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Collection and classification of human reliability data for use in probabilistic safety assessments

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FOREWORD

One of the most important lessons from abnormal events in NPPs is that they are so often the result of incorrect human action. The awareness of the importance of human factors and human reliability has increased significantly over the last 10–15 years primarily owing to the fact that some major incidents (nuclear and non-nuclear) have had significant human error contributions. Each of these incidents have revealed different types of human errors, some of which were not generally recognized prior to the incident. The analysis of these events has led to wide recognition of the fact that more information about human actions and errors is needed to improve the safety and operation of nuclear power plants. At the same time, the probabilistic safety assessment (PSA) practitioners have realized the need for proper human reliability data. No PSA study can be regarded as complete and accurate without adequate incorporation of human reliability analysis (HRA).

In order to support further the incorporation of human reliability data into PSA, the IAEA established a co-ordinated research programme with the objective of developing a common database structure for human error events that might be important risk contributors for different kinds of reactor systems. This report is a product of four years of co-ordinated research and describes the data collection and classification schemes currently in use in Member States as well as an outlook into the future, discussing what types of data might be needed to support the new improved HRA methods which are currently under development.

CONTENTS

1. INTRODUCTION

Human errors have been identified from event analyses as a major contributor to the risks of accidents at nuclear power plants. Estimates of the fraction of contributions to systems' failures that result from human error have varied, but many analysts have indicated that the fraction could be as high as 50% [1] for full-power operations, and as high as 70% [2] for low-power and shutdown (outage) operations. Given that the fractional contribution to systems' failures may be so high, it is important that the probabilistic safety assessments (PSAs) incorporate and quantify the probabilities of human errors correctly. In order to accomplish this requirement, human reliability analysis (HRA) methods must be selected and human error probability data calculated appropriately.

A prior programme by the IAEA has led to the development of guidelines for the incorporation of HRA techniques into PSA studies [3]. In addition, IAEA Technical Committee meetings have been held to discuss issues associated with human error classification and data collection [4] and human reliability data collection and modelling [5].

In order to support further the incorporation of human reliability data into PSA, it was planned that a co-ordinated research programme (CRP) be established with the objectives of developing a common database structure for human error events that might be important risk contributors for different kinds of reactor systems. Several Member States are developing such databases. The degree to which information in these databases can be shared will influence the ability of lessons being learned concerning the modelling of human errors and its importance in PSAs performed in the different countries.

However, to obtain this benefit, it is necessary to develop some standardization of terminology for the data reporting. Items that must be standardized to allow exchange of data are associated with such issues as performance-shaping factors, error modes and mechanisms, and conditions under which actions are taken.

The data collection and classification scheme described in Section 2 is intended to support HRA techniques currently used in many of the Member States. However, it was recognized that research is under way in several of the countries with the purpose of developing improved HRA methods and applying existing methods in new areas of application. Areas undergoing improvement in HRA method include: the modeling of human errors that occur in accident management processes, in low power and shutdown operations (such as refuelling) and to a lesser degree external events. Issues of importance in these analyses that are often not modeled explicitly in full power PSAs include: the impact of errors in ex-control room operations, the participation of more staff than only control-room crews, and the influence of decision conflicts and the burden imposed on the decision makers.

While it is not intended that data gathering programmes be started specifically to support this research, the early identification of the kind of information that will be needed can be considered when Member States and the IAEA refine and modify existing event reporting systems. The discussion of the data that might be needed to support new improved HRA methods is provided in Section 3.

Further into the future are developments to improve the capability of HRA to model the kinds of human errors that occurred in the accidents at Three Mile Island and Chernobyl. While these two events are often cited in many discussions of accidents at nuclear power plants and the impact of such discussions is thereby weakened, similar instances of human errors and their causes have been found in other non-nuclear plant accidents such as the loss of the Space Shuttle Challenger, the capsizing of the ferry Herald of Free Enterprise, the release of toxic chemicals at Bhopal and Seveso, and loss of the platform Piper Alpha in the North Sea. In general, these accidents involved human errors in decision making. Gaps in knowledge and flawed reasoning (though understandable) by the operators caused human actions that led directly to the termination of required safety equipment and the plant being operated outside of the designers' intended safety parameters.

Human errors such as these are not considered to be modeled explicitly by the current generation of HRA methods, yet experience both in the nuclear and other industries indicates that such errors in decision making may be critical as causes of major catastrophic accidents.

Research already performed indicates that significantly different data may be required to provide information of the causes and probabilities of occurrence of these kinds of errors.

While no methods yet exist to define explicitly what data will be required, the development programmes do seem to be indicating the kinds of issues being represented in the new models. In the future plans for several of the national programmes are efforts to identify and classify the kinds of data that will be required to support such methods.

2. THE COLLECTION AND CLASSIFICATION OF HUMAN RELIABILITY INFORMATION

2.1. INTRODUCTION

It is generally agreed throughout the reliability engineering domain that there is no readily available, truly believable, comprehensive compendium of human reliability data (see Ref. [6]). The reasons for the apparent deficiency are likely to be complex and to include: that human beings are unpredictable and therefore a comprehensive account of their general behaviour is sometimes difficult; that the logistics of creating a compendium would render such an enterprise difficult; and that some data collected by organizations can be of a sensitive nature, publication of which could have negative effects on its reputation. Williams in Ref. [7], however, suggests that *"many of the organisations operating in the reliability world already have partial human reliability data bases of the sort necessary to operate in a commercially or politically sensitive environment. What they lack is the assurance that their data base or the assumptions they make are wholly credible"*. Advances in theories of human error (for example, see Ref. [8]), recognition of the importance of human error to plant safety and the potential availability of data as described by Williams above has led to an increased interest in the collection of human reliability information. This CRP exemplifies this interest and aims to provide a structure for the collection of human reliability information.

