BASIC PROFESSIONAL TRAINING COURSE

Module XXII

Human performance

IAEA
International Atomic Energy Agency
Background

In 1991, the General Conference (GC) in its resolution RES/552 requested the Director General to prepare ‘a comprehensive proposal for education and training in both radiation protection and in nuclear safety’ for consideration by the following GC in 1992. In 1992, the proposal was made by the Secretariat and after considering this proposal the General Conference requested the Director General to prepare a report on a possible programme of activities on education and training in radiological protection and nuclear safety in its resolution RES1584.

In response to this request and as a first step, the Secretariat prepared a Standard Syllabus for the Post-graduate Educational Course in Radiation Protection. Subsequently, planning of specialised training courses and workshops in different areas of Standard Syllabus were also made. A similar approach was taken to develop basic professional training in nuclear safety. In January 1997, Programme Performance Assessment System (PPAS) recommended the preparation of a standard syllabus for nuclear safety based on Agency Safely Standard Series Documents and any other internationally accepted practices. A draft Standard Syllabus for Basic Professional Training Course in Nuclear Safety (BPTC) was prepared by a group of consultants in November 1997 and the syllabus was finalised in July 1998 in the second consultants meeting.

The Basic Professional Training Course on Nuclear Safety was offered for the first time at the end of 1999, in English, in Saclay, France, in cooperation with Institut National des Sciences et Techniques Nucleaires/Commissariat a l’Energie Atomique (INSTN/CEA). In 2000, the course was offered in Spanish, in Brazil to Latin American countries and, in English, as a national training course in Romania, with six and four weeks duration, respectively. In 2001, the course was offered at Argonne National Laboratory in the USA for participants from Asian countries. In 2001 and 2002, the course was offered in Saclay, France for participants from Europe. Since then the BPTC has been used all over the world and part of it has been translated into various languages. In particular, it is held on a regular basis in Korea for the Asian region and in Argentina for the Latin American region.

In 2015 the Basic Professional Training Course was updated to the current IAEA nuclear safety standards. The update includes a BPTC text book, BPTC e-book and 2 “train the trainers” packages, one package for a three month course and one package is for a one month course. The” train the trainers” packages include transparencies, questions and case studies to complement the BPTC.

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Editorial Note

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1 INTRODUCTION

Learning objectives
After completing this chapter, the trainee will be able to:
1. Explain the historical development of human factors.

In the early days of development of the nuclear industry emphasis was placed on design, hardware reliability, and quality assurance and quality control (QA/QC) with only an intuitive interest in human factors. Human factors and ergonomics were an afterthought and only after the Three Mile Island (TMI) accident an increased importance was placed on human reliability. Accidents in complex industrial facilities (non-nuclear) like the Challenger, Bhopal or Exxon Valdes catastrophes pointed out the importance of organizational and management factors and their influence on safety.

Human Performance is a systematic approach to the improvement of individual and organizational performance. In its simplest terms, managing Human Performance is the ability of a NPP to proactively identify and correct problems before they result in injuries or events.

The scope of what is meant by human performance includes organisational systems and is considerably broader than traditional views of human factors/ergonomics. Human performance should be included within the safety management system and should be managed and continually improved.

The systematic approach to Human Performance includes three interrelated aspects that must be considered: the job, the individual and the organization:
- **The job**: includes areas such as the nature of the task, workload, working environment, the design of displays and controls, and the role of procedures. The job should be designed in accordance with ergonomic principles taking into account both human limitations and strengths. This includes matching the job to the physical and the mental strengths and limitations of people. Mental aspects should include perceptual, attentional and decision making requirements.
- **The individual**: includes his/her competence, skills, personality, attitude, risk perception and individual characteristics. All these influence behaviour in complex ways. Some characteristics such as personality are fixed and others, such as skills and attitudes, may be changed or enhanced.
- **The organisation**: includes work patterns, the culture of the workplace, resources, communications, leadership etc. They are often overlooked during the design of jobs but have a significant
influence on individual and group behaviour. Managing Human Performance is focused on what people are being asked to do (the task and its associated characteristics), the individual conducting the task (the individual and their competence) and where they are working (the organisation and its attributes), all of which are influenced by the organizational culture.

Human Performance is an important element of a NPP’s Safety Culture as quoted in the IAEA INSAG-4 [1]:

> Except for what are sometimes called 'Acts of God', any problems arising at a nuclear plant originate in some way in human error. Yet the human mind is very effective in detecting and eliminating potential problems, and this has an important positive impact on safety. For these reasons, individuals carry heavy responsibility. Beyond adherence to defined procedures, they must act in accordance with a 'Safety Culture'. The organizations operating nuclear plants, and all other organizations with a safety responsibility, must so develop Safety Culture as to prevent human error and to benefit from the positive aspects of human action.

Safety culture and organizational effectiveness has a direct influence on the quality of human performance, both in a positive and in a negative way. If the value of constant improvement is embedded in the organisation’s culture, the organization will find its ways to continuously improve its safety record.
2 ERROR CLASSIFICATION

Learning objectives
After completing this chapter, the trainee will be able to:
1. Distinguish different human types of error.
2. Describe the concept of a Generic Error Modelling System.
3. Explain the organizational influence on human behaviour.

2.1 Human Error

**Human error**, behaviour that does not achieve its desired goal, is caused by a variety of conditions related not only to inappropriate individual behaviour but also to unsuitable management and leadership practices, and organizational weaknesses.

