Part I —

The Context of DOE's Accident Investigation Program

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Accidents: General Principles

1.1 The Nature of Accidents

Accidents are unplanned and unintentional events that result in harm or loss to personnel, property, production, or nearly anything that has some inherent value (i.e., targets). These losses increase an organization's operating costs through higher production costs, decreased efficiency, and the long-term effects of decreased employee morale and unfavorable public opinion.

Accidents are rarely simple and almost never result from a single cause. Most accidents involve multiple, interrelated causal factors. Accidents can occur whenever significant deficiencies, oversights, errors, omissions, or unanticipated changes are present. Any one of these conditions can be a precursor for an accident; the only uncertainties are when the accident will occur and how severe its consequences will be.

To conduct a complete accident investigation, the factors contributing to an accident, as well as the means to prevent accidents, must be clearly understood. Management prevents or mitigates accidents by identifying and implementing the appropriate controls and barriers. Controls help to prevent errors or failures that could result in an accident; barriers help to mitigate the consequences of potential errors or failures. Barriers to protect targets against loss can be **physical barriers,** such as machine guards and railings, or **management barriers,** such as work procedures, hazard analysis, requirements management, line management oversight, and communications. In a work environment, several barriers may be used in an effort to prevent accidents. Accidents occur when one or more barriers in a work system, including procedures, standards, and requirements intended to control the actions of workers, fail to perform as intended. The barriers may not exist, may not be adhered to, or simply may not be comprehensive enough to be effective. Personal performance and environmental factors may also reduce protection.

A certain level of risk is inherent in every activity. Accepting some level of risk is necessary, but to protect against unwanted loss (e.g., injury, property damage, production downtime), risks must be controlled, transferred, or eliminated. Understanding how to prevent or control accidents requires an understanding of the sequence of events leading to an accident in order to identify and implement countermeasures that contain risks within acceptable limits.

1.2 Human Factors Considerations

Human factors focus on people and their interaction with equipment, facilities, procedures, and environments in work and daily activities and how these considerations affect accidents. The human factors framework can be used by the investigator to:

- Identify the multiple, interrelated factors that may contribute to an accident

- Trace non-human causes back to potential human contributors.

These considerations should be assessed during the data collection process to ensure that they are considered as part of the overall analysis of an accident. Understanding human factors as they relate to accidents requires knowing how the human-machine interface operates in the workplace, the capabilities people bring to a task, and how the primary elements of the work setting affect human performance.

In most accidents, human performance is likely to be a significant causal factor. For example, an accident may be caused by a worker failing to follow safety procedures when operating equipment. In another situation, an accident may occur as a result of an equipment malfunction, which upon further investigation is found to result from a poorly constructed control device. In the first case, human error on the part of the equipment operator is a causal factor in the accident. In the latter case, human error on the part of the equipment designer is a causal factor in the accident. In both cases, human performance is an important causal factor. An investigation of both accidents would involve examining human activities, the equipment or machine, and the environment.

Human factors analysis starts by looking at the immediate context of human-machine performance. It then addresses how human capabilities, equipment considerations, and the environment can affect human-machine performance. The human factors framework consists of five key areas that should be addressed in any accident investigation:

- Human-machine interface
- Human capabilities
- Equipment/design considerations
- Physical work environment
- Organizational work environment.

1.2.1 Human-Machine Interface

In every accident, there is a human consideration, or a human-made object, or both. Generally, any accident can be attributed to a human activity or response. Figure 1-1 shows the relationship among humans and machines. This relationship provides a human-machine "activity model" that can be used to examine the immediate work activity and to examine potential causal factors of the accident.