Underlying this section is a view of human error and its causes. While it is beyond the scope of this introduction to fully introduce the topic of human error (for a useful introduction see Ref. [8]), it should be particularly noted that human error is influenced by a complex range of factors. These factors range from the particular skills of an individual, to the type of task they must complete and the organization in which they must work. This can be contrasted with equipment reliability, where the relevant influencing factors can more easily be identified and measured. This complexity in relation to human error is commonly cited as a reason why human reliability information should not be collected. Nevertheless any information which can enlighten a company, groups of companies or organizations regarding human reliability should be encouraged. This is particularly the case when it is accepted that PSA needs to more fully take account of the effects of human reliability on systems safety.

2.2. OBJECTIVES

The objectives of this section are:

1. To identify the overall requirements of an effective data collection scheme.
2. To propose an appropriate data classification scheme to structure data collected on human related events.
3. To identify possible existing taxonomies which could be utilised within the data collection and classification scheme.

2.3. GENERAL OVERVIEW OF THE COLLECTION AND CLASSIFICATION OF HUMAN RELIABILITY INFORMATION

The overall purpose of collection schemes is to provide necessary information for event analysis and PSA/HRA analyses being undertaken. It should be noted that there is a variety of human reliability information which could be collected. The main purpose of the collection and classification methods is the collection of human reliability information but it may be possible that the classification scheme is also applicable to the collection of event data for a variety of purposes.

In the context of both human reliability and event data collection there are a wide variety of sub-objectives which require different types of information for the analyses, e.g. improvements to a specific plant operation need information about errors on that plant; data to be evaluated for a PSA will have to provide information on the number of errors/failures and the number of opportunities for error. Also, details on the plant where the events occurred are required so that the applicability of the information to other plants can possibly be determined. Designers and managers are interested in the discovery, collection, classification and understanding of events for the purposes of developing specific error reduction strategies. In particular they may wish to improve work organization and operator performance at an immediate and practical level.

To summarize therefore, the goals of improved HRA data gathering are:

1. To provide qualitative improvements to plant safety and performance/availability;

    1(a) To identify human error problems.
    1(b) To introduce measures to reduce or prevent these errors.

2. To derive human reliability data for use in probabilistic safety assessment or other safety studies.

A number of human reliability databases are currently available and should possibly be reviewed for the purposes of data incorporation and/or classification, for example: the IAEA database project for CRP; NUCLARR [9]; IRS and related databases; CORE-DATA [10, 11]; NUREG/CR-2744 [12]; ORE [13]; Moieni et al. [14], etc.

In addition to the collection of information it has been suggested that a set of human reliability taxonomies or classification schemes need to be devised to help structure the data collection process and retrieval. It was established that the primary purpose of any taxonomy is to describe the structure and relationship of the constituent objects with regard to each other and to simplify these relationships in such a way that general statements can be made concerning classes of objects or behaviour, see Ref. [15]. Human reliability places considerable emphasis on the classification of human errors, and consequently a taxonomy must be able to describe all types of behaviour and depict all possible errors, thus making the taxonomy comprehensive.

Moreover the data structures used to compile and classify data needs to include information on what, why and how an error occurred and a description of the task/error scenario, if it is to provide a robust, accurate, exhaustive and mutually exclusive database. Only then will there be a sound foundation and understanding of the error.

2.4. DATA COLLECTION

While it is expected that the reader of this document is aware of event reporting methods, this section introduces the possible methods for HRA data collection. For all HRA data collection methods, the key aims are to identify human errors, their underlying causes and, where possible determine likelihoods for their occurrence. The type of data to be collected for HRA may vary, however the list below summarizes the key data resources that could be used:

- Event reports
- Maintenance reports
- PSA reports
- Equipment records
- Interviews with plant personnel
- Near miss reports
- Plant log books
- Good practice reports
- Simulator observation
- Expert judgement.

This data could usefully be collected for a range of nuclear facilities. Further information on data collection methods and methods for their implementation can be found in Ref. [16].

2.5. THE PROPOSED CLASSIFICATION STRUCTURE FOR HUMAN RELIABILITY DATA COLLECTION

The following provides outline guidance and supporting references to assist in the development of a human reliability data collection scheme. In order to fully develop a data collection scheme, utility staff need to be supported by human factors experts. Furthermore to ensure the appropriate use of the data collection scheme a comprehensive and detailed explanation of the content and meaning has to be provided. Moreover, it would be useful to facilitate the implementation of such a data collection scheme if the user was provided with definitions and examples of the classification system in action. Additionally the comprehensibility of the classifications underpinning the data collection scheme needs to be ensured.

The issues of what information needs to be collected for a human reliability data collection and classification scheme are outlined in Table I. Following Table I, each element of the scheme is defined in further detail. If necessary, plant specific and identifying information can be excluded to facilitate the sharing of information.

Table I. Summary of information for collection

1	Plant identification
2	Plant status
3	Event description
4	Equipment/controls
5	Description of location
6	Root cause analysis
7	Data collection or generation method
8	Performance shaping factors
9	External error mode (EEM)
10	Psychological error mechanism (PEM)
11	Human interaction type
12	Reference source and information origin
13	Human error probability (HEP) and uncertainty bounds
14	Error reduction

1. Plant identification: This should include information on the:
   - general type of facility, e.g. PWR, BWR or research reactor
   - plant name or number, e.g. DOEL 3 (Belgium)
   - design type, e.g. Westinghouse, etc.

2. Plant status: the state of the plant at the time of the event should be categorized, e.g.:
   - Full power
   - Outages (refueling, preventive maintenance, etc.)
   - Partial power
   - Start-up and shutdown, etc.

3. Event description: The event description will include the following. An error summary which is a simplified extract of the event description. This will involve a sentence to describe the error, e.g. "failure to maintain feed and bleed". Next, a detailed description of the event and the task failure by the plant personnel will be included. In order to have detailed information of constraints such as time, the event description should include the event time sequence. Also information pertaining to such factors as date of the event, resources available, the number of hours into the shift, where the event occurred, numbers of personnel involved, their job titles, and the sequence of the failure event should be considered in this field.

4. Equipment/controls: This classification system should consider the equipment/controls that were directly manipulated and/or were affected. This could consider such information at a very broad level, e.g. pumps or at a more detailed level and therefore considering the sub-components of that pump.

