MODELLING HUMAN INTERACTIONS IN THE ASSESSMENT OF MAN-MADE HAZARDS

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ABSTRACT

The human reliability assessment tools are not currently capable to model adequately the human ability to adapt, to innovate and to manage under extreme situations.
The paper presents the results obtained by ICN PSA team in the frame of FP7 Advanced Safety Assessment Methodologies: extended PSA (ASAMPSA_E) project regarding the investigation of conducting HRA in human-made hazards.
The paper proposes to use a 4-steps methodology for the assessment of human interactions in the external events (Definition and modelling of human interactions; Quantification of human failure events; Recovery analysis; Review). The most relevant factors with respect to HRA for man-made hazards (response execution complexity; existence of procedures with respect to the scenario in question; time available for action; timing of cues; accessibility of equipment; harsh environmental conditions) are presented and discussed thoroughly.
The challenges identified in relation to man-made hazards HRA are highlighted.

Key words: external hazards, human interactions, PSA

Introduction

The operating experience acknowledges that the effects generated by external hazards could have the potential to adversely impact the plant safety and the response of plant personnel. External events may lead to harsh personnel working conditions, problems in getting external aid and increases in emotional stress (site isolation induced as a consequence of the occurrence of a severe external event, adverse conditions for countermeasures requiring working outdoors, affecting the possibility of implementing emergency procedures).

The human reliability assessment (HRA) tools are currently not capable to model adequately the human ability to adapt, to innovate and to manage under extreme situations, even if the reliability of operator actions in mitigation of the external initiating event consequences represents a key issue for the evolution of an event. Not all the external hazards have a well-developed HRA methodology, only in case of seismic events or induced internal fire events, detailed information and HRA models are available. [1]
The international nuclear community is making serious efforts trying to develop and reach consensus on the modalities to perform a HRA in the occurrences of external events context.

Investigation of human interactions

More systematic developments after post-Fukushima lessons learned have emphasized the importance to assess the human performances in the context of external hazards occurrences. The reconsiderations for human performance analyses include the treatment of:

- o the psychological impact on operators and on persons taking decisions (uncertainties, stress, loss of trust or hope);
- o the feasibility of recovery actions and time delays (some actions require long time to be performed);
- o the effects of long-term scenarios (including fatigue, stress and cumulative dose);
- o prioritization of work by the people who make decisions (possibly due to incorrect information concerning the status of the plant or system and information received from external organizations);
- o high potential for commitment errors.

The Fukushima event showed that the events post core-damage can become much complex because of the potential loss of information and unexpected instrumentation failures or due to lack of personnel trained for accident specific conditions. The severe accident management guides (SAMG) cannot always cover the situations faced by operators. Sometimes, even supplementary resources (from off-site) do not timely secured the control of the situation, so there is a need to realistically analyze the potential time delays.

The current human reliability analysis (HRA) methods are limited in their ability to represent all important aspects of human performances due to lack of data, methodological limitations related to the limitations processing of time scale and the uncertainties regarding people behavior in accident conditions.

Among the HRA methods used in human factor analysis that may be used also to model the interventions in external events conditions, the followings can be mentioned:

- THERP (Technique for Human Error Rate Prediction); [2]
- SPAR-H (Standardized Plant Analysis Risk Human Reliability Analysis); [3]
- ATHEANA (A Technique for Human Error Analysis); [4]

THERP is an evaluation method of man-machine system degradation using: individual human error; human error in interaction with operating equipment, practices and operating procedures, and other system or human characteristics which influence the system objectives and functions. [2] This technique is used to generate quantitative estimations for actions reliability and recovery factors and represents a human reliability model defined as a set of operation relationships and principles.

The aim of SPAR-H [3] is human error probability estimation in case of actions and decisions realized as a response of operator/ intervention team to initiating events occurred in NPP. This method is based on a cognitive response and is related to a behavior model.

