INTEGRATED EMERGENCY CONTROL BOARD INCLUDING DESIGN EXTENDED CONDITIONS FOR KRŠKO NPP

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ABSTRACT

In the aim of implementing post-Fukushima safety measures, Krško Nuclear Power Plant is developing a Safety Upgrade Program. Krško NPP is upgrading the remote shutdown capabilities and implementing ways to prevent and mitigate the consequences of potential Severe Accidents.

This modification enhances remote shutdown capabilities of the plant to prevent potential severe accidents and improve the ways to mitigate their consequences. Within the set of plant design modifications, addressed the design, construction, and commissioning, of a new Emergency Control Room (EMCB. Tecnatom is the responsible of the design modification of the plant together with Idom, that participates with Tecnatom in the project as a joint venture, who provides a new set of field instrumentation, including its design and the corresponding wiring.

EMCB integrates Human- System Interface throughout centralizing capabilities to safety shutdown and cooldown the plant as well as to control the new Design Extension Systems. The process relies on a Human Factors Engineering (HFE) analysis applying a specific methodology based on NUREG-0711 [1]. Tecnatom has developed a specific HFE Program Management Plan to proceed with the analysis in a documented, traceable and reliable way. HFE activities ends with an Integrated System Validation in the actual full scope simulator involving MCR crews.

This paper describes different phases of the project, the integrated schedule between HFE and I&C activities, benefits of upgrading main and emergency control rooms beyond design bases and addresses Tecnatom lessons learned obtained during the project execution.

Key Words: HFE, modernization, Remote Shutdown, Design Extended Conditions, operation, panels.

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1 INTRODUCTION: PROJECT PHASES

Based on both, Slovenian nuclear regulation related to Plant Life Extension and consequences due to the accident in Japan, Slovenian Nuclear Regulatory Commission (SNSA), who follows NRC standards and regulations, issued a request to NPP NEK in September 2011 to reassess the existing measures used for Severe Accident Management.

Subsequent to this review, NEK, company owner of Krško Nuclear Power Plant, should implement necessarily safety improvements for severe accidents prevention and mitigation of their consequences. In January 2012 NEK NPP presented an analysis/reassessment and an action plan, reviewed and approved by the SNSA in February 2012.

These measures will include the best available technology solutions and will follow current international nuclear industry practices, specifically in the areas of reliable core cooling, maintaining Containment Integrity, supervision and severe accidents management and spent fuel cooling.

In this paper, the modification related to the Engineering, Design, Procurement and Delivery of the major components during the construction of the Emergency Control Room, is described as a part of Plant Safety Upgrade Program.

2 HUMAN FACTORS ENGINEERING ACTIVITIES

One of the most frequent pending tasks during project executions is to integrate the Human Factors Engineering activities during design phase. It is even more relevant to consider this task when the latest regulation regarding HFE is applied to a Nuclear Power Plant (NNP) designed in the 70's, before TMI event happened; before multi-failure design appeared. Moreover, to design a such a great upgrade based on current standards and licensing it with the ones available in the 70's is a goal.

Before the modification, the Krško NPP had some decentralized local panels for safety shutdown. Understanding as safety shutdown as Hot Standby; local panels (outside to Main Control Room) provided the controls required to perform the activities to stop criticality and cooling the reactor using steam generators and without Residual Heat Removal system in operation.

Nowadays, the modification requested to centralize controls and indications for Hot Standby and to add those related to both, Cold Shutdown and Beyond Design Bases; including feed and bleed of the primary and secondary systems by means of alternatives safety injection and feedwater systems. In addition, an alternative emergency power supply is also included. These new controls, indications and equipment will be installed in a special building with bunker characteristic; designed against plane accidents and flooder events.

The design of the complete modification was performed according to US standards. Specifically, the twelve elements of the NUREG-0711 Rev. 3 [1] were applied throughout Methodology implemented in a specific tool, both developed by Tecnatom. The task analysis result, including results of Operating xperience and Functional Analysis and Allocation of Functions, was the main input used to start the modification design phase.

The following Figure 1, represents the Tecnatom project schedule. HFE activities are performed before, during and after the manufacturing activities.