There are two basic categories of errors [2]; active errors and latent errors. An active error is defined as an error that results in an immediate undesired consequence to the physical plant. For example, if the incorrect switch is turned which results in a feed pump shutting down in an unplanned manner then the act of turning the inappropriate switch is the active error. Latent conditions create errors resulting in undetected organization-related weaknesses or equipment flaws that lie dormant. Latent conditions can be characterized as an accident waiting to happen. Latent condition needs a triggering event to develop into an undesirable situation, i.e. from an event to an accident. Examples of latent conditions include:
- Design and construction deficiencies,
- Management failures,
- Maintenance errors,
- Component weakness,
- Inadequate procedures,
- Routine violations.

Another division of primary error types which is widely recognized among human factor specialists is Rasmussen’s categorization into [3]:
- Slips;
- Lapses;
- Mistakes.

Such primary error types can occur at any stage of an action sequence. Any action sequence is first conceived and then carried out. Therefore we distinguish three stages in any action sequence; planning, storage and execution. The first stage of planning involves identification of a desired outcome and the means to achieve it. Since the execution does not necessarily follow immediately after such planning, it is possible
to have an intermediate stage of storage. The last stage then is execution.

The primary error types can then be classified for the above action stages as follows:

- Slips and Lapses are errors which result from some failure in the execution and/or storage stage;
- Mistakes are made in the planning stage either in the selection of goals that the action should achieve, or in identification of the means for goal achievement.

There are of course also other ways of classifying error types which relate to the stages involved in an action sequence and can be summarized as doing nothing, doing something wrong, or doing something right at the wrong place or time.

The main possibilities are:

- **Action errors**: either no action is taken when required, the wrong action is taken, or the correct action is carried out but on the wrong object/time.
- **Checking errors**: when the system requires checks to be made, the checks are omitted, the wrong checks are made, or the correct check is made on the wrong object/time.
- **Retrieval errors**: when information is required, either from human memory or from another reference source, it is not received or the wrong information is received.
- **Transmission errors**: when information has to be passed to someone else, either no information is sent, the wrong information is sent, or is sent to the wrong place/time.
- **Diagnostic errors**: when an abnormal event arises, the actual situation is misinterpreted.
- **Decision errors**: after the circumstances have been considered the wrong decision is made.

### 2.2 Generic Error Modelling System (GEMS)

GEMS is an error classification scheme developed by Reason [2] that focuses on cognitive factors in human error as opposed to environmental or other context-related factors. It is based heavily on Rasmussen’s three major categories of errors: skill-based slips and lapses, rule-based mistakes, and knowledge-based errors [3]. The GEMS taxonomy of error types is a useful method to assess cognitive determinants in complex technological environments.

It is easiest to understand GEMS when the categories are first viewed as levels of performance. The first level of performance is skill-based, this second level of performance is rule-based, followed by a final level of performance which is knowledge-based. In this Rasmussen’s skill-rule-knowledge framework the three levels of performance correspond to decreasing levels of familiarity with the environment or...
The first **skill-based** category is a level of performance in which the individual is so skilled at an activity that it requires little or no attention to the performance. In fact, when an individual is said to have a skill-based level of performance, their level of proficiency is so great that little to no thought is required for the completion of the task. Performing the task with little or no thought (non-cognitive) can be a dangerous condition in a NPP and workers should always strive to pay attention during task performance. A classic example is a person who has been driving a car for many years in a familiar area; the driver typically does not need to pay attention to the act of driving. The adult uses this time to think of other situations requiring his cognitive attention instead of driving. The increased risk then arises in the presence of distractions such as speaking on a cell phone or adjusting the radio, etc. For example, as the driver continues along a familiar route he believes he has the cognitive ability to talk on the cell phone while driving the car. The driver’s attention is now on the cell phone and his conversation and he is less apt to see a child run near the car. *The driver’s inability to properly manoeuvre the car safely away from the child becomes a skill-based error.*

The second **rule-based** category is a level of performance in which the individual follows a rule for the performance of a task. Rule-based performance is behaviour based on a selection of stored rules which follows an IF, THEN logic. The rule can be internal such as the law of addition learned as a child, or the rule can be external such as a procedure/work document. *A rule-based error is when the wrong rule is chosen, the rule as misapplied, or the rule is ignored.*

The third **knowledge-based** category is a level of performance that results in behaviour in response to a totally unfamiliar situation (no skill, role or pattern is recognized by the individual); a classic problem solving situation that relies on personal understanding and knowledge of the system, the system’s present state, and the scientific principles and fundamental theory related to the system. *A knowledge-based error is in error caused by incomplete or inaccurate knowledge.*

### 2.3 Application of GEMS in error prevention

The theory of GEMS can be used to create the foundation of an error prevention programme. Human error prevention tools can be used to prevent the errors described within GEMS (Figure 2.1). For example if a technician is performing a very routine task that he has performed successfully many times, because of their expertise they may be thinking about other issues instead of focusing on the task. A simple human error prevention tool can be used to focus the technician on the elements of the routine task. In many NPPs workers use an error prevention tool called STAR. Prior to the technician beginning his
task he simply STOPS (focusing on the task at hand), THINKS (cognitively reviews the rule to apply), ACTS (takes the directed action from the procedure or work document) and then REVIEWS (confirming the expected response from the action). Reviewing this task within the GEMS model would reveal that the technician is in the skill-based category of performance which could result in a skill-based error if a latent condition exists. Because the technician uses STAR he has a higher level of awareness and is able to identify a latent condition, such as a loose wire. In effect the use of STAR takes the technician from a skill-based to rule-based category of performance reducing his probability of making an error significantly.

Figure 2.1: Skill, Rule and Knowledge based errors in GEMS.

If a worker is given a job that he or she is to accomplish for the first time, he may have an inaccurate mental model of the system or system response. If the worker is able to recognize that they do not have a good rule to apply to the situation, he should stop before proceeding further. When a worker stops and asks a supervisor for guidance, the worker moves from knowledge-based performance to rule-based performance. This is important because a worker’s probability of error while in a knowledge-based category is nearly 50%. A worker’s probability of error while in a rule-based level of performance is only 1 to 3%. A simple tool used in many English speaking NPP’s is OOPS, which stands for Outside of Procedure, Process, or Parameters,
STOP and contact my supervisor. Any work guidance such as a procedure, process or parameters used by the worker is in fact a set of external rules which reduces the probability of error.