ATHEANA method [4] is based on a multidisciplinary framework which considers both human centered factors (man-machine interfaces, procedures content and form, training) and NPP conditions which increase the necessity for actions and create the operational causes for man-machine interactions (wrong indications, equipment unavailabilities or other configurations or abnormal operation circumstances). This HRA method is especially designed to identify, model and quantify the commission or omission human errors, in a specific complex scenario (it involve diagnosis or cognitive complexities resulting in many credible judgments from which the operator has to make a choice). A key observation representing the basis for application of this method is that the real human failure event (HFE) cannot usually randomly appear or as a result of a simple spontaneous behavior.

After an external initiator two contributions should be considered in HRA: the success of operators to follow related emergency procedures, as the success of improvised recovery actions for human and equipment failures, in opposition with inadvertent and erroneous actions having the potential to worsen the situation.

New factors should be considered in the assessment and in the estimation of HEP, different from those taken into account in internal events PSA level 1. For example, the operator actions taken outside of the control room should be evaluated for their feasibility including the necessary time, location availability, availability of the right personnel and environmental hazards (after-shocks, radiation).
The “new" factors (redefined by the context) that influence the performance are relevant to events extended in time, such as fatigue (the Fukushima operators have spent much time on-the-job) and level of stress (Fukushima operators were clearly anxious because of their personal safety).

No specific methods have been proposed up to now for modeling the impact of external hazards on the quantification of human factor in the external event PSA. The impact of external events on the quantification of human factor in the external events is in general based on the “extension” of the existing HRA methods, with the idea that the assessment of human error probabilities for external hazards should follow the basic assumptions from PSA for internal events that will be tailored on external hazard conditions. As results, more pessimistic factors in the HEP quantification, or rough modification of the quantified HEP is used.

ASAMPSA_E project

The ASAMPSA_E (Advanced Safety Assessment Methodologies: extended PSA) project has started on July 2013. The project is coordinated by the French Institute for Radiological Protection and Nuclear Safety (IRSN), and is based on the contributions from 28 project partners (from 19 European countries), representing well-known organizations with activities in the development and application of PSA. US-NRC, TEPCO and Japan Nuclear Safety Institute (JANSI) have also joined the project.
The project offers a new framework to discuss, at a technical level, how good is the existing PSA methodology in identification of any major risk induced by the interaction between a NPP and its environment, and to derive some technical recommendations for PSA developers and users. [7]

The ASAMPA_E partners have examined how they can collect relevant experience or formulation of needs through an external survey for PSA stake-holders (utilities, vendors, safety authorities, research and TSO). The developed survey intends to foster useful exchanges in the PSA community, helping to specify the needs for guidance in performance and application of extended PSA.

Among further actions related to common issues for HRA (for external hazards) the following might be mentioned: [9]

- Analyse HRA modelling demands for extreme external events
- Analyse HRA modelling demands for multi-unit PSA (sharing the team/ resources between units, site management complexity - capabilities and limitations, equipment restoration possibilities, inter-reactor positive or negative effects)
- Examine how to improve HRA modelling for multi-unit external hazards conditions to tackle specific issues, such as high stress of NPP staff, number of tasks to be performed, potential lack of written operating procedures, accident management and possible site contamination

As potential challenges, the following were identified: [9]

- Human performances in the context of combinations of external hazards with other anticipated events or hazards
- Better understand, and predict human performance at all levels
- Systematic multi-unit analysis covering in particular those issues with operating and non-operating units
- Better analyses tools, easy to use, support for enhanced and more cost-effective analyses

The obtained results were presented at the ASAMPSA_E end-user workshop held in Uppsala, and it was recommended that the project shall examine how to improve HRA modelling for external hazards conditions to tackle the following issues: [8]

- the high stress of NPP staffs,
- the number of tasks to be done by the NPP staffs,
- the impossibility, for rare events, to generate experience or training for operators actions (no observation of success/ failure probability (e.g. simulator),
- the possible lack of written operating procedures,
- the possible wrong information in the MCR or maybe the destruction of the MCR,
- the methodologies applicable to model mobile barrier installation (for slow developing event),
- the methodologies available to model use of mobile equipment (pumps, DGs) and conditional failure probability (human and equipment),
- the methodologies applicable to model equipment restoration (long term accident sequences, specific case of multi-units accidents)

Considerations on the Performance Shaping Factors

Any factor influencing the human performance, through mechanisms which may have heterogeneous, endogenous or exogenous nature, is named performance shape factor (PSF). The accurate identification of these PSFs and of their influence mechanisms on the human factor require an interdisciplinary approach that combines sociological, psychological and technical expertise. These factors are evaluated in modeling of the human actions, and provide real opportunities to reduce the likelihood for human errors.

