives signals that have already been checked. UC-06 uses plant data and anomaly information to diagnose causes and predict possible effects, including trends in trip-related variables. UC-07 then uses diagnosis results and plant data to present relevant procedures or actions for review. This sequence defines how information can support a developing assessment while keeping the response decision with authorized staff.

Emergency and Disaster Support

G3 separates understanding an emergency from following the response and preparing a report. UC-08 provides emergency, weather, earthquake, natural-hazard, and video-based information. UC-09 brings together event information, response procedures, and user input to show required actions and whether actions have been performed. UC-10 uses emergency or disaster information and a report template to prepare a situation report. These use cases describe distinct outputs for shared awareness, response tracking, and communication with relevant organizations.

Records and Supporting Management

G4 defines the records and management functions needed to support the other groups over time. UC-11 covers shift logs and handover documents, while UC-12 supports the retrieval of similar events and system information for report preparation. UC-13 addresses data quality, reference information, AI model management, access, security, and system status. Preserving data and model histories is particularly relevant when reviewing how an AI output was produced. This group therefore gives the operational use cases a common basis for maintaining information and reviewing earlier work.

Table 2: Function, input, and output specification (G1).

Function	Input	Output
UC-01: Integrated plant status monitoring		
01.1 Monitor main variables, equipment states, and safety indicators.	Plant data	Plant/system states and safety indicators
01.2 Display unit alarm presence and counts.	Plant data or unit early warnings	Alarm presence and counts
01.3 Display an emergency/ disaster overview.	Unit emergency/disaster information	Emergency/disaster overview
01.4 Display unit communication status.	Not specified	Normal/abnormal unit communication status
UC-02: Detailed review and trend comparison		
02.1 Display real-time variable values.	Plant data	Real-time plant/system variable values
02.2 Compare values with normal ranges.	Plant data; normal ranges	Values compared with normal ranges
02.3 Display variable trends.	Plant data	Variable trends
02.4 Display maintenance status and history.	Maintenance status	Maintenance status and history
02.5 Compare variables across similar units.	Data from similar units	Cross-unit variable comparison
UC-03: Alarm and event management		
03.1 Display alarms and early warnings.	Unit alarms and early warnings	Current alarms and early warnings
03.2 Sort by priority, system, acknowledgment, or clearance.	Unit alarms and early warnings	Sorted alarm list
03.3 Provide alarm and early-warning histories.	Alarm/early-warning histories	Alarm/early-warning histories
UC-04: Power supply coordination support		
04.1 Display power supply and reserve margin.	Power supply; reserve margin	Power supply and reserve margin
04.2 Display power system operator requests.	Power system operator requests	Requests for review
04.3 Display response history for these requests.	Responses to operator requests	Response history
UC-05: AI-based early anomaly detection		
05.1 Check signal completeness, noise, and missing values.	Plant data	Signal completeness status
05.2 Detect anomalies using checked signals.	Plant data checked for completeness	Early indication of abnormal data
UC-06: Cause and impact analysis		
06.1 Diagnose abnormal-condition causes.	Plant data; anomaly information	Diagnosis results
06.2 Predict affected variable values.	Plant data	Predicted variable values

(Continued)

Table 2: Continued.

Function	Input	Output
06.3 Predict trip-variable trends.	Trip-related variable data	Predicted trip-variable values
06.4 Assess short- and long-term plant effects.	Diagnosis results; plant data	Short- and long-term plant effects
UC-07: Response information and procedure support		
07.1 Provide relevant procedures or technical guidance.	Diagnosis results; plant data	Relevant response procedures
07.2 Present actions for review if no suitable procedure is available.	Diagnosis results; plant data	Response actions for review
UC-08: Emergency and disaster information sharing		
08.1 Display plant emergency status.	Plant emergency information	Plant emergency status
08.2 Display earthquake information.	Plant earthquake information	Earthquake information
08.3 Display weather information.	Plant weather information	Weather information
08.4 Display natural-hazard information.	Natural-hazard information	Natural-hazard information
08.5 Detect off-site fires from video.	Off-site video	Off-site fire indication
08.6 Detect on-site fires from video.	On-site video	On-site fire indication
08.7 Detect unusual situations from plant video.	Plant video	Unusual-situation indication
UC-09: Emergency and disaster response tracking		
09.1 Display response information.	Not specified	Response situation-board information
09.2 Display whether plant response actions were performed.	User input; event information; response procedures/guidelines	Response action completion status
09.3 Display actions required by procedures/guidelines.	Response procedures/ guidelines	Required actions from procedures/guidelines
UC-10: Emergency and disaster reporting		
10.1 Prepare situation reports for management, regulators, and relevant organizations.	Emergency/disaster information; report template	Emergency/disaster situation report
UC-11: Shift logs and handover		
11.1 Prepare shift logs.	Not specified	Not specified
11.2 Prepare handover documents.	Not specified	Not specified
UC-12: Report preparation and post-event review		
12.1 Search for similar operating events.	User input	Similar-event information

(Continued)

Table 2: Continued.

