A HUMAN RELIABILITY ASSESSMENT SCREENING METHOD FOR THE NRU UPGRADE PROJECT

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INTRODUCTION

The National Research Universal (NRU) reactor is a 130MW, low pressure, heavy water cooled and moderated research reactor. The reactor is used for research, both in support of Canada's CANDU development program, and for a wide variety of other research applications. In addition, NRU plays an important part in the production of medical isotopes, e.g., generating 80% of worldwide supplies of Molybdenum-99.

NRU is owned and operated by Atomic Energy of Canada Ltd. (AECL), and is currently undergoing upgrading as part of AECL's continuing commitment to operate their facilities in a safe manner. As part of these upgrades both deterministic and probabilistic safety assessments are being carried out. It was recognized that the assignment of Human Error Probabilities (HEPs) is an important part of the Probabilistic Safety Assessment (PSA) studies, particularly for a facility whose design predates modern ergonomic practices, and which will undergo a series of backfitted modifications whilst continuing to operate.

A simple Human Reliability Assessment (HRA) screening method, looking at both pre- and post-accident errors, was used in the initial safety studies However, following review of this method within AECL and externally by the regulator, it was judged that benefits could be gained for future error reduction by including additional features, as later described in this document.

The HRA development project consisted of several stages; needs analysis, literature review, development of method (including testing and evaluation), and implementation. This paper discusses each of these stages in further detail.

NEEDS ANALYSIS

The NRU Upgrade project has a number of specific needs in terms of a Human Reliability Assessment method: the reactor has over 30 years of operating experience but information has not been recorded in a form suitable for HRA use. Therefore, a method was required that would supply generic data which could be modified to take advantage of that experience.

This project was carried out by a Human Factors Specialist and a Probabilistic Safety Analyst. Other safety analysts were also involved throughout the development and review stages. The needs analysis performed at the start of the project identified a number of criteria based on past experience with the existing method and on the future needs of the project. It was concluded that the method should:

- be an extension of the original simple method,
- be directed towards incorporating human factors considerations into the assessment of existing systems and the design of new systems proposed under the NRU Upgrade package,
- be able to quantify both diagnostic and execution errors,
- make effective use of limited resources,
- be applicable to the control room as well as all other areas,

- be adaptable for use in other AECL safety assessments,
- be compatible with other Canadian nuclear industry methods,
- be useful as a coarse screening approach for setting system 'design' targets, and
- be useful as a fine tuning capability of HRA as system details are better defined.

REVIEW OF EXISTING METHODS

A number of available HRA methods, considered to be sufficiently developed, were examined for their suitability. Each method was rated against the specific NRU criteria above, as well as more general criteria [1]. The results of the review indicated that no single method was appropriate for the specific needs of the NRU Upgrade Project. The elements which were found to be common to most of the techniques were then identified. The methods were then re-examined for the best representation of each of these elements, which were then incorporated into the NRU HRA method. These elements are listed as follows:

- a comprehensive mutually exclusive human error classification scheme,
- a database of generic HEPs,
- a broad range of Performance Shaping Factors (PSFs),
- a method of modeling dependency between human errors,
- definitions for important terms to ensure consistency of interpretation,
- audibility, and
- identification of practical means of reducing the error likelihood.

DEVELOPMENT OF THE METHOD

One of the principal features of the NRU HRA method is that errors are classified into pre-accident errors, which encompasses operational and maintenance errors, and post-accident errors made during remedial action in a situation following an incident. Pre-accident errors were judged to be dominated by errors in task execution, however, post-accident errors were subdivided into diagnosis and execution parts.

The major steps in the method were identified as:

- Identification of Errors,
- Assignment of a Basic HEP,
- Assessment of PSFs,
- Assessment of Dependency between Errors,
- Assessment of Recovery Options, and
- Application of Error Reduction Mechanisms.

Identification of Errors

Error classification schemes were developed to aid the analyst in systematically identifying errors. The pre-accident error scheme was derived from Technique for Human Error Rate Prediction [2] (THERP) and the scheme used for diagnosis errors was derived from Reason [3].

Assignment of a Basic Human Error Probability

In the first draft revision of this method, the Basic Human Error Probabilities (BHEPs) for execution errors were taken from the Human Error Assessment and Reduction Technique [4] (HEART). In HEART, these BHEPs are then multiplied by negative PSFs as appropriate. However, following the pilot study and correspondence with other HEART users, it was felt that:

- Particularly for post-accident errors, the resulting HEPs were inconsistent with other methods; e.g., THERP, DPSE [5] etc.,
- Inter-user consistency was found to be low when users were simply asked to pick the most suitable task description. This was in part due to several task descriptions being equally appropriate for the selected NRU tasks.
- When experts were using HEART, they tended to only use two of the BHEPs and this choice was based mainly on the probability value and not the task description.