The factors considered to have the greatest effect on the performance are discussed below:

Available time

The available time refers to the amount of time that an operator or a crew has to diagnose and act upon an abnormal event [10]. A lack of time can affect the operator's ability to think clearly, to consider and analyze the alternatives, as well as the ability to perform the required tasks. Time pressure leads to complex situations and high and extremely high stress levels. It is important that the time available and the time required carrying out the action to be considered along with many other factors and requirements of the sequence. The following special considerations can be identified in the external hazard occurrence context: [7]

- use of less familiar or even different procedure steps and sequencing could change the anticipated timing of actions in response to a man-made hazard;
- interfacing with other organizations (e.g. fire brigade) working in the vicinity or on the site may delay performing some actions;
- accessibility issues, harsher environments, and/ or the need for other special tools may impact the overall timeline of how quickly actions normally addressed in response to internal events can be performed under the conditions imposed by man-made hazards;
- for ex-control room local actions, the available resources, the number and locations of the necessary actions and the overall complexity of the actions that must be taken may have a most significant impact on the time required to perform the actions.

Stressors and stress

The stress is defined as bodily or mental tension and stressor as any external or internal force that causes stress. [2] The environmental factors are often referenced as stress factors (heat, noise, humidity, smoke, radiation or poor ventilation) that can impair thinking or operators physical performances. The stress elements can be classified as elements of psychological stress (load speed, monotonous work) and physiological elements (fatigue, discomfort). The stress can include mental stress, excessive workloads or physical stress (difficult environmental factors). It includes aspects of limited attention, and may induce general fear or panic associated with an event.

The relationship between stress and human performance is curvilinear (figure 1). Both too little and too much stress can lead to a poor performance.

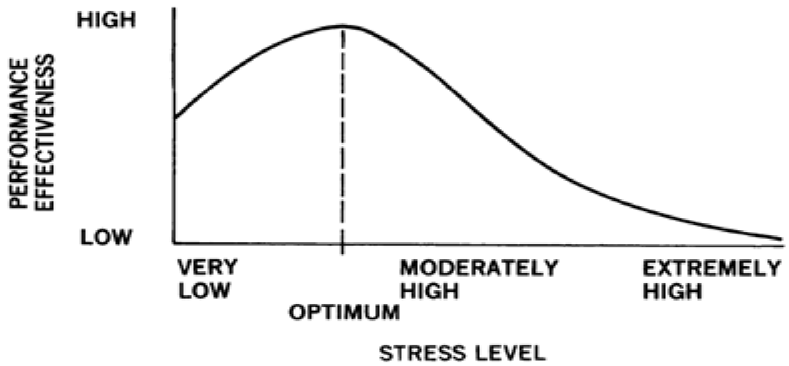

Figure 1 - Hypothetical relationship of psychological stress and performance effectiveness [2]

A routine task has usually assigned three stress levels (up to moderately high level). The psychological tests for prediction of performance of the individual in a stress situation have not been sufficiently analyzed and evaluated to be widely used. The highest stress level is dangerous and involves emotional reactions to the situation, even the possibility of losing control. In modeling human performance considering extreme external events, only two levels of stress should be used: high and extremely high, allocation depending on the location and on the dimensions of impact.

Task complexity

Most man-made hazard related scenarios may be considered as complex tasks due to multiple induced transients, unavailability of multiple equipment, large number of actions required, misleading or absence of indications, transitioning between multiple procedures and large amount of communication required. Moreover, for local and MCR abandonment actions, the crew may be required to visit various locations that may increase the complexity of the situation.