### 2.4 Identification of Situations with Likelihood of Error

The identification of error likely situations is an important factor in preventing events at NPPs. An error likely situation is a work situation in which there is an increased opportunity for error when performing a specific action or task due to the presence of **error precursors** (also known as error traps). An error precursor is an unfavourable condition at the jobsite that increases the probability of an error. Managing error precursors allows workers and supervisors to reduce the probability of error in a given task.

A list of the top ten error precursors (error traps):

- Stress;
- High work load;
- Time pressure;
- Poor communications;
- Vague or poor work guidelines;
- Overconfidence concerning work and or abilities;
- First time performing the task;
- Distractions;
- First working day following time off;
- 30 minutes after a meal or waking up.

**Organizational defences** are used to manage error precursors. For example, a validated procedure would remove the error trap of vague or poor work guidance, or provide an experienced worker to work alongside someone who is performing the task for the first time to minimize “first time performance” type errors. An organizational defence is a measure used to protect plant equipment or people against hazards or active errors. Such defences protect against various hazards such as radiation, chemicals and heat. In contrast, a flawed defence has defects that under the particular circumstances may fail to protect plant equipment or people against hazards or fail to prevent an active error.

Examples of flawed defences are:

- Inaccurate procedure;
- Inadequate training;
- Poor supervision;
- Inadequate use of error prevention tools;
- Poor use of personnel protective clothing.

Undetected deficiencies in management processes (strategy, policy, work control, training and resource allocation) or values (shared beliefs, attitudes and norms) can provoke error by creating error precursors and degrading the plant defences. These deficiencies can be
considered latent organizational weaknesses.

### 2.5 Organizational Influence on Worker Behaviour

The organization of the NPP influences the worker’s behaviour at the jobsite. In the illustration below organizational processes, programmes and culture create and maintain organizational defences. Concurrently the same organizational processes and programmes create precursors associated with the job site. Defences are created to manage jobsite precursors thus helping to ensure that the appropriate behaviour of the worker results in successful completion of the task (Figure 2.2).

![Organizational defences and error traps.](image)

**Figure 2.2:** Organizational defences and error traps.

Organizations can prevent events by taking proactive actions which involve the entire organization in efforts to reduce human error. One such effort is the identification of situations with the likelihood of error combined with the intelligent application of error prevention tools by individuals and supervisors. Effective communication between workers and managers about job-site conditions enables error precursors and flawed defences to be brought to the attention of those
who manage the systems. These can then correct any latent organizational weaknesses creating these flaws.

**Figure 2.3:** Precursors outweigh organizational defences.

Situation with the likelihood of error exists if the influence of the jobsite precursors outweighs the influence of the organizational defences (Figure 2.3). For example, if a work instruction is created in the form of a detailed procedure to ensure a complex task is completed in the correct order, this defence guarantees the steps of the complex procedure are carried out as required. However, if the worker is influenced by multiple precursors such as time pressure, stress and distractions, these error traps could lead to the worker skipping a step by mistake. The result is that multiple precursors weaken the defence
of a detailed procedure, increasing the probability of an error which could lead to an event.

### 2.6 Conclusion

Improving Human Performance is a systematic approach to improving individual and organizational performance. A key aspect is to understand the organization’s influence on individual behaviour, which can either reduce errors or provoke them. Proactive actions taken to strengthen and reinforce defences will help manage situational precursors that cause error-likely situations. Each NPP should continuously evaluate their organizational processes, programmes and culture in order to identify any latent organizational weaknesses which damage defences and increase the negative influence of situational precursors.
3 COGNITIVE ENGINEERING

Learning objectives
After completing this chapter, the trainee will be able to:
1. Explain the concept of cognitive engineering.
2. Describe the issues of computerized operator support systems including expert systems.

The original designs of the working environment were very much technology-centred, where the system was the main focus of the designer. Over the years this approach changed and it became more and more user-centred. This development was a direct consequence of advances in the application of ergonomics and psychology to the design of the working environment.

With the rapid development of computational power and its reduced cost more and more automation of process control was introduced into the main control room of nuclear power plants. This development resulted in a radical change of the work environment and the cognitive demands placed on the operator. The operator’s role has shifted from that of a controller to a supervisor who monitors and manages semiautonomous resources. This change reduced the physical burden on the operator but increased his mental load. Computerization therefore greatly increased cognitive demands on the operator. In order to address this shift, the need for so-called cognitive engineering became apparent [4].

Apart for computerized process control which is increasingly being utilized in the main control rooms of nuclear power plants, computerized operator support systems have also been increasingly introduced. Initially they were simple status quo presentation devices but soon they developed into a decision aid with capabilities for diagnosis, trend analysis and checking of recovery actions. Again, the operator role has changed. The key question in the human factor area became how best to integrate human intelligence and machine power in a single integrated system that maximizes overall performance, and to understand what constitutes effective support to the operator. Cognitive engineering deals with these issues and concerns about the human behaviour in a complex worlds.

The goal of cognitive engineering is to enhance the performance of problem-solving systems i.e. the human-machine system.

To achieve the goal of enhanced performance of problem solving systems, cognitive engineering must first identify the sources of errors, i.e. why, where and how the human-machine system breaks down. The first reason can be missing, incomplete or wrong knowledge. This can be corrected by providing the missing knowledge
or correcting the erroneous date. But a more critical question may be how knowledge is activated and utilized. Research in education and training has identified that very often knowledge is acquired but at the same time the person often fails to recognize its use in the problem solving situation. The fact that a person has acquired knowledge does not guarantee that it will be activated and utilized when needed. This is termed inert knowledge.