Function	Input	Output
12.2 Retrieve system drawings and information.	User input	System drawings and information
12.3 Prepare situation-sharing reports.	Drawings; alarms; plant data; diagnosis; event sequence; action results; similar events	Situation-sharing report
UC-13: Data, AI model, and security management		
13.1 Check quality rules; preserve raw values, sources, times, and processing history.	Plant, linked, and manually entered data; quality rules	Quality results/history; preserved raw values and processing history
13.2 Maintain and distribute tag definitions, ranges, and common identifiers.	Tag/equipment data; normal ranges; plant tag-change notices	Current tag definitions, ranges, and identifiers; revision history
13.3 Manage model approval, versions, and rollback; monitor drift and data lineage.	Model versions; false-alarm/missed-detection metrics; training-data versions	Model status; retraining alerts; model-data lineage
13.4 Record AI outputs with versions, inputs, confidence, and user feedback.	UC-05/06/07 outputs; user confirmation	AI decision history; labeled data for 13.5; error-count data for UC-12
13.5 Structure and tag records for search/training; maintain data and document versions.	Operating experience; event records; daily analysis reports; revised procedures/templates	Training datasets; data lineage; current documents and version history
13.6 Retrain, recheck against acceptance criteria, approve, and deploy models.	Retraining alert from 13.3; dataset from 13.5; acceptance criteria	Retrained model and recheck results; deployment history
13.7 Manage access, authentication, and sessions; log user and AI actions.	User accounts; action, approval, manual-entry, and AI-decision events	Access settings; audit logs
13.8 Manage security policies, vulnerabilities, patches, and media controls.	Security policies; interface configuration	Security status; inspection history
13.9 Monitor data, alarm, video, and document interfaces.	Interface status	Interface status; fault alerts
13.10 Detect system faults.	System health-check status	Fault/failover status; recovery history
13.11 Monitor performance/ resources; manage retention and archiving.	Latency/refresh metrics; resource usage	Performance/resource status; threshold alerts; retention/ archive history
13.12 Monitor quality and sensor drift; exclude faulty data from AI use.	Plant data; signal histories; quality results from 13.1	Quality status; suspected drift/data-error list

Links Between AI Outputs and Model Review

The AI management functions define a specific link between operational outputs and later model review. Function 13.4 records outputs from UC-05, UC-06, and UC-07 together with their model versions, inputs, confidence, and user feedback. These records supply labeled data to Function 13.5. A retraining alert from Function 13.3 and the dataset maintained by Function 13.5 become inputs to Function 13.6, which includes rechecking against acceptance criteria before approval and deployment. The specification thus identifies the information needed to trace and review model changes; implementation must still define the criteria and responsibilities for these steps.

RESULTS

The main result is a specification that connects four center goals to 13 use cases and 51 top-level functions. G1 contains four use cases and 15 functions; G2 contains three and eight; G3 contains three and 11; and G4 contains three and 17. The first three groups cover monitoring, early review, and emergency support, while the fourth covers records and supporting management. The contribution is the explicit relationship between the intended work of the center and the functions needed to support it.

The input and output descriptions make information reuse visible across related functions. For example, the completeness check in Function 05.1 supports the checked data used by Function 05.2 for anomaly detection. Plant data and anomaly information are inputs to the diagnosis in Function 06.1. Diagnosis results and plant data are then used by UC-07 to present response information. These entries describe a possible path from a signal to information for a response decision. They provide a basis for connecting the functions during system design.

Report preparation brings together information that is otherwise described under several use cases. Function 12.3 uses system drawings, alarms, plant data, diagnosis results, the event sequence, action results, and similar-event information. UC-02 and UC-03 describe access to operating values and alarms, UC-06 provides diagnosis results, and UC-09 addresses the completion status of response actions. The specification therefore identifies related information that can be reused when preparing a report. Whether this reuse reduces repeated searches or data entry must be examined in a later implementation.

The specification also identifies information that needs further definition before interfaces can be designed. Six input or output entries remain unspecified: the inputs to Functions 01.4 and 09.1, and both inputs and outputs for Functions 11.1 and 11.2. For example, the shift functions name the documents to be prepared, but their detailed information requirements have not been set out. Defining these entries will require decisions about document content and information sources. Recording the open entries makes this remaining design work explicit.

The proposed structure can guide review of a future center by making individual information needs inspectable. A reviewer can start with a

goal, identify the related use cases, and examine the inputs and outputs of each function. The same structure can help connect a proposed screen or information interface to a stated task. However, the current result is a functional specification, and it does not establish operational effectiveness or the performance of the proposed AI functions. Its present value is a concrete basis for detailed design and subsequent evaluation.

CONCLUSION AND FUTURE WORK

This study developed a use case specification to guide the design of an integrated monitoring center for NPPs. The intended responsibilities of the center were organized into four goals, which were used to define 13 use cases and 51 top-level functions. The resulting specification covers a common view of plant conditions, early detection and review, emergency support, and the management of records and supporting resources. It gives designers a structured account of the work that the proposed center should support. However, the proposed use cases have not yet been evaluated in a realistic control-room setting. Their effects on operational usability, staffing, operator workload, and safety performance therefore remain to be validated.

The function inputs and outputs provide the main connection between the use cases and later system requirements. They show where plant information, analysis results, response records, and managed data can be used by related tasks. They also expose information requirements that remain open, including those for shift documentation. These descriptions can provide a practical starting point for deciding what information a future center should receive, present, preserve, and share.

Future work should specify the information interfaces and evaluate the proposed functions with representative users and tasks. The next design stage should resolve open inputs and outputs, define data formats and update needs, and develop screens for the use cases. After a prototype is developed, human-in-the-loop evaluation should examine the proposed functions in representative operating situations. The evaluation should broadly consider usability, workload, coordination, staffing, safety-related performance, and interaction with AI-supported information. Specific scenarios, measures, and acceptance criteria can be determined in later studies according to the purpose and setting of each evaluation. Until then, the expected benefits of the proposed functions should be treated as design goals rather than confirmed effects.

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