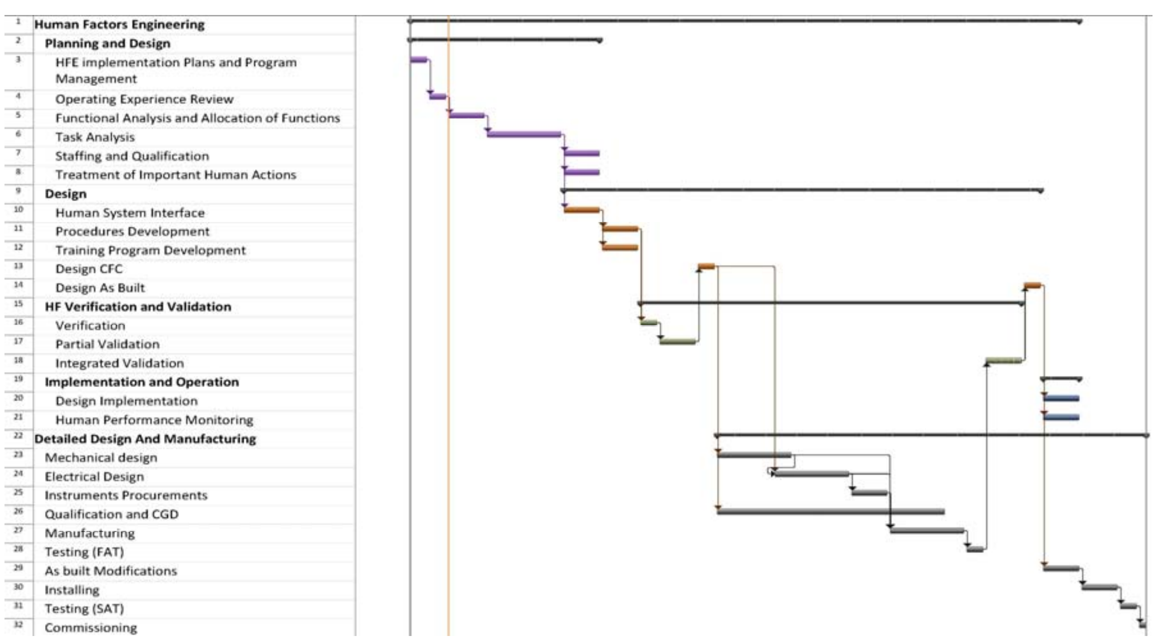

Figure 1. Simplified typical project schedule.

The design activity was performed in three phases:

1. Design of the interfaces based on the results of the HFE analysis and plant documentation. The results obtained were used to perform the "Partial Verification and Validation". This activity is performed in a real size mock up "running" the operating procedures associated to a set of scenarios to test the complete panel functionality. This is a preliminary design that will not be used for manufacturing.
2. Certified for Construction (CFC) Design, including the result obtained, lessons learnt and hazards founded in the Partial Verification and Validation. This design will be used for the construction.
3. As Built Design, including all improvements found during:
   - Integrated validation in a full scope simulator
   - Manufacturing
   - Testing

2.1 HFE Analysis

As the HFE analysis performed during the project followed the twelve elements described in NUREG 0711 Revision 3 [1], the Tecnatom HFE Program was also divided into twelve parts. On the other hand, this program was implemented in two main stages described below.

First stage was to prepare an HFE Program Management where is defined:

1. General Goals and Scope of the HFE program for conducting all HFE activities
2. HFE Organization, Teams and member qualifications
3. HFE Process and Procedures/Methodologies
4. HFE Issue Tracking System
5. HFE Technical Program (HFE Elements), phases and duration

The second step, and final one, before the detailed plant analysis, an analysis of the previous experiences in the nuclear industry regarding to similar panels was performed.

The Operating Experience Review (OER) is a valuable source of information to learn and improve NPPs safety and reliability. During the operation of NPPs, deviations, inconsistencies, problems detected from design modifications, conditions, events and practices occur. The process followed for reviewing the Operating Experience was to identify safety issues to avoid the previous mentioned issues and their recurrence. The process covered gathering the Transfer Panels and Emergency Control Room appropriate information, evaluating and checking its applicability and outlining the positive and negative aspects, including corrective measures, that matched to the concerning modification part of the Plant Safety Upgrade Program.