The challenge of cognitive engineering is to develop ways of enhancing knowledge and minimizing inert knowledge.

A further step in the development of computerized operator support systems was the introduction of expert systems, which apply a knowledge base to solve practical problems [5]. Expert systems can today be regarded as sufficiently mature to be used to create a variety of user support applications, but there is no question of them either fully replacing the human contribution to a system or of these being used in a superior role to humans. Expert systems, sometimes also called knowledge-based systems, are used to [6]:

- Improve safety by monitoring, diagnosing and prognosing plant conditions;
- Extracting significant data from large data bases;
- Give operator advice;
- Give early warning about plant conditions;
- Facilitate operator tasks;
- Facilitate operator workload in particular fields;
- Train staff, also on simulators;
- Help in planning complex activities.

Ergonomic aspects of the user interface and the acceptability of expert systems by the operator are crucial for their successful implementation. If the system is to be accepted by the operator we must [7]:

- Involve them from the very beginning in the design of such system;
- The system must also be used in routine tasks such as data logging so that familiarity with the system is gained and the situation does not arise in which a need occurs and the operators are expected to turn to a system with which they have very little experience.

In human-machine interface, the practitioner’s judgement of machine competence and predictability can be misjudged, leading to excessive trust or mistrust. The system can be either underutilized or ignored when it can provide sound solutions, or be trusted by the operator in situations which challenge or even exceed the machine’s range of competence. This issue also needs to be addressed by cognitive engineering.
4 HUMAN ERROR IN THE JOB

Learning objectives

After completing this chapter, the trainee will be able to:
1. Describe a model of human error analysis.
2. Explain possible ways to minimize the influence of human error on nuclear safety.

From the usual in-depth evaluation of events (which is today performed in all nuclear power plants) analysts found some trends regarding behavioural factors such as confusion, unawareness and lack of attention in the person involved. This very often involves a quick judgment, and analytical efforts to study the internal attributes of persons involved in NPP events are needed. It may be helpful to use the explanations of behavioural psychologists and go further and build a pragmatic approach to human errors such as those described by Reason and his associates [8]. These authors studied the problem of the responsibility of persons acting under particular circumstances, and found that their reactions were highly dependent on external aspects. Further, they also studied the thought processes involved in human behaviour. Undoubtedly, it is important to take into consideration these internal processes to develop effective corrective measures to decrease the frequency and severity of human errors.

Event reports generally avoid this problem of responsibility by indicating that it is not their purpose to attribute blame, but rather to analyse how the error came about. They also point out that the error results from a combination of several factors, the most important of which have nothing to do with the individual who carried out the task. However, it is not a good idea to avoid completely the individual responsibility for an error. It is known that the individual demands a certain degree of autonomy in his/her work, and, ipso facto, accepts responsibility for the actions in which he/she is involved, either as an individual or as a member of a team.

The concept of responsibility is a particularly complex one. Responsibility can be defined in terms of many different parameters: moral, civil, penal, individual or collective etc. There are objective and subjective responsibilities. Objective responsibility refers to the compliance of an act with an external rule. Subjective responsibility takes intent into account. Both components can be found in the concept of human error. An objective component of responsibility can be found, insofar as the concept of error refers more or less clearly to that of the norm: an error occurs because not everything that should have been done was done. The subjective component leads to the questions: to what extent is an individual involved in the production of what is considered to be an error, to what extent could he have prevented this error, and did he recognize the error as such?
There is no quick and simple answer to the question: “How can we define being responsible for an error?” It is necessary to clarify the analysis of the error and to provide useful elements to improve the human error question. Analysis of the intention of the action can be useful to elucidate the roots of the error and discuss the level of responsibility of the person involved. This can also be helpful in identifying accurately and adequately links with other factors (technical, organizational, etc.) and providing a hierarchy of the different roots of errors.

### 4.1 Models to help in error analysis

Some elements from cognitive psychology can be transformed into a simple model showing the different steps involved in the process of task performance by a person on the job. The general model (see Figure 4.1) shows the successful completion of a task. By contrast, other models show a breakdown in this process, and explain different types of errors, violations, mistakes, and slips.

![Figure 4.1: Steps involved in the process of task performance.](image-url)
The general model explains the links between the planned required state of the system, the task prescribed, and the other individual aspects such as understanding, intention and action. An error is a discrepancy between the result of the actions and the planned result of the task to reach a required state, i.e. a breakdown in the flow of the process. According to the place of the breakdown, the roots of errors are not the same because the components of the model are not sensitive to the same factors. Thus, the extent of the responsibility of the person involved is different. Consequently, the corrective measures against errors should also be different. The different types of errors are listed below.

4.2 The successful job process model

The general model (see Figure 4.1) shows the mechanism for success in actions:

- The “prescribed task” corresponds in detail to the “actions to reach the required state”;
- The operator/person understands the “prescribed task” or the “actions to reach the required state” themselves;
- His/her intention reflects the “actions to reach the required state”; his instrumental intention is coherent with the goal and in accordance with the available schedule, resources and tools. If the operator completely follows his original goal intention and acts according to his instrumental intention, without disruption, he will succeed and reach the goal: The system reaches the state 2.

This general model was developed using the following definitions:

*Prescribed Task*: "Prescribed task," means prescriptions which cover the procedures and assignments. These can vary in the degree of detail; however, the term - prescribed task - will be used for all cases considered. The prescribed task reflects the different steps and the order of the actions. Such prescribed actions should ensure a state of the system without risks evaluated from experience or analysis.