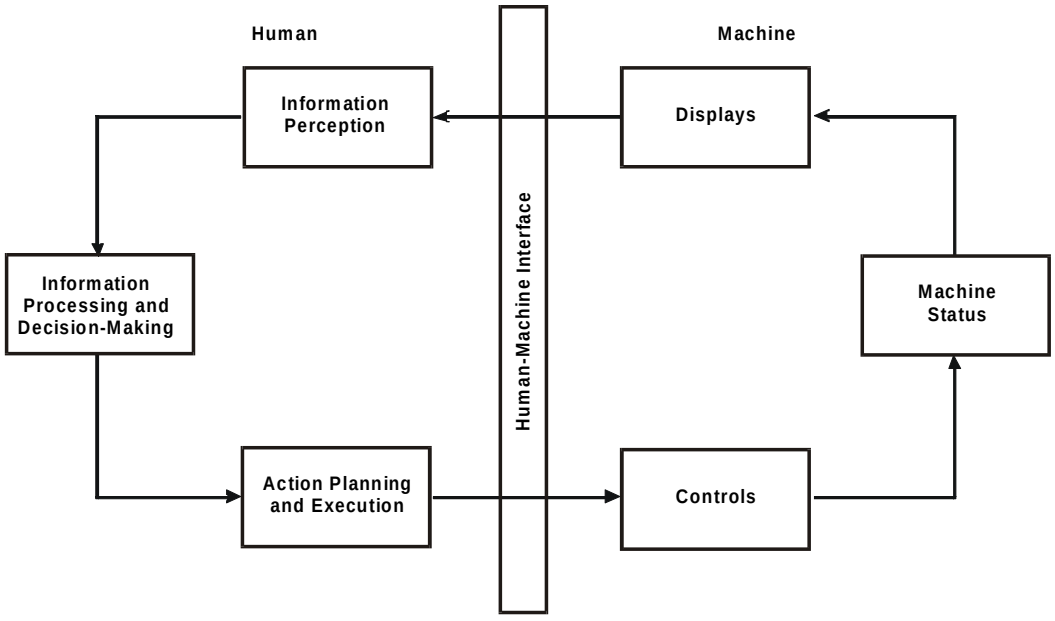

Figure 1-1. Human-machine "activity model."

Before examining factors that may contribute to accidents, it is important to understand the process people use to perform a task or activity. As shown in Figure 1-1, humans perform the following activities to complete a task:

- ***Information perception:*** Perceiving information means that the human has detected some type of signal; this may be visual, auditory, or tactile. For example, operators perceive information from annunciator panels. The activity of monitoring displays and perceiving information serves as a trigger to an action.

- ***Information processing and decision-making:*** This activity involves processing the information to determine its meaning and formulating an appropriate response. For example, operators must continually process the meaning of the information provided by machine displays and determine the appropriate action. Often, determining the appropriate action requires effective sharing of information and collective decision-making in order to formulate the most appropriate action.

- ***Action planning and execution:*** When a decision is made, the human then plans and executes the course of action. In the case of operators, the action might need to be coordinated among many operators. The action is executed by manipulating controls that initiate a change in the status of the machine. The machine, in turn, responds by providing feedback via displays indicating the new status of the plant.

1.2.2 Human Capabilities

Determining whether worker capabilities match work requirements is another human factors consideration. For example, military and commercial aircraft pilots are selected, in part, for their quick response time, problem-solving abilities, and visual acuity. Persons in this occupation who lack high levels of these capabilities have a greater propensity to cause accidents.

Table 1-1 lists human capabilities that contribute to the actions described in the "activity model." These are only a sample of capabilities that contribute to effective performance. Many other capabilities can affect performance, depending on specific task requirements:

- ***Experience, knowledge, and training:*** For any task or work activity, human performance is generally enhanced if the person has previous experience in performing the task, has knowledge of the input, and understands the meaning of various indicators and the implications of various actions. This knowledge and experience can be gained through formal training, education, and on-the-job training.

- ***Physical aptitude, fitness, and behavior:*** A worker's capability to perform effectively may be reduced by: (a) recent injuries or surgery or temporary physical limitations; (b) seasonal allergies or other temporary disorders; (c) changes in visual capacity (e.g., decreased visual acuity due to aging, color vision, and night adaptation) or changes in work that demand greater visual abilities; (d) hearing loss due to noise exposure; and (e) physical and neurological effects due, for example, to exposure to toxic materials.

- ***Stress:*** Workers may experience stress because of work-related or personal events. Sources of stress may stem from: (a) drug use—which can impair motor and cognitive functions—including taking prescription or over-the-counter medications to alleviate a condition or injury (e.g., taking antihistamines for allergies); (b) alcohol consumption, which can reduce sensory perception resulting in loss of physical coordination;

Table 1-1. Human capabilities contribute to work performance.

