6

Data Collection and Incident Analysis Methods

6.1. INTRODUCTION

The preceding chapters of this book have focused on how accidents due to human error can be prevented at source. These preventive measures include systematic design strategies, techniques to identify potential errors with serious consequences, and audits of performance-influencing factors in existing systems to specify opportunities for improvements. To complement these proactive strategies, it is important to have feedback systems in place so that lessons can be learnt effectively from minor incidents, near-misses and from major accident investigations. This chapter describes a range of techniques and systems to achieve these objectives.

To most plant managers, the term *data collection,* at least in the context of safety, refers to the collection of statistical data in areas such as lost-time accidents and other reportable injuries. Because such data are required by law, and because they are perceived to have a major impact on accident prevention via their motivational effects, considerable resources are expended every year to produce these data. They constitute the "bottom line" that will be used to justify the safety performance of the organization to the public, the regulators, and to its shareholders. Although the central importance of this aspect of data collection is acknowledged, this chapter will describe a much wider range of data collection activities that need to be carried out in order to maximize the effectiveness of error reduction programs in organizations.

Another publication produced by the Center for Chemical Process Safety, *Guidelines for Investigating Chemical Process Incidents* (CCPS, 1992d), is directed at achieving similar objectives but from a differing perspective and with differing emphasis. Both sources of information can be used in a complementary manner to improve the quality of data collection and incident analysis in the CPI.

This chapter is divided into the following sections:

Overview of Data Collection Systems (6.2)
This section provides an overall structure within which the different aspects of data collection and incident analysis methods can be integrated. The importance of effective data collection systems as part of the continuous improvement process in Total Quality Management.

Types of Data Collection System (6.3)
The major categories of data collection systems are described. These include:

- *Incident reporting systems,* designed to identify underlying and direct causes for larger numbers of incidents with relatively minor causes
- *Near-miss reporting systems*
- *Root cause analysis systems,* intended to provide in-depth evaluations of major incidents
- *Quantitative human reliability data collection systems* for generating human error probabilities for use in quantitative risk assessment.

Organizational and Cultural Aspects of Data Collection (6.4)
This section discusses the company culture that is necessary to support effective data collection and root cause analysis.

Types of Data Collected (6.5)
The types of data required for incident reporting and root cause analysis systems are specified. Data Collection practices in the CPI are described, and a detailed specification of the types of information needed for causal analyses is provided.

Methods of Data Collection, Storage, and Retrieval (6.6)
This section provides information on the personnel who should be involved in data collection and the design of reporting forms. The specific data needs for major incident analyses are discussed, together with the storage and retrieval of data for the purpose of analysis.

Data Interpretation (6.7)
The need for a causal model to guide data collection is emphasized. This makes the connection between the nature of the error and the PIFs in the situation.

Root Cause Analysis Techniques (6.8)
A range of techniques is described for analyzing the structure of incidents and the causal factors involved.

Implementing and Monitoring the Effectiveness of Error Reduction Measures (6.9)
The specification and implementation of error reduction measures arises directly from the identification of causes. The data collection system needs to be able to evaluate the effectiveness of such measures.

Setting up a Data Collection System in a Chemical Plant (6.10)
This section sets out a step-by-step procedure for setting up a data collection system, including the important issues of gaining workforce acceptance and management support.

6.2. AN OVERVIEW OF DATA COLLECTION SYSTEMS

The function of this section is to provide an overall framework within which to describe the important aspects of data collection systems in the CPI. As mentioned in the introduction, the emphasis in this chapter will be on methods for identifying the causes of errors that have led to accidents or significant near misses. This information is used to prevent reoccurrence of similar accidents, and to identify the underlying causes that may give rise to new types of accidents in the future. Data collection thus has a proactive accident prevention function, even though it is retrospective in the sense that it is usually carried out after an accident or near miss has already occurred.