*Understanding*: Two levels of understanding are distinguished in this model:

- The beginner may understand the sequence of the procedure and know how to apply it to the system;
- The experienced person understands the process, the consequences of the actions on the process, including implicit risks not described by procedures.

*Intention*: The concept of intention encapsulates the idea of picturing, triggering and directing actions. This concept is related to that of scheduling. Intention is present when an individual acts toward
achieving a goal, chooses means to achieve the goal, and corrects them if necessary. The transition from intention to action is then a result of a decision-making process, which brings into play the context, the importance of the task as regards motivation, and the expectation of success.

In the context of this general model, the intention of a person corresponds to a specific task. This intention could be valid for a few minutes or for a few days (during the actions).

In this model, two important distinctions regarding "intention" were used: Goal intention and instrumental intention. The intention thus consists of two components:

- “What result has to be achieved” - goal intention;
- “How to act” - instrumental intention.

The goal intention is formed before the corresponding actions.

The instrumental intention relates to the methods of performing the task in compliance with the mental representation of the result and reflects the readiness of a person to use specific means, tools and technology. It provides a comprehensive view of all the steps and means which the person plans to reach the goal, including personal attitudes, the use of tools, the help of other people, the level of quality achievable in the available time, etc.

Task: All the actions performed at the right time in the right sequence to bring the system from the initial to the required state. In this sense the task is on a higher hierarchical level than the action.

Actions: Conscious or unconscious work steps to perform a task, i.e. to change the systems state from the initial state to the required one.

Actions to reach the required state: Actions required by design fundamentals and physical laws to bring the system from the initial state to the final required state.

Automatic actions: With experience and development of skill, the structure of the task execution changes. The steps in developing automatic execution are the following:

- At the beginning of skill development, basic actions are linked together, achieving conscious intentions, then gradually the status of the actions changes. These operations become automatic so that “soon they require no conscious control”. Subsequently, these actions become part of another operation with a complex make-up.
- By controlling the basic units, originally what was a closed-loop operation gradually becomes an open-loop operation: “The action is directed by a feed-forward rather than a feed-back principle”. In other words, the mental pictures of the goal are
adequate for implementing the imagined action without the need for conscious control. Thus, at the same time, conscious goals cover increasingly larger groups of execution.

Types of disturbances in a sequence of automated actions are confusion, omission and lapses. If an intended action is skipped, an omission results. If an action is replaced by an action in the intention of another (parallel) task, a lapse results. Confusion can be the result of an unconscious choice (wrong switch, wrong way to find a system, etc.).

### 4.3 The detailed work process model

The detailed model in Figure 4.2 shows the links between the individual, technical, organizational and extra-organizational aspects. The organization prescribes the task but also provides the training to improve the understanding of the system. The organization can also promote other criteria which can influence the intention of the staff (e.g. reduce the cost, the delay, etc.).
Some external factors encountered during working conditions can be contingent on the organization. Of course, understanding depends on the experience and competence of the individual. Extra-organizational aspects (e.g. a restricted time schedule, etc.) can so influence persons that they develop an intention not in compliance with their proper understanding. The contingency of the situation can change some internal conditions of the individual (fatigue, awareness, etc.).

### 4.4 Small models for each type of error

**Model of violation**

Figure 4.3 shows a graphical model of violation. Although the person has a good understanding of the "prescribed task“, he/she develops an intention not in compliance with his understanding. The reason for this may result from various sources (internal or external). This kind of behaviour is called a violation. As an example, the operator wants to follow his “personal intention” due to personal motivation (e.g., the operator does not follow a procedure in order to go home earlier, etc.). In this case, the operator is fully responsible for his action.
There are other cases in which the operator’s responsibility must be investigated in more detail and more general situations must be taken into account. For instance:

- the person wants to satisfy other criteria such as personal safety aspects, power production or even the efficiency of a larger project that includes this particular task. Recommendations have to be addressed to this kind of compromise and something must be done to clarify the decision making;
- the person thinks that he knows a better solution than that provided by the procedure;
- the person cannot perform the task because the conditions have changed and the task cannot be done as prescribed because of time constraints, or work load, or because tools are not available;
- the person is tired and has changed his work procedure. The identification of such conditions may change working rules and arrangements for the individual and the organization.

**Model of mistakes**

Figure 4.4 shows a graphical model of mistakes. The intention is wrong or the instrumental intention is not appropriate because
understanding is not in compliance with the “prescribed task”. This can be explained by the total or partial ignorance of the operator due to internal or external factors.

Internal factors could be described by the following:
- Incompetence of the operator who failed to understand or to recognize the task, or failed to determine how to use the tools, or failed to simply use the tools needed for achieving the objective.
- Forgetfulness (especially when situations occur infrequently or are unplanned).

External factors could be described by the following facts:
- The task is poorly defined because even experts understand it poorly, or it is insufficiently defined with respect to the knowledge of the worker who will perform it.
- The task is performed in a conflicting situation. It is possible that the organization has solutions for these conflicts, but these have not been clarified.
- The conflicts between speed and accuracy, and quality and quantity need more knowledge to be resolved correctly.
- Insufficient training has been provided to the individuals who have to perform the task.

When the analysis shows clearly (or by deduction) that the persons concerned did not understand the procedures, the aforementioned factors should be examined in-depth in order to provide more accurate recommendations for improvement, i.e., training of the persons involved in the NPP incident.
Figure 4.4: Model of mistakes.

Model of slips

Figure 4.5 shows a graphical model of slips. The intention was good, but the action was wrong. This family of errors is concerned with all events where the analyst can say that the person did not pay attention (carelessness). Slips occur when an action is not in compliance with the intention because something occurred during the execution of automatic actions (distractions, interruptions, multitasking, etc.). A good understanding of the definition of automatic actions is very important here. Also, a detailed analysis of the task has to be made during the root cause analysis in order to determine which part of the task may contain unconscious, automatic actions.
What are the factors which lead to automatic actions, possibly with disastrous consequences?