As a result of these findings, it was concluded that this lack of comparative validity and consistency could present a problem. A brief literature search was then carried out to investigate existing BHEP databases in an effort to identify a simple comprehensive database 'free' of any negative PSFs, to which the appropriate PSFs could then be applied. Negative PSFs are those factors which have a negative effect of performance, such as lack of training or a poor interface. The results of the literature search are shown in Figure 1.

Most of the databases shown in Figure 1 contain negative PSFs, particularly at the more knowledge-based end of the spectrum; e.g., Systematic Human Action Reliability Procedure [6] (SHARP) high values. This was taken into account, and the BHEPs selected for use in the NRU method were extrapolated from the above data.

A common basis for many of the databases was shown to be the complexity of the task. The term 'complexity' can encompass several factors, but in practical terms, this was as pure a scale as could be found in the literature (detailed definitions of terms such as complexity are given in the method documentation). In the NRU method, in order to choose between levels of complexity, a flowchart was developed to guide the analyst. The BHEPs included in the NRU HRA method are shown in Table 1.

The BHEP database for diagnosis errors is based on the Time Reliability Correlation [7] (TRC). The nominal model of the TRC was used as a basis (shown in Table 2) because NRU-specific PSFs will be applied to the BHEP, and the TRC screening model already incorporates some generic PSFs. This ensures that the method is as specific to NRU's situation as possible. In addition, the NRU model retains the conservatism that no credit is taken for operator actions required within the first fifteen minutes.

Assessment of Performance Shaping Factors (PSFs)

The potential PSFs, and the method in which they are applied to modify the BHEP, were taken from HEART. HEART was found in the literature review to contain the most comprehensive database of performance shaping factors, and gives a list of thirty-five 'Error Producing Conditions', not all of which were relevant to NRU. This list was reduced to nineteen relevant PSFs. It was considered very important to relate the choice of PSFs to the experience of activities within NRU. Therefore, a survey of staff was carried out in order to identify which task-specific PSFs should be included in the HRA screening method. The PSFs selected for inclusion are shown in Table 3.

In order to ensure that users are as consistent as possible, guidance tables were produced regarding the appropriate weighting of each PSF, based on actual NRU experience and human factors experience.

A criticism of the application of PSFs in HEART is that the multiplication of factors can cause HEPs to exceed 1.0. HEART deals with this in a simplistic cut-off manner. For the NRU HRA method, the asymptotic function $HEP=1-e^{-p}$ for $p>0.1$ was used for modeling higher probability errors.

Assessment of Dependency between Errors

Dependency was felt to be a necessary component to allow assessors to take credit in the PSA for changes in the task which would result in decreased potential dependency. THERP's dependency model remains one of the few available models in the field of HRA, and fulfilled the NRU criteria. The relevant parts were therefore selected and incorporated into the NRU method. In order to make the method both as usable as possible and increase inter-user consistency, guidance has been given for the assessment of dependence as complete, high, moderate or zero for pre-accident errors and complete or zero for post-accident errors. (This difference between pre- and post-accident errors is simply one of relevance to NRU.) A flowchart was produced to aid analysts in choosing the appropriate level of dependency, based upon Table 5-1 in THERP.