Work Activity	Human Capability	Specific Examples
Information Perception	Perpetual Processes	Vision Hearing Pain
Information Processing and Decision-Making	Cognitive Processes	Short-Term Memory Long-Term Memory Problem Solving
Action Planning and Execution	Motor Processes	Repetitive Movements Tracking Movements Manual Dexterity Muscular Strength Reaction Time

and (c) smoking, which can cause muscular deterioration and weakness among other things.

- ***Fatigue:*** A worker may become fatigued due to disruptions in sleep patterns resulting from social, familial, or work factors such as an excessive workload for an extended period.

- ***Work or shift changes:*** Changes in working hours (from day to evening) can alter a worker's effectiveness until he/she has adjusted to the change in schedule.

1.2.3 Equipment/ Design Considerations

Equipment can also contribute to an accident in two main ways. One way is for an equipment malfunction to directly cause the accident. A second way is for the equipment to contribute to a human error that then causes the accident. Even if equipment malfunction rather than human error appears to be the direct cause of an accident, it is important to trace the equipment malfunction back to potential sources of human error.

There are two main sources of human error: design flaws and improper maintenance. When an accident involves some type of equipment, it is useful to examine the equipment to determine whether the design is compatible with human capabilities and consistent with commonly accepted operating practices and norms. Equipment design features that can impact human-machine interaction are shown in Table 1-2. Accident investigations involving equipment should also include a review of the equipment's technical manuals to ensure that operation and maintenance are congruent with design specifications.

1.2.4 Physical Work Environment

Environmental factors can influence human-machine performance and thereby contribute to an accident. The physical work environment is the setting in which the accident occurred.

Many physical work environment requirements are specified in Occupational Safety and Health Administration (OSHA) regulations. Environmental factors that may influence the effective performance of both humans and equipment include:

Table 1-2. Equipment design can affect human performance.

Features	Interaction Characteristics
Large Equipment	■ Equipment to carry or house humans should be designed with specified size, stature, and sitting height limitations. ■ A proper field of view should be provided.
Control Replacement and Operations	■ Control knobs and dials should be positioned so that an operator can easily reach and operate them. ■ Controls should be placed in an arrangement that logically reflects the normal sequence of operations. ■ Control operation should be compatible with widely accepted standards or norms (e.g., knobs turn clockwise to increase power and counterclockwise to decrease power).
Visual Displays	■ Information presented in visual displays should be easy to perceive, process, and interpret. ■ Coded information should be compatible with widely accepted standards or norms (e.g., color-coded indicators, such as red for danger, yellow for caution).
Audio Indicators	■ Audio alarms should be easily interpreted and distinguishable from other audio indicators. ■ Audio alarms should be compatible with widely accepted standards or norms, so that high frequency and rates indicate urgency.

- ***Illumination:*** The level of lighting must be sufficient for workers to have a good view of their work environment, the equipment, and the materials they are working with.

- ***Noise:*** High levels of noise can distract workers from concentrating on the task they are performing. In addition, high levels of extraneous noise can interfere with audio indicators that workers rely on to signal actions or activities.

- ***Vibration and motion:*** High levels of vibration and motion can interfere with human task performance, especially tasks that require fine motor movement. Vibration can also interfere with equipment performance, causing unexpected performance decrements in equipment that is normally considered highly reliable.

- ***Thermal conditions:*** Worker performance is influenced by temperature extremes, which can often influence worker concentration (information processing and decision-making). Extreme temperatures may also affect human control responses by requiring additional clothing or gear for protection. In addition, equipment may have limited operating conditions under extreme temperatures. Therefore, it is important to identify the limits of equipment and machines under extreme temperatures.

- ***Altitude and depth:*** Humans can experience physical functioning problems when performing at high altitudes and extreme depths; in general, humans also experience cognitive functioning decrements under both these conditions.

Humans and equipment are limited in their capacity to perform effectively under extreme or unusual environmental conditions. When investigating an accident, it is important to characterize the environmental conditions at the time of the accident and the potential human or machine performance decrements that could result.

1.2.5 Organizational Work Environment

Organizational factors can contribute to accidents. Effective safety management systems are critical to establish a work environment in which safe operations are assured.