- The organizational conditions of work make it more likely for these effects to be produced, particularly hyper-specialization, excessive training for short-cycle and repetitive tasks, and speed and output limitations that instil a need for increasingly developed automation.
- Technical conditions and Man Machine Interaction can introduce error conditions.
- The absence of equipment standardization (a new item of equipment with a mechanism which invalidates the operator’s responses, although these were correct for the old system).
- Management of experience: when a person acquires experience in doing a certain task, the original "knowledge based" activities for performing the individual steps of the tasks move down to "rule based" and finally "skill based" activities. An experienced person no longer thinks in steps but rather in sequences (rules) of steps that are executed automatically with little attention. In this operational state the person is more prone to slips and lapses. This carries the danger that a whole sequence of actions
may be omitted or replaced by another sequence (lapse) not intended for this task.

In addition, another effect may occur that also gives some potential for errors: during the gain of experience, the task becomes less and less demanding for this person. This may lead to a loss of motivation, which is an essential prerequisite for good performance.

As a conclusion, automated actions are a result of experience and are needed for efficient work. To decrease errors associated with automatic actions, it is necessary to analyse the technical and organizational causes of such underlying automatic response in order to modify these attitudes. To interrupt an automatic action which includes a specific safety risk, it is necessary to substitute recommendations instead of “pay attention”; for example, to create a stopping point in a phase, or to include a more conscious action or control and surveillance by other persons.

Organizations can find solutions by management of experience. Usually organizations solve the problem of motivation and the use of too much reflex and cognitive bias in work by career development of the skilled person, i.e., by promoting him to a higher position where he can use his knowledge to supervise people in this specific task. These skills are very precious for organizations in mastering the process. These kinds of skills may be developed in large complex tasks where employees can acquire an integral view of their job. Personnel should have the opportunity to obtain experience in other related tasks in order to change their point of view.

**Model of errors due to the decomposition of tasks**

Figure 4.6 shows **errors caused by interface problems**. While organizing the work, the actions prescribed in the same procedure may be performed by different persons.

This transition can occur during or at the end of the shift. When the shift changes, communications are more or less sufficient to help other persons to continue the task. The responsibility for some important phases of the task may not be explained well enough (for example, putting back or removing certain pieces used during tasks can be forgotten and this can change the design of the plant). The error by the person in charge of the second part of the work depends on different factors:

- Different understanding by two persons of the same procedure;
- Different intentions after reading the procedure by each person can result in two tasks that will not be in compliance;
- Lack of communication about the condition of the interfaces between subtasks often leads to errors;
- Lack of communication during parallel tasks in the same procedure;
- Important details seen by the first person may not be transmitted to the second person. (e.g., dismounting and mounting a valve).

![Figure 4.6: Errors caused by interface problems.](image)

This would not be the case if the same person perform the task, since he/she includes this information automatically in his task. The challenge is here to be conscientious and to explain explicitly such automatic actions to the other person.

**Model of dynamic errors**

Figure 4.7 shows a graphical model of dynamic actions. The intention was in compliance with actions to reach state 2, *but during the execution of the action (time T) the state has changed*. The original intention appropriate to reach state 2 is no longer in compliance with this new state. The evolution of the state has not been perceived by the person because of his limited knowledge of the system, because of the incompatible delay of decisions and actions with the dynamics of the system, or because of the characteristics of the information coming from the system or other sources. For example, this problem may also occur in the case where more than one person is working on the same
system and the work areas overlap and the results are not communicated. The complexity of nuclear systems can reinforce this type of error.

In the case of dynamic errors, possible questions regarding responsibility are the following:

- To what extent can these uncontrollable or fairly unpredictable disruptive factors be taken into account in the previous intention?
- To what extent can persons, focused by actions, and comprehending the evolution of the system state, be very conscious during an action (without any automatic actions), and be completely alert and attentive to outside information?

![Figure 4.7: Model of dynamic errors.](image)

This model of dynamic errors can also be used for additional comments on the model of violation. Persons with some experience can anticipate the evolution of the system when it is in state 1. Following this anticipation, these persons can decide not to perform the procedure or to change it. The problem comes from the reliability of the arguments or the process controlling the decision-making.
4.5 Minimizing the influence of human errors on plant safety

The need for and possible solutions for corrective actions strongly depend on the particular situation in a NPP. Examples of provisions to be considered to minimize the influence of human failures on plant safety could be as follows:

- Comprehensive task analysis to identify weaknesses and hence the need for appropriate provisions;
- Improvement of design (e.g. redundancy, diversity, interlocks etc.);
- Improvement of work organization and supervision;
- Improvement of content and scheduling of tests;
- Improvement of equipment surveillance;
- Improvement of procedures.

Special emphasis should be paid to work preparation and performance. NPP operators should be informed about possible consequences and recovery measures.
5 EVENT ANALYSIS WITH A HUMAN FACTOR COMPONENT IN THE IAEA/NEA IRS

Learning objectives

After completing this chapter, the trainee will be able to:
1. Describe the main purpose of the IAEA/NEA IRS and the importance of reporting human performance deficiencies.

The safe operation of nuclear power plants around the world and the prevention of incidents in these installations remain the key concern for the nuclear industry. In this connection, the feedback of operating experience plays a major role; every nuclear power plant or nuclear utility needs to have a system in place for collecting information on unusual events, whether these are incidents or merely deviations from normal operation. Reporting important events and lessons learned to the regulatory body is normally carried out through the national reporting schemes based on regulatory reporting requirements. The most important lessons learned are then further shared internationally, through, for example, the Joint IAEA/NEA International Reporting System (IRS), or the event information exchange of the World Association of Nuclear Operators (WANO) [9].