Figure 1
A Comparison of HEP Databases

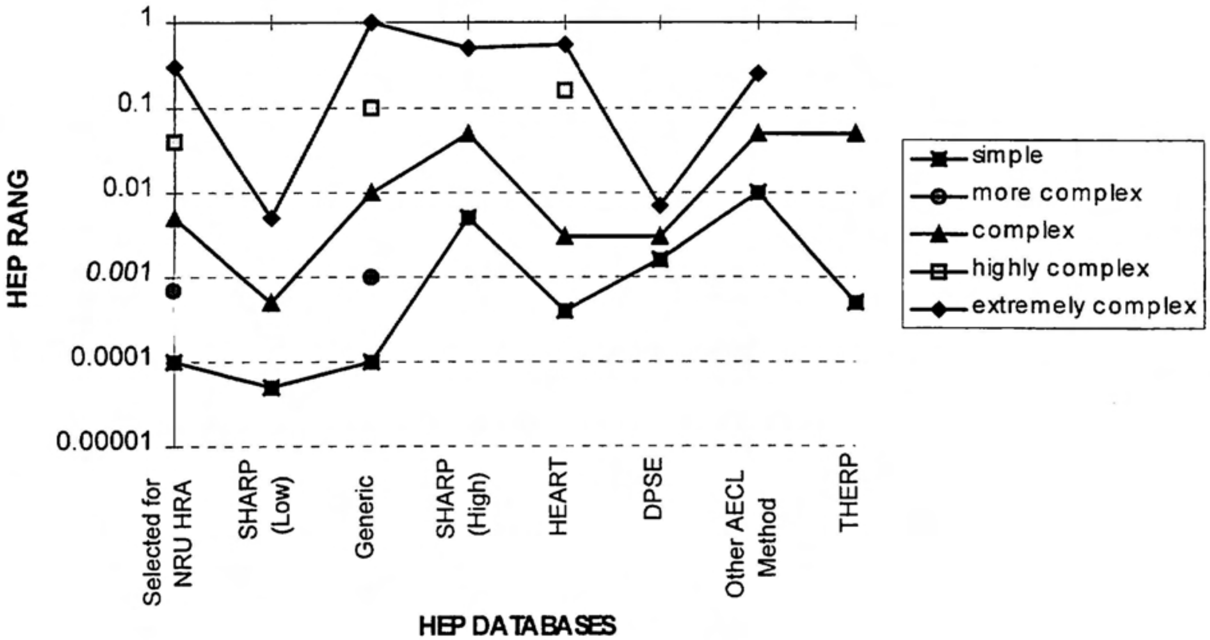

Table 1
Execution Basic Human Error Probability Database

BHEP Task Description	BHEP
Extremely complex task	0.4
Highly complex task within a long procedure	0.2
Highly complex task within a short procedure	0.06
Complex task within a long procedure	0.02
Complex task within a short procedure	0.008
Less complex task within a long procedure	0.003
Less complex task within a short procedure	0.0009
Simple task within a long procedure	0.0003
Simple task within a short procedure	0.0001

Table 2
Diagnosis Basic Human Error Probability Database

Time	Basic Human Error Probability
0-15 minutes	1.0
16-20 minutes	0.1
21-30 minutes	0.01
31-60 minutes	0.001
>61 minutes	0.0001

Table 3
Summary of PSFs incorporated into NRU HRA Method

	Post Accident	
Pre-Accident	**Diagnosis**	**Execution**
Poor Procedures	Unfamiliarity	Unfamiliarity
Unfamiliarity	Information Overload	Poor Procedures
Lack of Job Aids	Poor Procedures	Poor Feedback
Insufficient Checking	Excess Alarms	Design Mismatch
Poor Feedback		
Design Mismatch*		

Assessment of Recovery Options

Recovery steps; e.g., where there is component surveillance or a verification inspection program that is independent of the maintenance or testing task itself, are modeled separately from the relevant error. They are assigned an HEP of 0.1, a figure commonly given to inspection tasks in Canadian HRA methods and consistent with values in THERP.

Application of Error Reduction Mechanisms

Error reduction mechanisms are identified by assessing where the main contribution to the error probability originates from. Error reduction mechanisms can not only be applied to the PSFs, but also to the dependency levels, and BHEPs. Specific NRU guidance is given on each of the BHEPs, PSFs and dependency levels to indicate the most appropriate mechanism to reduce the error probability.

Error reduction mechanisms reduce the level of effort and resources required for detailed assessment. If an error is found to be significant during an initial sensitivity analysis, then the related task can be improved, in ergonomic terms, during the screening process, reducing the need for more detailed assessment. Therefore, this method again focuses on improving the safety of tasks at an early stage rather than solely quantifying probabilities.

Testing and Evaluation

Once the method was developed, two evaluations were carried out to ensure that the method was:

- reliably consistent with a range of users, and
- valid in terms of comparisons with other methods.

* A mismatch between the operator's mental model of the plant and the actual design.

To fulfill the first objective a pilot study was carried out. Four realistic potential errors were identified and supplied along with necessary background information to ten assessors/engineers who were asked to quantify the errors using the revised method. The results identified a number of areas were the model was weak, and a number of changes were incorporated. In particular, guidance flowcharts and definitions were improved and expanded, to assist PSA analysts in applying the method consistently.

The second evaluation was then performed by comparing the developed method against a number of well known HRA techniques by quantifying the same four errors. The results showed that the NRU method fell within the range of the other methods.

IMPLEMENTATION

The method was issued in 1995 August and is being used in all the PSA studies within the NRU upgrade project. Before implementation, all users are given a brief training session on the use of the method. The application of the method is monitored by the authors to ensure that it achieves its targets of quantifying, screening and, most importantly, reducing human errors in the NRU reactor. The method has been sent to the AECB for comment.

CONCLUSIONS

It is recognized that no strong consensus exists on the best methods to perform HRA. All methods have their merits and limitations under the particular circumstances in which they are applied. The NRU HRA screening method described in this paper has been developed to address a number of criteria, such as providing initial direction toward the identification of risk-significant errors, providing a means of reducing the potential for those errors and making effective use of limited resources. These criteria have all been met and the method will continue to be monitored to ensure it continues to meet the project needs.

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