5. Description of location: To enable this data collection scheme to be meaningful and useful to a variety of participants a general description of the error location (e.g. type of building (i.e. switchgear, control room or offsite) should be included in this information

field. It was also suggested that to make the data collection scheme more plant specific (for individual countries) additional information such as the level or room number within a particular plant could be useful for plant specific applications.

6. Root cause analysis: Where appropriate an investigation of direct causes, root causes and barriers that failed should be undertaken. Further information can be found in Refs [17] and [18].

7. Data collection or generation method: This refers to the approach used to model and quantify the human failure. Thus it is expected that the items of information which could be included in this field would be as follows:

   - In-field data (e.g. event data and data from observation of tasks).
   - Simulator data (e.g. data from observation of simulator tests).
   - Modeled data (e.g. using techniques such as THERP and HEART (see Ref. [16] for more information)).
   - Expert judgment (e.g. using absolute probability judgment (see Ref. [16] for more information)).

8. Performance shaping factors (PSF): Concern the human factors present in the operating environment which influence performance, e.g. time pressure or inadequate procedures. A review of existing PSF taxonomies should be performed in order to ascertain the most suitable taxonomy for incorporation into the data collection scheme (see Table II).

9. External error mode (EEM): Refers to the external manifestation of the error, e.g. errors of omission or errors of commission. It is suggested that a review of the available EEM taxonomies to ascertain the most relevant classification scheme for incorporation within a human reliability information system be done. See Table II.

10. Psychological error mechanism (PEM): If possible, the operators internal failure mode should be collected, e.g. memory failure, misdiagnosis, etc. A number of PEM taxonomies were identified for review, see Table II.

11. Human interaction type: Human interaction categorized according to the IAEA safety practice terminology (see Ref. [3]):

    Category A: human errors, that lead to degradation of the availability of the safety related systems.
    Category B: involves errors that can initiate an unanticipated transient.
    Category C: human errors that can occur during or following a transient or accident sequence.

12. Reference source and information origin: This should be the full reference to allow the assessor to access the original source document and details pertaining to where the original information was collected. It is recognized that some references will need to be confidential. Examples of references would be: "Utility Event Report XYZ" or "Public Research Report 123".

13. Human error probability (HEP) and uncertainty bounds (UB):
    HEP: It is recognized that it will not always be possible to generate an HEP from each piece of data. Nevertheless it was generally agreed that countries who were able to complete this data field should do so.

TABLE II. TAXONOMIES

1. PSF taxonomy

The following PSF taxonomies have been suggested for review:

- THERP, Swain and Guttmann [19]
- Bellamy [20]
- PHECA, Whalley [21]
- SRK, Rasmussen [22,18]
- Murphy Diagrams, Pew et al. [23]
- Altman's [24]
- NUCLARR, Gertman et al. [9]
- INTENT, Gertman [25, 26]
- HEART, Williams [7]
- Human Reliability Management System (HRMS), Kirwan [27]
- CORE-DATA, Taylor-Adams [11]

2. EEM taxonomy

A number of EEM taxonomies have been identified for review:

- THERP, Swain and Guttmann [19]
- HAZOP, Kletz [28]
- PHECA, Whalley [21]
- SHERPA, Embrey [29]
- HRMS, Kirwan [27]
- Altman [24]
- Rook [30]
- SRK, Rasmussen [22,31]
- Metwally et al. [32]

3. PEM taxonomy

The following references can be reviewed for PEM taxonomy examples:

- SRK, Rasmussen [22,31]
- GEMS, Reason [8]
- PHECA, Whalley [21]
- SHERPA, Embrey [29]
- HRMS, Kirwan [27]
- Norman [33]
- Altman [24]
- CORE-DATA, Taylor-Adams [11]

VB: Refer to the upper and lower bound HEP values such as the 5th and 95th percentiles. This information was considered important information when it be collected, for example it is particularly difficult to collect this type of information from event and event reports, etc. However if the data collection scheme is used to collect information derived from human reliability quantification techniques such as THERP then this information collection is plausible. Therefore the collection of this information is dependent on the type of data collected.

14. Error reduction: A set of qualitative information should be provided to focus on issues of reducing such errors in the future. It is probable that a close examination and the event description would be necessary to offer a useful set of error reduction strategies. These fields should not include such information as improve procedures or reduce time pressure, just because the PSFs suggested that inadequate procedures and high time pressure were a contributory cause of failure. Rather, more detailed advice should be given, for example, information pertaining to the specific re-drafting of a particular problematic procedural step or area could be proposed. The derivation of error reduction strategies would need the specialist advice of human factors personnel.

2.6. REMARKS

A range of comments have arisen as a result of the CRP regarding data collection and classification. These comments have been grouped into the sections below.

2.6.1. Uses of human reliability data

The current uses of a human reliability data collection scheme would be for the following reasons:

- To produce generic HEPs for updating purposes;
- To validate HRA models;
- To support HRA research and models;
- To provide for calibration HRA techniques, e.g. SLIM;
- Improvements and feedback for training and procedures.

The following points were also noted regarding collection requirements:

- It should always be ensured that the data collection system provides information which is compatible with PSA requirements.
- The collection and classification scheme should provide information in sufficient degree of detail for later evaluation.

2.6.2. Application of data from one situation to another

It is accepted that human error is affected by a wide range of factors, for example task, psychological and organizational factors. This leads to uncertainty as to how data can be applied from one situation to another where different factors may be relevant. These factors may vary for different situations at a plant, between plants and between countries.

Nevertheless, the data is still of significant use for investigating the situation from which the data was drawn. While there is no detailed guidance with which to assess the applicability of data to other situations or contexts, judgment can be used to assess this factor. Application of data from other situations may be suitable where the situations are viewed to be similar and data does not currently exist or where data cannot currently be collected (e.g. plants which are being designed).

2.6.3. Current status regarding development of an international data set

Many countries are not currently in a position to supply their data to an international database due to the following reasons:

- problems of data confidentiality;
- different countries collect data for different reasons and therefore the data are not easily compatible;
- data is currently collected in different formats.