In order to properly assess the event, an adequate event investigation methodology has to be utilized. It needs to determine direct causes, root causes and to propose appropriate corrective actions and corresponding lessons learned. The overall goal of root cause analysis is the prevention of events or their recurrence and thus the overall improvement of plant safety.

Throughout the years it has been observed that 70% of root causes can be attributed to some kind of human error and yet the reporting of human errors was found to be inadequate. The quality, consistency and completeness of information in the identification of human factor aspects of events were found to need improvement.

When the NEA and IAEA IRS reporting systems were merged together in 1997, new guidelines for reporting were developed. In order to strengthen the reporting of events involving human factors, new recommendations and coding systems were developed in cooperation with WANO. Their purpose is to identify the type and detail of information on human and organizational factors that should be expected in the IRS reports and to provide guidance on how this information could be presented within the body of the event reports.

In order to utilise the already large amount of data stored in the IAEA database, a pragmatic approach had to be followed, making maximal use of existing documents. The guidance aimed to be not too difficult
to use by those who are not human factor specialists and who do not necessarily have specific training in human factor analysis techniques.

It should be realized that there are inherent limitations to human factor analysis due to national culture, regulatory reporting requirements, legal issues, etc., as well as some reluctance to provide information related to human performance within plants, nationally or internationally. In this respect, the establishment of a blame-free reporting culture is essential and must be promoted. The availability and systematic use of human and organizational factor-oriented event investigation methods is also recognized as a condition for improved human factor reporting.

One of the potential problems identified in analysing, reporting and retrieving human factor related information is the lack of use of a common language. A possible way to overcome this problem would be by reaching a consensus on the taxonomy to be used regarding reporting of human and organizational factors. The method chosen to introduce such a common taxonomy in the IAEA/NEA IRS was by providing a limited list of human and organizational factor codes. In this way a consistent and manageable short list of codes is created. The danger that some human or organizational errors are not found within this limited list is overcome by providing a longer list of keywords supporting each proposed code.

For those events where human performance was deficient or where organizational problems were highlighted the following main steps as a minimum need to be followed:

- The first step: clarify what happened during the event.
- The second step: demonstrate why the event is of safety significance.
- The third step: provide answers to the questions "why did it happen?" – direct cause and “why it could not be prevented” – root cause.
- The fourth step: answer the question "how should the situation be modified?"
6 ORGANIZATIONAL FACTORS

Learning objectives
After completing this chapter, the trainee will be able to:
1. Explain the basic organizational factors influencing human performance in NPPs.

Complex systems such as nuclear power plants require maximum orderliness in methods of operation. The work must be clearly defined, properly assigned, executed according to predetermined and written procedures, carefully recorded, regularly supervised, and the whole system readily corrected when necessary. A state of organizational confusion is frequently the root cause of many errors. It has been largely recognized that an accident is rarely due only to individual confusion or the single act of one person but is more frequently due to a chain of faults. A situation of organizational confusion can be more damaging as organizational confusion about one or more human functions generates further malfunctions or faults.

In the past, three periods can be identified during which the set of methods used by organizations to assess safety have been developed:

- The initial period when the emphasis was on design certification and the establishment of a set of safety requirements for operations.
- The second period when the emphasis was on operations and associated guidance (documentation, operator behaviour). In this period, the "certification" of operations was based on Quality Assurance and document improvements. Studies of human factors and human errors were developed in order to have a better coherence between documents and human behaviour. Safety authorities in this period reviewed documents and verified procedural adherence by workers/operators.
- The present period which emphasizes the organization of all processes needed to manage the installation safely, as well as on the global view of the organization of the plant, which guarantees its safe operation.

Since the Ontario Hydro report was published, which revealed gross organizational deficiencies, it is recognized that it is not sufficient to review the technical safety issues and the adherence to procedures, but it is also necessary to evaluate an organization to see if it copes with a situation in a safe way. If the organizational problems are not detected and solved, the nuclear plant or installation is not safe.

It is also recognized that organizational factors have always been taken into account but implicitly. The assessment of the organization makes the organizational factors and their links explicit, in order to identify potential deficiencies. The goal of assessment is also to show the coherence of safety management through the plant’s activities. It is
also a good exercise for managers; it reveals to them the main features of safety management in which they are involved every day in a routine manner.

Figure 6.1 represents three stages of organizational development and methods for their assessment.

<table>
<thead>
<tr>
<th>Safety Evaluation issues</th>
<th>Methods</th>
</tr>
</thead>
<tbody>
<tr>
<td>Safety in the work process</td>
<td>Organisation, assessment, audit, OSART</td>
</tr>
<tr>
<td>Safety in coordination and communication</td>
<td>Quality assurance, documentation and proceduralisation Human factor analysis</td>
</tr>
<tr>
<td>Safety in the whole management</td>
<td>Safety requirement reference set- safety rules-design certification</td>
</tr>
<tr>
<td>Safety in operation</td>
<td>Safety in maintenance</td>
</tr>
<tr>
<td></td>
<td>Safety in testing and reviewing</td>
</tr>
<tr>
<td></td>
<td>Technical safety</td>
</tr>
</tbody>
</table>

**Figure 6.1:** Three stages of organizational development.
(OSART: Operational Safety Review Team)

More details on the importance of organizational factors are given in Module 21 dealing with Management systems, Leadership and Safety culture.
7 TAKING HUMAN FACTORS INTO ACCOUNT AT THE DESIGN STAGE

Learning objectives
After completing this chapter, the trainee will be able to:
1. Describe human factor considerations during the design stage of an NPP project.

At the design stage, two major questions guide how human factors are taken into account:
- The labour distribution between operators and technical systems;
- Specification of the means given to operators to fulfil the roles they are actually assigned on the installations.