In an overall proactive error management system, data collection provides feedback information on the effectiveness of specific interventions that have been made to reduce error potential. However, in most plants in the CPI such proactive error management strategies will not be in existence. Therefore, the setting up of a data collection system which addresses human error causes will often be the first stage of an error management program. The advantages of this are twofold. First, both company and regulatory requirements mean that some form of data collection system, even if it only fulfills the most basic of statutory requirements, will probably already be in existence. It is therefore possible to build upon this to develop a more comprehensive system designed to address the underlying causes of incidents. Setting up a data collection system as the first stage of an error management program provides insights into where the major problems lie, and hence allows subsequent proactive interventions to be targeted at the areas where the most rapid benefits will be obtained.

Figure 6.1 provides an overview of the structure of a data collection system. As with all aspects of human error management, the attitudes and beliefs held by the company and plant management to safety in general, and human factors in particular, will be critical in developing a successful data collection system. Management will influence the effectiveness of data collection systems in three ways. First, they control the resources required to set up and maintain the system. Second, management will be responsible for determining the culture that exists in the plant. As will be discussed in more detail in Section 6.5, if management encourages a culture which emphasizes blame and punishment for errors, then it is unlikely that a data collection system which is intended to address the underlying causes of incidents will ever be successful. Third, the attitudes of management will determine the "model" of