It is hoped that this CRP has provided sufficient grounds for the development of such a data set. Even in the absence of an international database, progress in the direction of adopting a common data structure in a country's own programmes would be helpful. It would support the use of compatible terminology and facilitate any exchanges, e.g. in exchanges between countries or organizations or in the communication of single/few database record(s).

2.6.4. Quantification issues

Quantification of human error is central to the incorporation of HRA data into PSA. The following points were noted regarding quantification:

- While raw event data can be collected regarding human errors, it is commonly difficult to translate this data into human error probabilities. This is due to difficulties in applying probabilistic methods, identifying the number of opportunities for error and because errors are usually infrequent occurrences.
- For countries with a small number of nuclear facilities it may be useful to combine their data with that of other countries so that more reliable HEPs can be obtained.
- The danger of misapplying and oversimplifying analyses whilst using HEPs, instead of adequately evaluating the human factors should be recognized.
- The usefulness of numerical values (HEPs) to be included within a collection and classification scheme is a controversial subject area. One viewpoint is that the inclusion of derived (not traceable) numbers referring to a specific complex event are of limited use. Where HEP data can be produced, this should be incorporated within the collection scheme. The resolution to the problem of whether HEP data should be collected and incorporated within the human reliability data collection scheme was to be decided by individual countries based on their own data requirements.

2.7. CONCLUSIONS

1. Human reliability information should be collected.

2. One objective of this section has been to provide a classification scheme for the collection of human reliability information. Some of the data within the scheme will need to be further classified using taxonomies. It will be necessary for those implementing such a scheme to review and select the most appropriate taxonomies for their needs from the selections provided in Table II.

3. Although HRA data could not be transferred at this point in time, the data collection scheme would enable data to be collected in a standardized format, which could possibly be pooled at a later stage.

3. HRA DEVELOPMENTS AND THEIR DATA NEEDS

This section discusses current and future trends in PSA applications and considers how these influence the developments in HRA. The HRA quantification methods needed to model human performance in the situations characteristic of these PSA applications and the data that would be required to apply these HRA methods are presented here.

3.1. CURRENT AND FUTURE DEVELOPMENTS IN PSAs

At present, PSAs are performed in various countries based on mature methods and techniques. Thus, PSA applications generally deal with standard aspects, e.g., full power operation state, conservative assumptions regarding success criteria and a quasi-static treatment of plant response as well as human behaviour. PSAs are currently being extended to consider plant safety more comprehensively. This includes the assessments of areas such as:

- non-full power conditions (including refueling and other outages)
- external events (fires, floods, earthquakes)
- accident management (AM) and/or level 2 PSA.

A recent extension of PSAs that has already begun is the consideration of non-full power plant operating states (sometimes referred to as shutdown). The nature of some operations in shutdown and the differences compared to full-power operations place new requirements on HRA methods. A second area of development is the treatment of human actions in scenarios initiated by external events. A third area concerns accident management and guidance for operations in beyond-design-basis accident situations; one outcome of this trend is that future PSA studies are likely to need to consider more human actions in this phase. The remainder of this section discusses what some of the new requirements on HRA are and their associated data needs.

3.2. SOME COMMON THEMES

In the consideration of the above-mentioned extensions of PSAs, some common themes can be identified. These themes need to be focused on with respect to the HRA developments. They are:

- actions outside the control room
- co-ordination and communication within and between teams
- actions without procedures
- decision burden.

3.2.1. Actions outside the control room

In standard PSAs, the analysis of actions outside the control room has not been adequately treated. In some cases, this was based on the implicit or explicit assumption that actions outside the control room are simple and so the probability of their failure could be neglected. In the extended PSA applications focused on here, the weakness of this assumption becomes only more apparent.

In the past, HRA methods and data for these "local" actions have not received much attention. In addition, it should be pointed out that in some plant designs actions outside the control room are both necessary and difficult during responses to transients (initiating events) in full-power operation scenarios.

Action outside the control room may be viewed in terms of four distinct phases. These are:

- command delivery
- movement (access)
- execution
- feedback.

A more detailed discussion of the scope of the first three phases is probably not necessary here. The feedback phase includes all of the task elements required for both the local personnel and the control room personnel to detect the initiation and completion of the task as well as to evaluate the outcome of the local action. Consequently, the feedback phase needs to model both opportunities for error, for instance, when feedback is not locally available, and for recovery.

3.2.2. Co-ordination and communication within and between teams

The present state of human reliability data collection mainly focuses on the individual's behaviour related to a task. The expansion of the scope of PSA to include the three main areas mentioned in Section 3.1 requires the development of models for group behaviour and for co-ordinated behaviour. The number of persons or groups involved in the response to an event expands in the shutdown condition, in external event scenarios, and in accident management conditions.

In shutdown, more groups are making decisions (at different levels). One issue is the co-ordination or control of the different groups. Another issue is conflicts (or unforeseen consequences) of the actions of different groups. A third issue may be the lack of written procedure for some of the tasks during shutdown (see Section 3.2.3).

For external events, the theme of co-ordination and communication is a combination of the first two issues mentioned above for shutdown and that of the actions outside the control room.

Three main features are characteristic of accident management conditions. First, decision and responsibility moves as the accident progresses. Second, with the number of groups involved, the issue of flow of information (among the persons or groups) or information being accessible arises. Third, these persons may be at the plant, at a remote location (e.g., the "crisis center"), or both.

3.2.3. Actions without procedures

The degree of availability of appropriate procedures with respect to the main areas listed above (all outages, external events, and accident management) varies from country to country.

The lack of adequate procedures for event response in outages is widely recognized. It largely reflects the numerous configurations possible and the difficulty of writing procedures valid for all of the different configurations. In terms of human performance, the lack of procedures requires an operator response to the initiating event that is more strongly based on his knowledge and training. The uncertainty of the operator regarding plant configuration may lead to potential errors. In addition, mistakes in considering potential consequences while planning a response are possible.

In accident management (AM), an important aspect of operations are the transitions from Emergency operating procedures (EOPs) to extended EOPs to AM guidance. The lack of procedures reflects the unconstrained possibilities on the state of the plant as design-basis conditions no longer apply (e.g. as defined by loss of core cooling geometry). In addition to the transitions from a procedural to a guidance-based response, it should be noted that the decision maker may also have changed.