7.1 Criteria guiding the distribution of work between operators and technical systems

To define the design choices with full knowledge (i.e. after having weighed the consequences of these choices in the short, medium and long term), it is necessary to be familiar with the operators' actual work. Only reference to these activities can guarantee the relevance of the options chosen. Knowledge of the work must include the following:
- Strong points to maintain;
- Weak points to overcome;
- Actual conditions in which tasks are carried out; activities carried out by the operators in order to achieve the goals of the man/machine system; and actual consequences of the work for characteristics later found in the operation of the system.

In order to constitute a true reference for design guidance, this knowledge must help to establish a prognosis of the future situation. On the one hand, a diagnosis of the original situation must be available before starting the project. On the other, one must foresee the way in which present needs will develop considering the future environment, and thus establish a projection of future activity.

The diagram in Figure 7.1 shows the principle of the iterative approach implemented in order to establish this prognosis.

Iterations of this diagram show that this projection does not stop with the analysis of needs. It continues throughout the whole specification phase in a more reliable way, thanks to the use of models and prototypes.
Diagram of what exists

- Situation at the start
- Reference situation

Collected data
- Strong points to keep/Weak points to avoid,
- Categorization of operating situations,
- Intrinsic characteristics of activities,
- Operating modes.

Diagnosis of what exists

- Situation at the start
- Reference situation

Activity Analysis

Specifications
- Missions of the Man-Machine system,
- Task distribution,
- Operational means: functionalities,
- Organization,
- Training.

Adjustments

Prognosis of future situation
- Sample scenarios,
- Operators,
- Criteria relevant to activity.

Evaluation,
Adjustment of specifications.

DETAILED SPECIFICATIONS

Figure 7.1: Iterative approach in the design of the man-machine interface.

Diagnosis of the original situation
This diagnosis aims to identify:
- The different operational situations and their requirements;
- The operators' activities in these different situations;
- The current difficulties.

Thus, on the whole, we seek to identify the needs to be met by the future system. For this, we use the operational feedback available, supplemented by more qualitative analyses carried out in the field.

These field analyses focus on the operators' activity and, more generally, on that of the work teams. They are derived from interviews
and observation aimed at a better understanding of the work in order to find out "how it works well" and "why it doesn't work".

Various questions can act as guides to these analyses:
- What are the goals pursued by the operators?
- What information is available to them?
- How is this information used?
- What decisions do the operators make?
- What are the difficulties they encounter?
- What are the means available to them?
- What are the types of action carried out?
- What are the risks observed?

Prognosis of the future situation
In order to obtain satisfactory specifications (first general, and then more detailed) both at the operational level with respect to the tasks to be carried out and from the point of view of human acceptability, these must be defined to take into account the consequences they will have on the work activity.

As the project progresses, two means are used to establish this prognosis of the future situation on which to build a projection of the activity according to the specifications adopted for the new socio-technical system:
- Analyses of reference situations, in which principles close to those one wishes to put in place have been adopted. These field analyses are guided by the same questions for the analysis of what already exists.
- The use of models and prototypes that simulate the specifications which are being perfected in order to achieve a more detailed projection of the future activity. The principle is to put future operators in real life situations. Sample scenarios are used, which allow familiarisation with future work situations, given the technical and organizational options envisaged. Beyond mere adjustment modelling/prototyping there is also an opportunity to evaluate alternative options.

7.2 Conditions for taking human factors into account in a design process

For specification of the human factors to be taken into account at the design stage, the approach implemented must possess certain characteristics. Beyond the two points earlier mentioned - diagnosis of what already exists so as to allow analysis of the needs to be met by the future system, and indispensable projection of the future situation based on analyses of reference situations and modelling/prototyping - two other characteristics constitute sine qua non conditions for taking human factors into account:
The approach must be open in the sense that it must not be guided by the wish to validate technical progress, which would lead to making a priori technical choices. This means that:

- The first design stage consists of identifying, through the analysis of needs, the aims of the man-machine system as a whole.
- The second stage consists of matching these means, that is, in defining the distribution of tasks between men and technical systems.
- Only at that point can technical solutions be introduced. This implies, for example, that automation be considered as a means (not a goal) to be envisaged just like other means (technically) available. For example, automation can be used for certain supervisory tasks or for performing routine calculations. In addition it can be used to give advice or support for decision making (but not for taking decisions).

The approach must be iterative. It must include evaluation loops throughout the specification stage. Indeed, the increasing complexity of systems no longer allows envisaging the whole specifications only using a top to bottom approach. Moreover, the prognosis of the future situation can only be established step by step.

The diagram in Figure 7.2 shows the various possible interventions (right side of the diagram) of specialists in charge of human factors in the design process (represented schematically on the left side of the figure).
As shown in Figure 7.2, not only are human factors to be taken into account early in the design stage (and not as was done in the past only at the end of the process of evaluation), but also throughout the major phases of the design and work.
8 QUESTIONS

1. What is normally understood under the term »human performance«?
2. What is believed to have the biggest influence on human performance?
3. Name three primary error types in Rasmussen's human error framework.
4. Describe the basic characteristics of the GEMS model.
5. What problems does cognitive engineering try to solve?
6. Name a few examples of the use of computerized operator support systems.
7. Describe the main steps involved in the process of task performance.
8. What are the possible actions that can be taken by an NPP management to reduce the influence of human error on plant safety?
9. What are the main steps that need to be undertaken when analysing IRS reports with a human factor contribution?
10. Name three stages in which methods used by organizations to assure safety have been developed.
11. Briefly describe the interaction between the human factor specialist and the equipment designer at the design stage of a human-system interface.
9 REFERENCES


The views expressed in this document do not necessarily reflect the views of the European Commission.