Experience in DOE facilities and in other industries in which safe operations are required has enabled DOE to identify the characteristics of organizations that are necessary to prevent accidents. These characteristics are defined in DOE Policy 450.4, *Safety Management System Policy*, and include:

- Line management is directly responsible for the protection of the public, workers, and the environment. Direct responsibility means that senior managers set clear policies that are implemented throughout all levels of the organization and are clearly communicated and understood. Managers create a safety culture by emphasizing safety in each management decision. Workers are empowered to raise issues, design safe work processes, and to stop work or refuse unsafe work assignments.

- Lines of authority and responsibility for ensuring safety at all organizational levels must be clearly defined. Managers and workers at all levels understand that they are responsible for assuring the safety of any work activities within their span of control. They translate and communicate safety goals to their subordinates. Managers and workers are held accountable for safety performance through a variety of means, such as safety performance evaluation in annual performance appraisals, and establishing meaningful consequences for safety successes and failures.

- Competence is commensurate with job responsibilities. All personnel in the organization have the experience, knowledge, skills, and abilities to perform their technical work and to perform it safely. Competence to perform work safely means that managers and workers are aware of the hazards associated with the work activities for which they are responsible and of the hazard controls that are necessary to protect the public, workers, and the environment from harm. Training programs are strong and kept current.

- Priorities must be balanced. Decisions regarding resource investments achieve a balance between mission and safety goals. Schedule pressures are not allowed to compromise safety in work activities. Safety programs and initiatives are not eroded by budget cuts or staff reductions.

- Safety standards and requirements are implemented. Managers and workers ensure that all safety standards and requirements are met when work is performed. Changes to standards and requirements lead to changes in safety management policies and procedures. Changes in mission, functions, and work activities are analyzed to detect any new hazards. Required hazard controls are identified and implemented.

- Hazard controls are tailored to the work being performed. The scope and purpose of work activities are defined in advance. Hazards are identified,

analyzed, categorized, and then controlled. Workers' knowledge of any hazards is used in planning for the job, and their experience in performing the work is captured and institutionalized in procedures and training programs.

- Operations are authorized. Work activities are planned and performed in accordance with the work plan. The scope, purpose, and staffing requirements of work activities are defined in advance. Work is authorized only when the work plan has been reviewed and accepted, and work is then performed within the controls. Hazard controls are implemented and workers are informed of the work to be performed and the hazard controls required.

In addition, safe and efficient organizations use operational experience to improve their performance. Safety performance is evaluated and the results are used to enhance operations. Systems are created to gather safety performance information from systematic measurements, from external and self-assessments, and from analyses of local incidents and near-misses. Any deficiencies in safety management are immediately corrected. Lessons learned at other facilities and in other industries are examined for applicability to the local work environment.

Comparing the organizational work environment in which the accident occurred to these critical organizational characteristics is likely to provide important information for understanding the accident.

KEY POINTS TO REMEMBER

Accidents are unplanned and unintentional events that result in harm or loss to personnel, property, production, or anything that has some value. Barriers (physical and management) should exist to prevent accidents or mitigate their consequences. Accidents occur when one or more barriers in a work system fail to perform or do not exist.

Human factors are important in assessing the causes of accidents. Two basic principles are important in assessing the role of human factors in an accident:

- Nearly every accident has more than one cause
- Human error can be identified as a causal factor in nearly every accident.

The major human attributes that affect work performance are:

- Experience, knowledge, and training
- Physical aptitude, fitness, and behavior
- Stress
- Fatigue
- Work or shift changes.

In conducting the investigation, it is helpful to consider how the following factors contributed to the accident.

- ***Human-machine interface:*** The immediate activity involving the human and the machine/equipment that preceded and continued through the accidental event.
- ***Human capabilities:*** The capabilities of the worker or person directly involved in the accident.
- ***Equipment/design considerations:*** Equipment can contribute to accidents by either directly causing the accident or contributing to human errors that cause accidents. Even if equipment malfunction is the direct cause of the accident, equipment malfunctions can often be traced back to human error (poor design or maintenance).
- ***Physical work environment:*** The environmental conditions at the work site (extreme temperatures, poor lighting, high noise levels, or vibration) can impair human performance.
- ***Organizational work environment:*** Organizational factors such as line management responsibility for safety, personnel competence, safety prioritization, and hazard analysis and requirements, as well as other management system characteristics, directly impact safe operations.