Actions in some external events present some similarities to the accident management case in terms of procedures and/or guidance. One example is the loss of plant functions and communications as a consequence of the propagation of fires. Again, the indeterminacy of plant configurations precludes the development of procedures.

In addition to the three main areas of interest there are two types of actions that should be explicitly addressed when talking about "actions without procedures".

With regard to system recovery actions after an initiating event, procedures may often be missing. It is likely that detailed and specific procedures cannot be developed, due to the variability of the situations in which the recovery has to be performed.

With regard to maintenance actions, procedures are more often available. Here, the work order and supervision practices are in a very important position in directing the activity itself and the restoration of equipment after the maintenance. It should be pointed out that planning errors should be distinguished from errors in executing a plan.

3.2.4. Decision burden

Decision burden refers to the operator's consideration of any undesired consequences of a required action. The issue appears to require a qualitative and descriptive consideration. A quantitative approach appears problematic especially in view of the fact that decision burden only appears in conditions where the consequences are real, and not in hypothesized or simulated conditions. Decision burden has various aspects that can be distinguished in the following way.

The first aspect refers to the uncertainty of the decision maker regarding the plant state. The uncertainty can be due to unexpected "values" of indications. For instance, when event-based procedures are used, an abnormal event has to be identified and verified on the basis of annunciators appearing as the consequence of the (not immediately identifiable) initiating event. Then some indicators are not appearing although expected and/or others come up, which are not according to expectations.

Further, decision burden can be related to actions foreseen and/or planned in the operating procedures, which are not in accordance with the general, overall safety concept of the plant. This aspect refers, for example, to the interruption of automatically initiated injection relatively shortly after a LOCA in order to prevent a possible flooding of certain equipment in case of additional failures and leaks.

The next aspect of decision burden refers to situations involving probability-consequence trade-offs. For example, the operators may have to choose between one option leading to a certain (with probability = 1), lesser release now and a second option (with a lower probability) with a chance of generating a larger release later. In such situations, the HEP will be related to the operator's assessment of the current condition or chance for recovery).

A further aspect is the uncertainty about the management support for specific decision options during emergency operating conditions. Such options include actions with "drastic" effects or costs. This aspect of decision burden is related to safety culture and its formal/informal manifestations. Formal manifestations refer to written policies and the like; informal manifestations refer to "what generally happens to individuals who have taken similar decisions".

The last aspect refers to decision options that have consequences for plant personnel. This includes decisions in which plant personnel may be endangered.

3.3. DATA NEEDS

The issues discussed in Section 3.2 lead to:

- additional requirements on the data structure used in data collection, as well as
- the need for human reliability data for the tasks that arise in these situations.

This section highlights some of these data structure requirements and provides examples of the kinds of tasks for which human reliability data would be needed. Furthermore, it provides some indication of how such data could be obtained.

3.3.1. Actions outside the control room

The data needs for a human reliability analysis of actions outside the control room would directly correspond to the aspects delineated above and considered necessary in modelling such actions. The data requirements for HRA would essentially cover:

(i) efficiency of plant layout, quality of component/equipment identification and tagging schemes,
(ii) practices followed in respect of communication between crews and members within a crew using verbal as well as written protocols, effectiveness of crew co-ordination and crew resource management. A well-described taxonomy of the problems that can arise in communication would aid the acquisition of requisite data,
(iii) physical movement of crew personnel could be quantified in terms of time available and time required to reach requisite locations (which in turn depends on plant layout factors and familiarity of crew with area demarcations), area access controls and permissions, etc. Information in respect of these can be obtained by walk-throughs and task analyses,
(iv) quantitative analyses for execution of actions outside the control room can be carried out using data available for support of established HRA techniques,
(v) quality of information feedback indicative of success/failure of actions carried out is linked not only to the type of indications and displays available at local sites but also the verbal protocols followed for control room–local operator communication. Data is also required in respect of these aspects for the HRA to be complete.

From the perspective of the phases identified earlier (command delivery, movement, execution, and feedback), the above data needs can be specified as follows:

The most important information to be gathered for analysing the **command delivery** phase consists of:

- operability of communication hardware (e.g. in a fire event)
- quality of this hardware (e.g. sound quality)
- ambient conditions (e.g. background noise)
- conventions for communications between operators (e.g. wording, specificity, language used)
- co-ordination of orders (e.g. priority of commands, omission of one of multiple orders, conflicts between orders)
- the need to remember verbal instructions.

The information needed to consider the **movement and access** phase are:

- knowledge of plant layout
- time available and necessary
- accessibility (e.g. keys, blockage).

This information can be obtained by walk-throughs and task analyses foreseen in existing methods.

The **execution** phase of actions outside the control room considers only the operations on the equipment at the accessed location. It can therefore be treated according to standard methods, for example, THERP.

In general case, the **feedback** phase represents an additional possibility to ensure the success of the action taken. For actions performed outside the control room, feedback contributes significantly to the success/failure of the action. As a result, it is particularly important to include this information in the context of describing events. The following information is needed:

- all aspects of communication
- confirmation practice (e.g. the requirement to call back the control room after performance of the action)
- the availability of local indications
- the availability of control room indications.

3.3.2. Co-ordination and communication within and between teams

To support the analysis of tasks in which co-ordination and communication are key aspects, the data requirements are twofold. First, failure data for the co-ordination and communication elements of these tasks are needed. Examples of such elements are command delivery within the control room, between the control room and local operators, information delivery in the control room.

Second, for event data (reported errors), the description of the causes and performance shaping factors needs to include the co-ordination and communication standards. For example, when a human failure event occurs in an event due to communication failures, the event description would need to include not only that it was caused by a failure of 'information' delivery from one crew member to another but also the communication 'standards' for this part of the scenario.

For the analysis (quantification) of co-ordination and control elements, the following aspects need to be included:

- Communication procedures, such as formal standards that require the receiver to repeat a command to acknowledge that it has been received and to allow the sender to confirm that it has been properly understood. Any applicable informal standards (norms) for communication will also have to be specified.
- The type of communication equipment involved.
- Leadership 'style' in the general sense.