Experience and training

Training or experience should be relevant to the situation of external hazard. Another important aspect to be considered is whether the script is new (whether or not the team or the individual has been involved in a similar scenario, in training or operational situation).

Procedure

Specific operational procedures must be set to monitoring real time and human action that follows an external event. [10] This PSF could have negative influence if it has features such as those below:

- Situations where operators are likely to have trouble identifying a way forward transmitted by procedure (ambiguous, unclear or non-detailed steps)
- Requirements to rely on considerable memory
- Situations for which there is no procedure or the procedure is likely to be unavailable, confusing situations, interpretable

Alarms and indications

The instrumentation is an important factor in human performance, both for the control room actions and for local actions (indications should be clear so that operators know the status of the plant and when to carry out the required actions). This factor may have a negative influence in the following cases: [10]

- loss of indications, inaccuracies or defects in the instrumentation could lead to wrong actions
- too many changes of indications and alarms or indication in short period (difficult to notice the important indications and alarms)

In case of external hazards, possible erroneous information in MCR could be considered as having a high probability. The human-machine interfaces differently impact the performance of operators, depending on the location of the action [5].

Communication

For local actions, this factor may be more important due to possible difficult situations. Communication issues that may impact negatively the response implementation might be: [10].

- Mistakes in communication. The data communicated in verbal instructions are revoked incorrectly by people who implement the instructions
- Inadequate hearing. Information or data sent by an individual are not heard as it was intended (e.g. environmental noise, inadequate channels (radio, mobile).

Accessibility

Especially for local actions, the availability and operability of the equipment needed to be manipulated cannot be always ensured. After a human induced external event, there is the potential that the personnel path to the component location will be blocked and this fact will lead to a delay or inability to reach the action location. Where alternative routes are possible, the demands associated with identifying such routes and the extra time associated with the use of the alternative routes should be factored into the analysis. Sometimes, unique fitness needs are needed to access the important components: [7]

- having to climb up or over equipment to reach a device because the external event has caused blockage of the initial access path;
- need to move and connect hoses, especially if using a heavy or awkward tool;
- using SCBA, which can be physically demanding and hinder communication.

The mobile equipment should be available at demand and should be located in a safe environment.
The habitability within the building in toxic gases, smoke or extreme heat conditions are to be analyzed and evaluated. [7]

Results

To define the human interactions, similar stages as those used in SHARP-1 methodology [6] were proposed:

- Definition and modelling of human interaction events
- Quantification of human failure events (HFEs)
- Recovery analysis
- Review

Consistent with PSA tasks, the HRA stages are intended to emphasize the integration of the HRA into PSA model, with a special focus on the dependencies that exist between human interactions and other events. The four stages should be performed iterative, rather than in a stepwise manner.

Definition and modelling of human interaction events

The most important objectives of this stage are the followings:

- To provide an understanding of the context of human interactions
- To understand the impact of the human interactions on accident sequence development
- To incorporate the human interaction events into the plant logic models

Post-initiator operator response can be divided into four stages: detection of a critical situation, diagnosis of the situation, deciding on the necessary actions, and implementation of these actions.
The human interactions could be very scenario-dependent, related to actions dictated by plant operating procedure or related to recovery of failed equipment, establishing cross-connection within units, repairing equipment, etc.
The human interactions could be incorporated in the PSA model in the definition of initiating event and in accident sequence development. The interaction ways will be a function of the various conditions that can occur, as defined by the development of the PSA accident sequences and associated equipment

unavailabilities and failure modes. Some of the operator actions may be performed immediately and without regard to the specific situation, while others will be dependent on the plant status and cues. Recovery actions that cannot be performed due to the impact of external hazards of certain magnitude should be removed from the Level 1 PSA model or probabilities of failure whilst performing the action should be increased.

Quantification of human failure events

This stage provides as output the probabilities of human interaction basic events (HEPs) for each of HFE, the uncertainties of estimations and whatever revisions to the models are needed to properly account for the final human interaction definitions. The probabilities may be quantitative screening values, or the results of a detailed evaluation.

