1. Introduction

Human Reliability Analysis (HRA) is the incorporation of human interactions between operations staff and plant systems into the event sequence of probabilistic safety assessment of nuclear power plants. In practice this also includes the identification of critical human errors arising during both maintenance (pre-initiator actions) and emergency operations (post-initiator actions) and the quantification of these errors to assess their contribution to the overall failure probability of the system or accident sequence.

This paper will focus on the assessment of pre-initiator human errors.

2. Pre-initiator Human Errors Definition

Pre-initiator human errors are faults which occur before the beginning of an accident sequence, that is, before the initiating event.

These human errors are generally associated with maintenance, testing and possibly operations. They are those in which one or more components of a safety system are left in a non-standard state as a result of human error. The fault is assumed to be undetected (or detected but not corrected). The fault only becomes apparent when a demand is placed on the relevant safety system (e.g. emergency situations or fault detection test). Partial or complete failure of the safety system may then occur as a result of the component misalignment. An example is a manually operated valve which should be open but is left closed in error after maintenance. The human error is of importance only while the fault remains undetected and uncorrected.

2.1. Error Assessment

THERP (Technique for Human Error Rate Prediction) [Ref. 1] is a method to quantify Human Error Probabilities (HEP) and to evaluate the degradation of a man-machine system likely to be caused by human errors alone or in connection with equipment functioning, operational procedures and practices, or other system and human characteristics that influence the system behaviour. The method uses conventional reliability technology with modifications appropriate to the greater variability, unpredictability and interdependence of human performance as compared with that of equipment performance.

The THERP method is the most widespread method for judging personal actions. THERP offers some flowcharts for the quantification procedure. In this method, the individual is treated in a manner similar to technical components. THERP provides voluminous tables for the determination of HEP. According to the specific tasks, one looks for the entries within the table compendium that correspond to the actions to be evaluated. Subsequently, the way a task is influenced by Performance Shaping Factors (PSF) is evaluated, with the help of correction factors pertaining to the HEP. Performance Shaping Factors assess for the training level, stress level and other factors which may influence the task success. Finally, the possibility of so-called recovery factors and conditions of dependence between tasks is examined.

The possibility of detection and correction is taken into account in the calculation of the probability by so-called Recovery Factors (RF). Tasks are subject to certain degrees of dependence when the success or failure of a previously performed task directly influences the following or parallel task.

Other more contemporary methods and references are now often used to evaluate human cognitive behaviours and dynamic operator responses after an initiating event occurs. However, the THERP handbook remains generally acknowledged as the
most comprehensive summary of human reliability data and applications currently available for system specific pre-initiator actions. It provides estimates for human error rates in numerous situations, and it discusses various factors that may affect human performance. Some of the handbook estimates are based on observed results from simulator testing, actual human performance in the power plant environment, and experience from similar activities in other industries.

In order to quantify human errors probabilities, the THERP flow charts are followed scrupulously. Both errors of commission and omission are considered, for both maintenance errors and errors after test. The two HEP’s whether procedures are used or not during the action are credited, resulting in a so-called “joined” HEP. In order to assess for post-maintenance testing, Recovery factors are systematically computed. The recovery factor for which the performance factors match the best is retained for quantification. Fault detection contingencies by means of function tests during plant operation (on-line tests) are credited with a so-called “reduction factor”.

2.2. Uncertainty

Human Reliability Analysis is subject to substantially high uncertainties. Error distribution for HRA basic events usually follows a lognormal distribution. As may be surmised by the name, the lognormal distribution has certain similarities to the normal distribution. A random variable is lognormally distributed if the logarithm of the random variable is normally distributed. Like for almost all published generic data, HEP are assumed to be lognormally distributed. As a consequence, all applied correction factors are not discrete values, but probability distributions. As a result, any addition or multiplication should be computed using Monte-Carlo simulations.