Emergency response (accident management) exercises may be a particularly useful source of data.

3.3.3. Actions without procedures

With regard to the data needs of such actions two main categories have to be distinguished:

- actions in situations without a clearly applicable procedure
- actions without any procedural guidance.

In situations in which either (1) the event has progressed to a state which is not covered by the procedure used in its "initial" phase and an additional one has to be applied or (2) an unforeseen situation has occurred to which none of the existing procedures is clearly applicable, the operator has to first decide whether to adapt a procedure or to develop an alternative response plan to be performed. The adaptation as well as the development of an alternative plan involve knowledge-based cognitive behaviours.

Analysis of knowledge-based behaviour of the operators should be the most important element in any new HRA development concerned with actions without procedures. Data collected about human failure events usually contain some information about the knowledge based behaviour of the operators. Data collection system(s), however, should be reviewed from this respect and it has to be ensured that they will contain sufficiently detailed information in the case there is a failure event due to an action without procedures. Simulator can be another (maybe more important) source of data, since scenarios can be designed specifically for the observation of such actions. Of course, simulators may not cover all the main areas listed above, but the conclusions made about the knowledge based behaviour of the operators in situations that the simulators are capable to deal with are valid for others.

With respect to actions taken when the responsibility has moved to others than CR (or plant) personnel it can be stated that they cannot be observed on simulators. Due to the fact that (fortunately) such situations occur very rarely existing data bases cannot be used as information sources. Analysis of the organizational characteristics of the "crisis team" or the organization taking the responsibility in such situations seems to be necessary for the evaluation of these actions.

3.3.4. Decision burden

The issue of decision burden has to be addressed in a more qualitative and descriptive way in a PSA. A quantitative approach, for example, by designing corresponding simulator experiments (e.g., randomly modifying the occurrence of indicators) would not have the expected result because of the inherent fact that the operators are acting in a simulator and not in the real working environment. Despite the above, information on any decision burden contributing to the human failure event should be recorded in the human reliability data base to be developed.

3.4. SUMMARY OF FUTURE NEEDS

It should be noted that in future work, the data structure proposed in Section 2 of this report will need to be reviewed in view of the data needs identified here. Current trends clearly indicate that the scope of HRA is expanding and should expand further. The needs can be summarized as follows:

- Actions outside the control room

  Methods for quantifying actions outside the control room need to be developed. As a first step, these actions need to be characterized systematically. The choice of characterization is important for a traceable HRA quantification as well as for operational event reporting useful for HRA.

- Co-ordination and communication within and between teams

  The overall impact is a greater stress on quantifying the probability of correct decisions (or minimally the probability of the necessary conditions for correct decisions). In addition, the interaction of the actions of different persons/groups needs to be considered as initiators as well as in successful response.

- Actions without procedures

  It should be recognized that, in certain circumstances, the need for operators to act without procedures is unavoidable because of the difficulty of providing procedures due to the variability of situations. For example, the plant has entered an unforeseen state. In the applications of PSA considered in this section, it appears that actions without procedures or without adequate procedures may no longer be considered an anomaly in plant practice that can be eliminated. Therefore, methods should be developed to deal with this kind of operator action, namely the so-called knowledge-based operator behaviours.

- Decision burden

  Actions involving decision burden need to be identified and considered in a qualitative way in the PSA/HRA. Mainly, methods for systematically identifying the actions in which decision burden occurs are needed.

So as to support the outlined future PSA/HRA developments, methods and techniques for the quantification have to be developed.

4. MAIN CONCLUSIONS FROM THE CO-ORDINATED RESEARCH PROGRAMME

4.1. OUTPUTS OF THE CRP

(a) Research

The principal research outputs of this work were: (1) the application of new methods to assess human performance at nuclear power plants, for control room staff and other technical personnel, and (2) the creation of new databases for human reliability purposes.

The applications of new methods have supported the ability of the participants to identify and assess more realistically the risks of human errors within the framework of probabilistic safety assessments (PSAs). In particular, several of the participants have developed and applied methods of data analysis that are intended to support the modelling of errors in decision making — the so-called "cognitive" errors that have been identified as major elements in severe accidents. While these data analyses have often involved some degree of judgement, the use of these human reliability methods have provided frameworks for making judgements concerning the selection of performance shaping factors. Examples of these methods that were used by some participants include CREAM, HERMES, HRMS, and PHECA. While there are differences between the details of these methods, they all provide improved modelling of human errors, principally by their expanded analysis of errors in cognition.

In addition, participants have had the opportunity to collect plant- and country-specific human reliability data (for example, using plant–specific operating experience or simulators) to replace the use of generic data as a basis for estimating human error probabilities. This will allow the resulting HRA and PSA results to be more realistic and relevant to the plants being modelled.

Further, research in new modelling activities by some participants during this CRP are now allowing the identification of additional factors for future data gathering. One example is the ATHEANA method that places an emphasis on the conditions of the plant at the time of the error. Data on plant conditions are mostly considered in a simplistic manner in most existing human error reporting and data storage systems. In addition, experience was described for other new methods, such as CREAM and HERMES, which indicate there will be needs for new types of data, but until more experience has been gained in applying these methods, it is not entirely clear what specific data requirements will exist for the databases.

(b) Others

The opportunities for exchanges of information between participants during the CRP, particularly while attending the co-ordination meetings, has led to the adoption of new techniques in the gathering of data and their analyses, and in their application in new HRA methods.

4.2. EFFECTIVENESS OF THE CO-ORDINATED RESEARCH PROGRAMME

(a) Effectiveness in reaching specific objectives

The CRP has been very effective in reaching many of its key objectives. In particular, there has been a very effective exchange of information between all of the participants concerning the use of different types of HRA methods, with an emphasis on their data requirements. This has led to new methods being tried in some cases that increase the relevance and accuracy of the HRA and PSA results for safety management.