According to previous considerations, the methodology adopted for the OER contains the following stages:

1. Check-Consult the different OER input sources. For this project the implemented consult was the following:
   - WANO OE program — ENR (Event Notification Report), EAR (Event Analysis Report), MER (Miscellaneous Event Report), ETR (Event Topic Report), SER (Significant Event Report), SOER (Significant Operating Experience Report), Good practices, Just-in-Time and Peer Review Strengths- web based.

- INPO SEE-IN program — Significant Event Evaluation.
- IRS reports — joint IAEA and OECD/NEA services.
- Vendors Publications and Bulletins — Service Information Letters (SILs), Technical Bulletins (TBs), Nuclear Safety Advisory Letters (NSALs), etc.
- Krško NPP Documented Operating Experience.
- NRC Nuclear Safety Regulators Documents:
    - Generic Letters.
    - Information Notices.
- Owners Group reports.
- Plant to plant event reports and exchange of information databases: LER, DACNE, CNAT.
- Research and development organizations: NEI, ANSI, WENRA.

2. Screen (Pre-Selection) from the OER input sources and analysis of the OER issues for applicability
3. Process Outcome
4. Development of Conclusions

Functional Requirements Analysis was conducted, following NUREG-0711 [1] recommendations, to:

1. Define the high-level functions that should be accomplished to meet plant goals and desired performance
2. Delineate relationships between high-level functions and the plant systems (e.g., plant configurations or success paths) responsible for performing the functions
3. Provide a framework to determine personnel roles and responsibilities and automation

It was performed following the functional hierarchical structure shown in Figure 2:

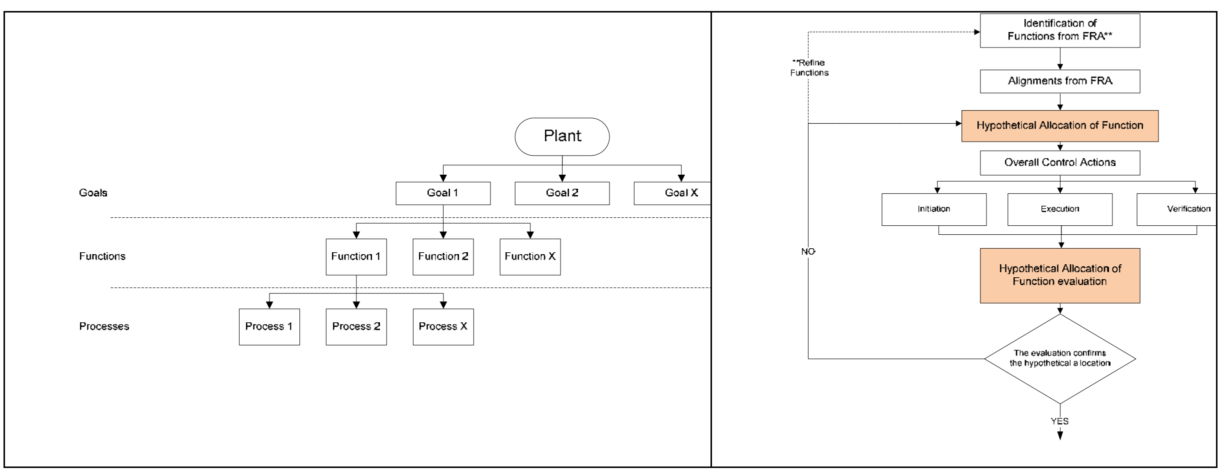

Figure 2. Example of Functional Hierarchical Structure and Function Allocation Process

Once this was done, the Function Allocation consisted of assigning the function to personnel and automation (hardware and software aspects of the plant), such as:

1. Personnel (e.g., manual control).
2. System elements (e.g., automatic control, passive phenomena)
3. Combinations of personnel and system elements, for example:
    a. Shared operation, the automatic operation of some aspects of a function, with others performed manually
    b. Operation by consent/delegation, automation takes control of a function when personnel direct it to do so under close monitoring and supervision
    c. Operation by exception, autonomous operation of a function, unless there are specific predefined situations or circumstances requiring manual human action

To assure the design safety and reliability, designers considered relative capabilities, strengths, and weaknesses of personnel and automation. In many cases the allocation could be shared between human and machine. Due to this, some of processes required to achieve the functions can be performed manually by the operator and others can be automatic. This allocation helps to decide the final setup of the Human System Interface (HSI) by affecting directly to the subsequent NUREG elements: Task Analysis and Human System Interface Analysis.

