1. Introduction

IAEA Safety Glossary (2007) provides definition of the terms 'nuclear safety' and 'safety culture':

- **Nuclear safety**: "The achievement of proper operating conditions, prevention of accidents or mitigation of accident consequences, resulting in protection of workers, the public and the environment from adverse radiation hazards." Nuclear safety is often abbreviated as just 'safety'.

- **Safety culture**: "The assembly of characteristics and attitudes in organizations and individuals which establishes that, as an overriding priority, protection and safety issues receive the attention warranted by their significance."

Thus, the safety culture concerns both normal circumstances of operation of a nuclear facility and emergency conditions. For the latter, safety assessment including Deterministic Safety Analysis (DSA) and Probabilistic Safety Assessment (PSA) is performed to ensure robust design and operator procedures to prevent accidents and mitigate their consequences should they occur.

PSA complements DSA and represents a comprehensive conceptual and analytical tool for quantitative evaluation of risk of undesirable consequences from nuclear facilities and drawing on qualitative insights for nuclear safety. The quantitative estimation of risk represents the frequency of such undesirable consequences as nuclear fuel (or reactor core) damage, different (e.g. early or late) releases from the damaged fuel, human health and societal effects from the releases. Quantitative evaluation of risk allows obtaining numerical risk profile from different contributing hazards and factors that allows drawing many useful qualitative conclusions and insights on different aspects of the design and human factors related to the nuclear facility. Many PSAs performed for Nuclear Power Plants (NPPs) all over the world demonstrate this.

One of the major tasks of PSA is Human Reliability Analysis (HRA). The objective of this task is to identify all safety-related human interactions with the facility, identify the factors impacting the human interactions, quantify the probability of failure to correctly perform the actions, and draw on qualitative insights for further enhancing the human performance.

IAEA produced many publications in Safety Standards, TECDOC and Safety Report series to provide general recommendations and more detailed information on performing specific analyses in the frame of PSA, including HRA for such complex nuclear installations as NPPs. This effort is continuing. Specifically, the HRA topic is receiving special attention after the Fukushima Daiichi Accident.

2. Overview of PSA Scope, Objectives and Outcome

The overall PSA scope for NPPs can be considered as three-dimensional. The diagram presented in Figure 1 illustrates the overall possible scope of PSA.

![Figure 1: Illustration of PSA Scope](image)

On X-axis, depending on the consideration of the extent of accident scenario development, Level-1, Level-2, and Level-3 PSA are distinguished:

- **Level-1 PSA** is focused on identification of fault sequences of components and/or human errors leading to core damage and calculates the core damage frequency.

- **Level-2 PSA** further analyses the progression of accident scenarios, identifies the ways in which radioactive releases can occur, and defines the composition, timing, quantity, and associated frequencies of the radioactive releases.

- **Level-3 PSA** is focused on the analysis of off-site consequences and calculates individual risk of death for a member of the public, early and late health effects, and other societal effects, such as contamination of land and food.

On Y-axis, different operational modes are shown. PSA can be conducted for full power operating conditions as well as for low power and shutdown modes of the plant. On Z-axis, different initiating events and hazards are shown.

A full-scale PSA for NPPs includes all elements depicted in Figure 1. Various human interactions are analysed and modelled in each PSA module shown in Figure 1.

PSA allows identifying more risky accident scenarios prospectively from the analysis of design features and human factors rather than from the evidence of incidents and accidents. Insights from the analysis provide useful information on the aspects needing further improvement. In relation to human factors, these aspects may include maintenance practices, operator procedures, training, man-machine interface, design changes or additional safety provisions, etc.

It is important that PSA should be of good technical quality and sufficient level of detail to provide meaningful insights and support effective safety improvement.

3. The Place of HRA within PSA and Types of Human Actions

The HRA within PSA is one of several other complex technical tasks, such as initiating events analysis, accident sequence modelling, systems analysis, analysis of data needed for calculation of risk metrics, etc. All analysis tasks and interconnections between them are shown in Figure 2 for Level-1 PSA (the figure is reproduced from the relevant IAEA Safety Guide SSG-3). Thus, HRA is an integral part of PSA that allows analysing the safety of nuclear installation in a holistic and comprehensive manner. Both technical and human-related aspects are modelled in the frame of one and the same PSA model; the results in terms of significant factors are analyzed holistically thus enabling a truly "systemic approach" to safety.

![Figure 2: Composition of Level-1 PSA Tasks](image)

Traditionally, three types of human errors for respective human interactions are analysed in PSA:

- **Type A**: Pre-accident or latent human errors (e.g. errors during maintenance of safety systems)
- **Type B**: Human errors as initiators of accident sequences (e.g. wrong manipulations)
- **Type C**: Human errors after an initiating event in the course of accident mitigation (e.g. missing a procedural action or wrong diagnostics) including dependencies between actions.

For all types of human interactions, specific methods are developed and applied by HRA and PSA practitioners. The methods are numerous and envisage a detailed task analysis addressing different factors influencing operator performance, in particular, the contextual boundary conditions, time available to accomplish the action, features of man-machine interface, workload, stress level, quality of available procedures, training, etc.

4. Some Insights for HRA from the Fukushima Daiichi Accident

The Fukushima Daiichi accident and the measures implemented at many nuclear facilities (such as installing mobile components and establishing severe accident management programmes) highlighted the need to adequately apply and/or further develop HRA methods to assess:

- **Human actions to deploy mobile components (e.g. mobile diesel generators or pumps) taking into account the effects caused by accident scenario and specifically by extreme external events**
- **Impact of organizational factors and command of control on the effectiveness of severe accident management (e.g. assessing the probability of timely decision to open filtered containment venting)**
- **Factors impacting human response in conditions caused by different extreme events and addressing these in estimating human error probabilities**
- **Errors of commission, etc.**

5. Conclusions and Further Development

Human and organizational factors are important elements of safety of nuclear installations and can be effectively analyzed using PSA as a supporting tool. Moreover, the PSA technique represents a true 'systemic approach' to safety explicitly integrating the technical, human, and organizational factors enabling holistic insights for further safety improvement.

The demonstrated commitment of an operating organisation to learn insights for further safety improvement prospectively from good safety quality analyses and PSA in addition to retrospective learning from operational experience (e.g. incidents) should be perceived as an attribute of a good safety culture.

Safety Assessment Section (SAS) of the Division of Nuclear Installation Safety is pursuing work to support Member States in further development of relevant methods and tools for safety assessment, including PSA and HRA as its part. Currently, a publication in the TECDOC series entitled "Considerations for Supplementary Safety Analysis of Nuclear Power Plants in the Light of the Fukushima Daiichi Accident" is being developed. In addition, further plans of SAS include developing a publication in the Safety Report series that would provide contemporary information on advances in HRA including the consideration of organizational aspects for the wide spectrum of human interactions considered in safety analyses.