The lognormal distribution is given below:

\[
f(x) = \frac{1}{\sqrt{2\pi} \cdot \sigma} \cdot e^{-\frac{(\ln(x) - \mu)^2}{2\sigma^2}}
\]

Where:
- \( x \)… the lognormally distributed variable
- \( f(x) \)… the probability density at \( x \)
- \( \sigma \)… standard deviation
- \( \mu \)… mean of the natural logarithm of \( x \)

Other important lognormal distribution parameters are given below:

**Median (M):**

\[
\int_{0}^{M} f(x) \cdot dx = 0.5 \Rightarrow M = e^\mu
\]

**Mean (\( \overline{x} \), EW):**

\[
\overline{x} = EW := \int_{0}^{\infty} x \cdot f(x) \cdot dx \Rightarrow \overline{x} = EW = e^{\mu + \frac{\sigma^2}{2}} = M \cdot e^{\frac{\ln^2(EF)}{4 \ln Erf(0.90)}} \equiv M \cdot e^{5.41109}
\]

Where: InvErf(\( x \)) the inverse function of \( Erf(x) := \frac{2}{\sqrt{\pi}} \cdot \int_{0}^{x} \frac{t^2}{2} \cdot dt \)

**Error Factor (EF):**

\[
\int_{0}^{M / EF} f(x) \cdot dx = 0.05 \Leftrightarrow \int_{0}^{M \cdot EF} f(x) \cdot dx = 0.95 \Rightarrow EF = e^{\frac{\ln^2(EF)}{4 \ln Erf(0.90)}} \sigma \equiv e^{1.64485 \sigma}
\]
2.3. Error Reduction via online testing

In a nuclear power plant, numerous function tests are performed in order to check for the system availability. The more often a function test is performed, the likelier the fault detection and the higher the system reliability.

Once the equivalent HEP has been quantified for both ommissional and commissional types of errors, for both test and maintenance activities, the error detections contingencies by the numerous fault detection tests (function tests) have to be credited. All function tests which are performed on a regular basis and which would surely detect the postulated fault (without causing it) have to be taken into account.

For example, a human action which is performed 3 times a year (see figure below) is considered.

This human action has an error probability $\text{HEP} = \text{HEP}_1$. It is postulated that the corresponding fault is implicitly tested by function tests once a year. The resulting, yearly average HEP is therefore reduced by a factor 5/6, assuming that fault occurrence actions and fault detection tests ($t'$) are randomly distributed over the year. It is also assumed that plant personal will identify and correct the fault, or shutdown the plant, if the error transgresses the Limited Condition of Operation (LCO). We call this factor “reduction factor”.

The overall, yearly average HEP is then expressed by:

$$HEP = \int_0^{1\text{year}} p(t) \cdot dt$$

Where: $p(t)$… probability density at time $t$

This conditional expression can be analytically integrated for low fault detection / fault occurrence frequencies, but cannot be generalized for higher frequencies. Numerical integration of equation 10 can be performed with the following numerical algorithm:
The relation between fault detection / fault occurrence frequencies and the resulting reduction factor is shown below:
2.4. Dependencies

Two events are called dependent if the HEP of one event changes if the other event has occurred.

Dependence between human errors are assessed and quantified. The following criteria are considered for assessing the dependence level of pre-initiator human errors:

- Temporal similarity
- Spatial similarity
- Similarity in the type of action
- Same people, or group of people

Different levels of dependence are given below, based on [Ref. 1], Table 20-21, for a $\beta$-factor model (second order dependency):

<table>
<thead>
<tr>
<th>Level of dependence</th>
<th>Dependent HEP (for 2nd error, given first error)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Median</td>
</tr>
<tr>
<td>Negligible</td>
<td>-</td>
</tr>
<tr>
<td>Low</td>
<td>0.05</td>
</tr>
<tr>
<td>Moderate</td>
<td>0.15</td>
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<tr>
<td>High</td>
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3. References