Second, the work of the CRP has led to extended specifications of the types of data to be gathered and the types of factors to be analysed in databases, both for currently used HRA and PSA methods (as discussed in Section 1 of this report) and for future applications (Section 2). These achievements are of significance considering the extent of the differences that have existed in earlier HRA-related activities.

(b) Factors that adversely affected the effectiveness of the CRP

There have been no significant factors that have adversely affected the effectiveness of the CRP.

One consideration (that is perhaps inevitable with a discipline like HRA) is that HRA methods have been undergoing evolutionary changes at the same time as this CRP has been examining HRA data needs for PSA applications. Therefore, it is the case that data needs will change for the new methods. The discussion in Section 2 therefore reflects our expectations of what will be needed for some of the new methods and issues, but experience with applying the new methods will no doubt refine and improve on these discussions.

4.3. IMPACT OF THE CO-ORDINATED RESEARCH PROGRAMME

The CRP has made a significant impact on the HRA programmes and their application in PSAs for almost all the participants.

This impact has been seen in several ways. First, several participating countries have started to examine or use improved HRA methods that have the possibility of providing more safety-relevant information beyond the more traditional methods. Second, plant-specific or region-specific data gathering have been undertaken to replace generic HRA data used previously.

In both cases, the CRP has acted as a catalyst in accomplishing some of these advances by providing a forum to discuss and exchange experiences, and from the discussions in the Research Co-ordination Meetings, to allow participants to actually carry out the work.

4.4. RELEVANCE OF THE CO-ORDINATED RESEARCH PROGRAMME

In many evaluations of nuclear power plant PSA technology, the area of HRA is seen: (1) as a critical area for safety, and (2) the area where there is lack of standardization and a high degree of variability in the methods and data. It is recognized that human actions can overcome almost all design features of redundancy and diversity by acting as a source common-cause failures of equipment. However, this is not always seen in the results of PSAs. Therefore the actions of this CRP to improve the standardization of HRA data gathering and analysis and to identify future needs is one important step in improving the ability of PSA models to identify safety concerns realistically.

REFERENCES

[1] INTERNATIONAL ATOMIC ENERGY AGENCY, Control Rooms and Man-Machine Interface in Nuclear Power Plants, IAEA-TECDOC-565, IAEA, Vienna (1990).

[2] HIMANEN, R., "SEPRA — Shutdown PSA for Olkiluoto NPP", SVA Postgraduate Seminar on Safety of Nuclear Power Plants during Outages, Brugg-Windisch, March 29–31 (1995).

[3] INTERNATIONAL ATOMIC ENERGY AGENCY, Human Reliability Analysis in Probabilistic Safety Assessment for Nuclear Power Plants: A safety practice, Safety Series No. 50-P-10, IAEA, Vienna (1995).

[4] INTERNATIONAL ATOMIC ENERGY AGENCY, Human Error Classification and Data Collection, IAEA-TECDOC-538, Vienna (1990).

[5] INTERNATIONAL ATOMIC ENERGY AGENCY, Human Reliability Data Collection and Modeling, IAEA-TECDOC-618, Vienna (1990).

[6] MEISTER, D., "Human reliability", Human Factors Society Review (Muckler, F.A., Ed.), Santa Monica, CA (1984).

[7] WILLIAMS, J.C. "HEART - a proposed method for assessing and reducing human error" (Proc. Ninth Advances in Reliability Technology Symposium), University of Bradford (1986).

[8] REASON, J., Human Error, Cambridge University Press, Cambridge (1990).

[9] GERTMAN, D.I, GILMORE, W.E., GALTEAN, W.J., GROH, M.J., GENTILLON, C.D, GILBERT, B.G., Nuclear Computerised Library for Assessing Reactor Reliability (NUCLARR): Vol 1: Summary Description, Rep. NUREG/CR-4639, US Nuclear Regulatory Commission, Washington, DC (1988).

[10] TAYLOR-ADAMS, S.E., KIRWAN, B., "Development of a human error databank", (Proc. International Conference Devoted to the Advancement of System Based Methods for the Design and Operation of Technological Systems and Processes, PSAM II), March 20–24, San Diego, CA (1994).

[11] TAYLOR-ADAMS, S.E., KIRWAN, B., Human Reliability Data Requirements, Int. J. of Quality and Reliability Management **12** 1 (1995).

[12] TOPMILLER, D.A., ECKEL, J.S, KOZINSKY, E.J., Human Reliability Data Bank for Nuclear Power Plant Operations, Vol. 1: A Review of Existing Human Reliability Data Banks, Rep. NUREG/CR-2744, United States Nuclear Regulatory Commission, Washington, DC (1982).

[13] SPURGIN, A.J., MOIENI, P., GADDY, C.D., PARRY, G., ORVIS, D.D., SPURGIN, J.P., JOKSIMOVICH, V., GAVER, D.P., HANNAMAN, G.W., Operator Reliability Experiments Using Power Plant Simulators, Tech. Rep. EPRI NP-6937, Vol. 2, Electric Power Research Institute, Palo Alto, CA (1990).

[14] MOIENI, P., SPURGIN, A.J., SINGH, A., Advances in human reliability analyis methodology, Part 1: Frameworks, models and data, Reliability Engineering and System Safety **44** (1994) 27–55.

[15] FLEISHMAN, E.A., QUAINTANCE, M.K., Taxonomies of Human Performance: The Description of Human Tasks, Academic Press, London (1984).

[16] KIRWAN, B., A Guide to Practical Human Reliability Assessment, Taylor and Francis, London (1994).

[17] INTERNATIONAL ATOMIC ENERGY AGENCY, Systems for Reporting Unusual Events in Nuclear Power Plants, Safety Series No. 93, IAEA, Vienna (1989).

[18] RASMUSSEN, J., DUNCAN, K., LEPLAT, J. (Eds), New Technology and Human Error, John Wiley and Sons, Chichester (1987).

[19] SWAIN, A.D., GUTTMANN, H.E., A Handbook of Human Reliability Analysis with Emphasis on Nuclear Power Plant Applications, Rep. NUREG/CR-1278, United States Nuclear Regulatory Commission, Washington, DC (1983).