Finally, the analysis stage end with the Treatment of the Important Human Actions (TIHA). The propose of this analysis is to identify the IHAs associated to the considered NPP modification and integrate them in the HFE Program, taking into consideration its impact in the rest of HFE Elements. For this purpose, the process was developed in three main steps:

1. Identification of IHAs
2. Integration of IHAs in the HFE Program
3. Specific Treatment of IHAs

2.2 Design and V&V phase

As a result of the analysis phase, preliminary design was delivered following the principle described in this paper, as well as recommendation driven by NUREG 0700 Revision 2 [2]. The new HSI design was designed to transfer control from the Main Control Room (MCR) to the Emergency Control Room (ECR) as well as to achieve Hot Shutdown and Cold Shutdown conditions. Moreover, this new interface counting on a new control board with the capabilities for the new DEC control. The new HSI design has the appearance shown in Figure 2.

As general consideration, design requirements defined the type of human-system interactions in order to develop an HSI, based on the following features:

1. Simplicity and ease of use: to reduce overall level of cognitive demands and the time to achieve the successful transference and subsequent plant stability from the ECR. Therefore, the HSI represent the simplest design consistent with functional and task requirements.
2. Clear designation of tasks: presenting information through display formats is unambiguous; tasks can be performed efficiently and safely minimizing potential operator response errors.
3. Operation consistency: operation rules for the new HSI of ECR are consistent with the current ones in MCR ; mental workload demands are not increased.
4. Familiar conventions: standards and conventions to be used for the new HSI Design are familiar to operation personnel, taking advantage of the previous experience with the current MCR HSI to avoid high level of modification which may lead to potential errors regarding interaction with new controls and indicators.

5. Personnel safety: the new HSI Design minimize the potential for injury.

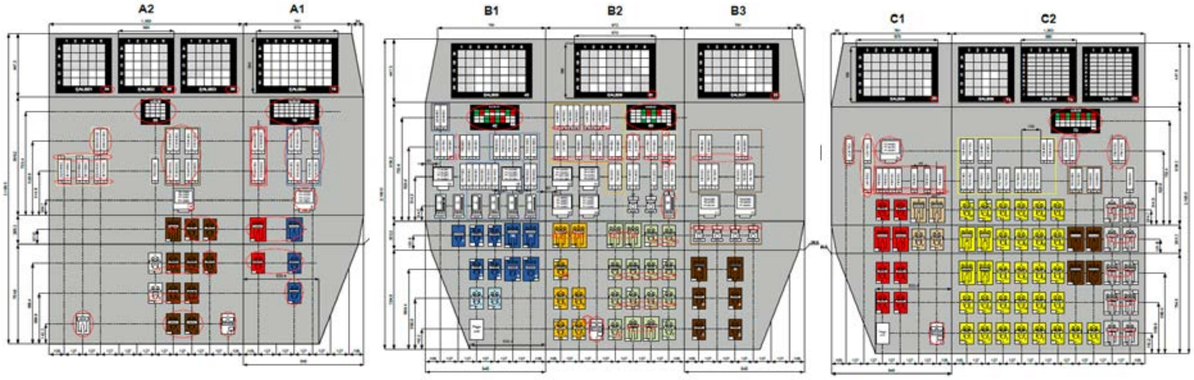

Figure 3. HSI Preliminary Design.

The Partial Validation was performed in a real size mock-up where allocation of each component is represented. The main objective of the Partial Validation report is to:

1. Demonstrate adequacy in terms of:
   - Usability: panels provide sufficient and understandable information to operators
   - Operational correctness: panels are compatible with plant responses, hardware is the adequate to perform a safety operation, and shift manpower is able to accomplish the steps listed in the procedures
2. To identify and document Human Engineering Discrepancies (HEDs).