In conditions of external hazards occurrence, a thorough check and associated adjustment should be performed in relation to recovery actions and probabilities of human errors. All post-initiator human errors that could occur in response to the initiating event, as modelled in the Level 1 PSA for internal initiating events, should be revised and adjusted for the specific external hazard conditions. As a minimum, the following induced effects on the operators performance shaping factors should be taken into account:

- Availability of pathways to specific structures, systems and components after an external hazard occurrence;
- Increased stress levels; Compared to accident scenarios caused by internal initiating events, the operators stress levels and conditions in the plant may differ considerably after an external initiating event.
- Failures of indication or false indication;
- Failure of communication systems.

There are likely to be interdependencies between the individual human failures events included in the logic model. Such interdependencies could arise from the use of a common cue or procedural step, incorrect procedures, an incorrect diagnosis or a plan of action in carrying out response actions, etc. Dependencies among human failure events in the same sequence, if any, can significantly increase the human error probability, and they should be identified and quantified in the analysis. Proper consideration of the dependencies among the human actions in the model is necessary to reach the best possible evaluation of both the relative and absolute importance of the human events and related accident sequence equipment failures.

Whether it use conservative or detailed estimation of the post-initiator HEPs, the evaluation should include both diagnosis and execution failures. Diagnosis tasks consist of reliance on knowledge and experience to understand existing conditions, planning and prioritizing activities, and determining appropriate courses of action.

Criteria for selecting or modifying the HRA models include availability of data, experience of the user with the model, importance of the action being modelled and the correspondence between the key influence factors identified for the human interaction and parameters used as input to the quantification model (e.g. such as the time available to complete the action).

Some performance factors may affect the decisions taken, while other influence factors will affect only the value of the human interaction probabilities. The plant model should be revised to account for additional scenario dependencies on human interactions which were not considered previously.

Recovery analysis

The recovery actions are identified for the scenarios, judged as feasible, explicitly defined and quantified, and are referring to other reasonable actions the operators might take to avoid severe core damage and/ or a large early release (they are not specifically modeled already). The failure to successfully perform such actions would subsequently be added to the accident sequence model thereby crediting the actions and further lowering the overall accident sequence frequency because it takes additional failures of these actions before the core is actually damaged.

Usually, the possibilities to worsen an accident by the operators, as the possibilities to perform recovery actions unplanned are omitted from the model.
The following issues should be considered in defining appropriate recovery actions:

- whether the cues will be clear and provided in time to indicate the need for a recovery action
- whether the recovery is a repair action of a failed equipment
- whether sufficient time is available
- whether sufficient crew resources exist to perform the action
- whether there is procedure guidance to perform the action
- whether the crew has trained on the recovery action including the quality and frequency of the training
- whether the equipment needed to perform the action is still accessible and in a non-threatening environment/ location

The influence factors may not only increase the time to complete the tasks but also cause unsuccessful recoveries.
The possibility to use mobile equipment (pumps, DGs) should be considered.
Another important point in modeling equipment restoration is the consideration of shared resources in case of multi units (e.g. management difficulties, sharing of human resources and equipment).

Revision

This step includes the revision of validity and completeness of the results obtained in the first stages of the procedure.

Conclusions

- ✓ The success of operator actions in mitigation of the external event consequences is a subject that has grown in importance after the Fukushima accident. Many international organizations have begun to develop approaches to analyze the reliability of operator actions after the occurrence of an extreme external event.
- ✓ The general procedure and the major analysis steps in HRA within a PSA for man-made hazards are actually in good agreement with the ones of HRA in general. However, some specific analysis tasks need particular attention or even further developmental efforts, especially regarding the identification of external performance shaping factors.
- ✓ The complex environment created by the occurrence of an external event can be modelled successfully, if there is an appropriate knowledge of the main factors that have an impact on the human factor, leading directly or indirectly to human performance.
- ✓ The estimated probability of human errors, are scenario specific and it reflects factors that may influence the performance of operators, including stress level, time available to accomplish the necessary tasks, availability of operating procedures, the training provided, equipment availability, communication, etc.

Acknowledgement

The authors wish to thank to EC and to ASAMPSA_E partners for their support, valuable contributions and ideas.

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