[20] BELLAMY, L.J., The quantification of human fallibility, Jnl of Health and Safety **6** (1991) 13–22.

[21] WHALLEY, S.P., Factors Affecting Human Reliability in the Chemical Process Industry, PhD Thesis, University of Aston, Birmingham (1987).

[22] RASMUSSEN, J., "Skills, rules, knowledge; signals, signs and symbols and other distinctions in human performance models", IEEE Transactions on Systems, Man and Cybernetics, SMC-13, No 3 (1983) 257–267.

[23] PEW, R.W., MILLER, D.C., FEEHRER, C.S., Evaluation of Proposed Control Room Improvements through Analysis of Critical Operator Decisions, NP 1982, Electric Power Research Institute, Palo Alto, CA (1981).

[24] ALTMAN, J.W., "A central store of human performance data", Quantification of Human Performance (Proc. Symp.), Albuquerque, NM (1964) 97–108.

[25] GERTMAN, D.I., "INTENT: A method for calculating HEP estimates for decision based errors", Proceedings of the Human Factors Society thirty-fifth Annual Meeting, (1991) 1090–1094.

[26] GERTMAN, D.I., BLACKMAN, H.S., HANEY, L.N., SEIDLER, K.S., HAHN, H.A., INTENT: A method for estimating human error probabilities for decision-based errors, Reliability Engineering and System Safety **35** (1992) 127–136.

[27] KIRWAN, B., "A resources flexible approach to human reliability assessment for PRA", Safety and Reliability Symposium, Altrincham, Elsevier Applied Sciences, London (1990).

[28] KLETZ, T., HAZOP, HAZAN - Notes on the Identification and Assessment of Hazards, Institute of Chemical Engineers, Rugby (1974).

[29] EMBREY, D.E., "SHERPA: A systematic human error reduction and prediction approach", International Topical Meeting on Advances in Human Factors in Nuclear Power Systems, Knoxville, TN (1986).

[30] ROOK, L.W., Motivation and Human Error, Rep. No SCIM-65-135, NM:Sandia National Laboratories, Albuquerque, NM (1965).

[30] ROOK, L.W., Motivation and Human Error, Rep. No SCIM-65-135, NM:Sandia National Laboratories, Albuquerque, NM (1965).

[31] RASMUSSEN, J., MANCINI, G., CARNINO, A., GRIFFON, M., COGNOLET, P., Classification System for Reporting Events Involving Human Malfunction, Rep. RISO-M-2240, Roskilde (1987).

[32] METWALLY, A.M., SABRI, Z.A., ADAMS, S.K., HUSSEINY, A.A., "A data bank for human related events in nuclear power plants" (Proc. 26th Human Factors Society Meeting), New York (1982).

[33] NORMAN, D.A., The categorization of action slips, Psych. Rev. **88** (1981) 1–15.

PARTICIPANTS IN THE CO-ORDINATED RESEARCH PROGRAMME

Basra, G.	Industrial Ergonomics Group, School of Manufacturing and Mechanical Engineering, Birmingham University, Edgbaston, Birmingham B15 2TT, United Kingdom
Dang, V.	Paul Scherrer Institute, Würenlingen and Villigen, CH-5232 Villigen, Switzerland
Dereviankine A.A.	ENTEK, POB 788, Moscow 101000, Russian Federation
Dusic, M.	Division of Nuclear Installation Safety, International Atomic Energy Agency, P.O. Box 100, A-1400 Vienna, Austria
Fabjan, L.	Jozef Stefan Institute, Jamova 39, P.O. Box 100, 1000 Ljubljana, Slovenia
Furuta, T.	NUPEC, Institute of Human Factors, Fujita Kanko Bldg. 17-1, 3-Chome Toranomon, Minato-ku, Tokyo, Japan
Gibson, H.	Industrial Ergonomics Group, The University of Birmingham, Edgbaston, B15 2TT Birmingham, United Kingdom
Hasegawa, T.	Manager, Investigation & Analysis Division, Institute of Human Factors, NUPEC, Fujita Kanko Toranomon Bldg. 6F, 3-17-1 Toranomon, Minatu-ku, Tokyo 105, Japan
Iqbal, M.	Directorate of Nuclear Safety & Radiation Protection, Pakistan Atomic Energy Commission, P.O. Box 1912, Islamabad, Pakistan
Karsa, Z.	Institute for Electric Power Research (VEIKI), Nuclear Engineering Division, Gellerthegy u. 17, H-1016 Budapest, Hungary

Kim, J.	Integrated Safety Assessment Team, Korea Atomic Energy Research Institute, P.O. Box 105, Yusong, Taejon, 305 600, Republic of Korea
Lasse, R.	Finnish Centre for Radiation and Nuclear Safety, P.O. Box 14, FIN-00881 Helsinki, Finland
Mavko, B.	Jozef Stefan Institute, Jamova 39, P.O. Box 100, 61 111 Ljubljana, Slovenia
Spitzer, C.	TÜV Energy and Systems Technique, Baden-Württemberg, Dudenstrasse 28, D-68167 Mannheim, Germany
Subramaniam, K.	Reactor Safety Division, Bhabha Atomic Research Centre, Mumbay 400 085, India
Tiippana, P.	Finnish Centre for Radiation and Nuclear Safety, P.O. Box 14, FIN-00881 Helsinki, Finland
Venkatraman, R.	Operations Directorate, Nuclear Power Corporation of India Ltd, Vikram Sarabhai Bhavan, Anushaktinagar, Mumbai 400094, India
Wreathall, J.	Dublin Operations, John Wreathall & Company Inc., 4157 MacDuff Way, Dublin, OH 43017, USA
Yoshimura, S.	Nuclear Engineering Laboratory, Toshiba Corporation, 4–1 Ukishima, Kawasaki-ku, Kawasaki, 210-0862, Japan
Yang, M.-Z.	Beijing Nuclear Safety Center, of National Nuclear Safety Administration, Beijing, China
Zhicheng, Z.	I&C Division, Nuclear Safety Center, State Science & Technology Commission, P.O. Box 8088, Beijing 100088, China

98-02913