Figure 4. Partial Validation on Mock-up

3 MANUFACTURING, DEDICATION, AND QUALIFICATION ACTIVITIES

3.1 Mechanical Design

As a part of the modernization scope, a detailed mechanical design was developed, based on the results of HFE activities. It was designed in order to be seismic resistance according to IEEE-344, 1987; taking into account the floor response spectra of the final location. Particularly, it was considered that the modal response of the panels was in the range of frequencies recommended by IEEE.

Figure 5. Manufacturing Phases

3.2 Electrical Design

Electrical Design consisted on both, instruments wiring design for proper performing and definition of power supplies needs to provide power to the EMCB panels. The electrical design, including wiring, was based on separation between trains and safety classes in accordance to the established in the IEEE 384, 1981 and IEEE 420 1982 and be maintained through all the EMCB panels.

3.3 Seismic Qualification and Commercial Grade Dedication

All safety-related components procured as class-1E, were qualified in accordance with 10CFR50 App. B. Additionally, a seismic qualification of the integrated EMCB was performed. The seismic qualification was achieved by means of testing a specimen of the EMCB designed and manufactured for that purpose. This specimen included at least one piece of each type of items to be included in the real EMCB. In addition, the number of pieces for those items was determined by the applicable standards subjected to commercial grade dedication processes.

For those equipment items or services not purchased as class-1E, Tecnatom developed a Commercial Grade Dedication (CGD) Plan according to IEEE 323 and performed the corresponding tests in order to provide needed evidences requested by the standards.

4 LESSONS LEARNED

HFE provides valuable design recommendations which improves operation minimizing the human error. In this section, significant improvements incorporated in the final implementation are listed:

4.1 Example of adding more components to the Emergency Control Board

The source was a recommendation from Task Analysis and it was validated during the Partial Validation. The recommendation was:

- The RH system is to be placed into service when cooling down the plant to Cold Shutdown. Valve PCV-135 could be added to the EMCB in order to adjust pressure when the RCS is solid and then provide control in case of a possible primary discharge isolation to Chemical and Volume Control System.

As a result of this recommendation, a new component was included in Emergency Console and its corresponding transfer switch in the associated board.

4.2 Example of changing the control mode on the Emergency Control Board

The Source was a recommendation from Functional Analysis. In certain components, the right transfer from Main Control Room to Emergency Control Room was impossible to check. This was resolved replacing the manual positioner with auto-manual stations for the critical ones: Steam Pressure and Auxiliary Feedwater flow regulators. For others, a specific alarm indicating the transfer status was included.

4.3 Other Miscellaneous examples

In the following list, minor changes as a result of human factors engineering activities they are described. Some of them, resulted from the analysis process. Others derive from the Partial Validation:

1. Color demarcations for controls and indicators were included; essential features to identify plant systems specially when operators will only operate this new control room in a special emergency conditions.
2. Reallocation of certain controls in order to accommodate them to the personal ergonometric.
3. As a result of the Partial Validation (to Emergency Control Board and Transfer Board) and based on the results of Staffing and Qualification analysis, two operators are requested to perform the transference instead of the unique initial defined, in order to meet time response requirements.

5 CONCLUSIONS

Human Factors Engineering Analysis enhances plant safety operation improvements. Nevertheless, applying HFE principles during a complex project such as Krško is a goal in terms of coordination between design engineers, costs, and schedule. Tecnatom, playing the role as the coordinating company, achieved the following goals:

1. Significant reduction of human errors, directly quantified in the Probabilistic Risk Analysis where the safety level was increased.
2. Associated reduction of both, cost and potential project delays. The design is evaluated at the same time as it is being developed and improvements done during the design phase are directly integrated. Moreover, the operating crew from the Partial validation, was part of the design equipment providing important comments to the design team. With this personnel strategy, human errors were reduced by including operating crew habits, costs, potential delays in the project schedule; enhancing customer satisfaction.
3. Project goal achievement. Modification was performed in order to increase plant safety, even in case of beyond design bases accident. HFE was continuously checking along the design process that design functions were correctly implemented.

6 ACKNOWLEDGMENTS

This paper is the result of the execution of an innovative project because Krško NPP decided to perform a safety upgrade and give the opportunity to Tecnatom to apply his technology and know-how in this innovative project

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