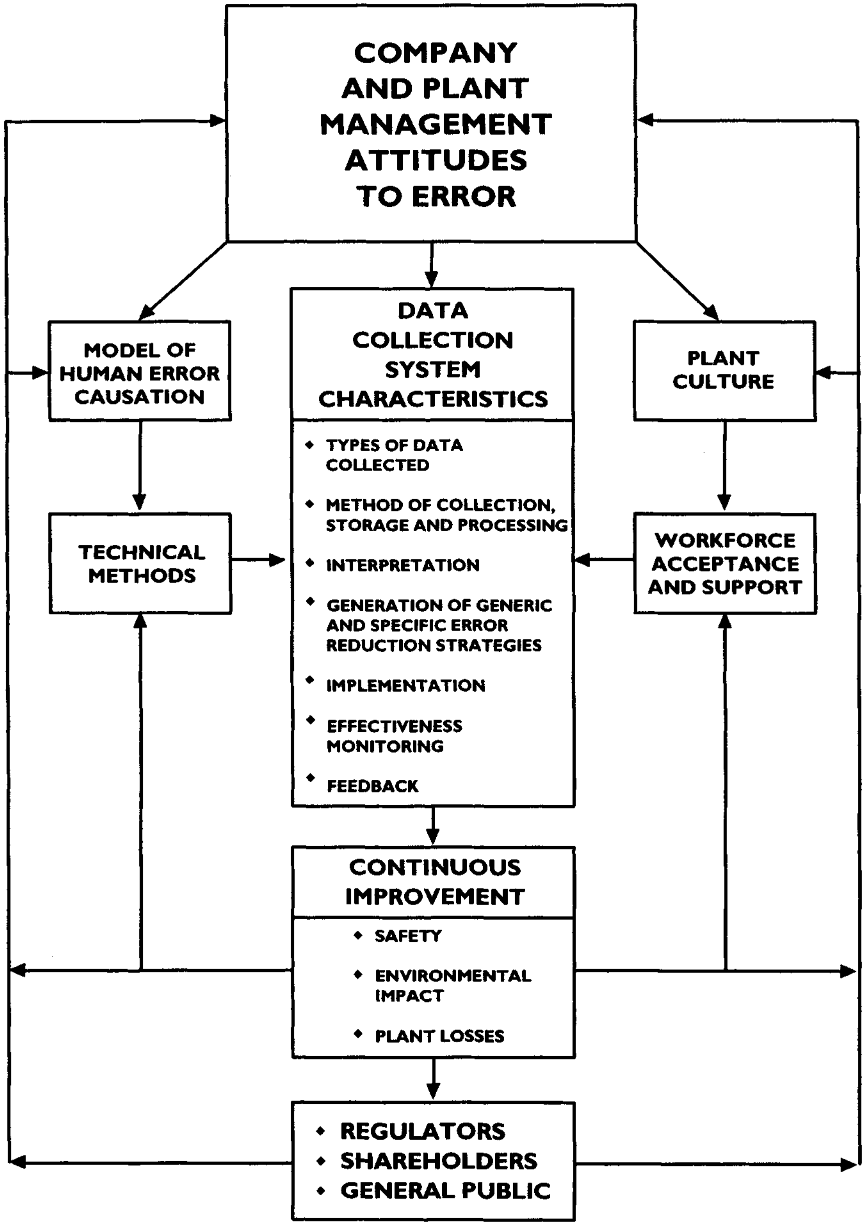

FIGURE 6.1. **Overall Structure of Data Collection System**

error causation that drives the data collection effort. Thus, the traditional view of human error which emphasizes individual rather than system causes of error (see Chapter 2) will lead to the use of data collection and analysis methods which focus on these factors. The use of the systems view will mean that there will be greater emphasis on the systemic causes of errors such as poor procedures, equipment design or training.

The model of human error held by management and the plant culture constitutes the environment in which the data collection system operates. Within this environment, all data collection systems need to address the topics listed in Figure 6.1. These topics, from the types of data collected, to the feedback systems that need to be in place, will be addressed in subsequent sections of this chapter.

Figure 6.1 emphasizes the fact that the outputs from data collection systems, particularly those that address safety and environmental issues, are of critical importance to an organization in that they are used as major indications of the acceptability of a company's operating practices by regulators, shareholders, and the general public. This criticality has both advantages and disadvantages. From the positive perspective, there is considerable pressure on a company to ensure that its policies produce low accident rates. On the negative side, there is equally strong pressure to produce data collection systems that present the operating record of a company in the best possible light. Unfortunately, these considerations can often work against the development of reporting systems that are designed to get at underlying causes of accidents.

Figure 6.1 also indicates that the output from data collection systems is a vital aspect of the Continuous Process Improvement cycle advocated in Total Quality Management. Feedback on the underlying causes of problems is necessary to ensure continuing support for error and accident reduction programs by senior management. Feedback also leads to changes in the model of error causation held by senior management and to changes in plant culture which can further enhance the effectiveness of data collection systems by gaining ownership and commitment from the workforce.

6.3. TYPES OF DATA COLLECTION SYSTEMS

Many data collection systems place the primary emphasis on the technical causes of accidents. There is usually a very detailed description of the chemical process in which the accident occurred, together with an in-depth analysis of the technical failures that are seen as the major causes. The human or system failures that may have contributed to the accident are usually treated in a cursory manner. Technically oriented reporting systems are very common in the CPI, where engineers who may be unfamiliar with human factors principles will, not unnaturally, tend to focus on the technical causes of accidents unless provided with very clear guidelines or training to allow them to consider the human causes.

Where data collection systems do address human error, they are generally driven by the traditional safety engineering view and focus on the outcomes of errors, which are usually assumed to be due to basic human weaknesses such as inattention or lack of motivation and commitment. The outputs from traditional data collection systems may be both descriptive and statistical. Descriptive information about specific accidents may be used to emphasize the implications of frequently occurring and potentially dangerous behaviors such as entering confined spaces without carrying out checks to test for toxic gases or violating operating instructions. Generally, little attempt is made to identify any systemic causes of these behaviors. The statistical information is in the form of aggregated data such as lost time accidents. These data are often used on a comparative basis to indicate trends over time, or differences among groups of workers or organizations. Another application is to provide inputs to safety campaigns and other motivational approaches to safety improvement.

The systems which are the major focus of this chapter are described below. They emphasize the identification of underlying causes and the use of this information to specify error and accident reduction strategies.

6.3.1. Incident Reporting Systems (IRS)

The main function of an incident reporting system (IRS) is to identify recurring trends from large numbers of incidents with relatively minor outcomes, or from near misses. One of the important characteristics of an IRS is that the time and resources required to evaluate an incident and incorporate it into the database must be minimized. This means that the designers of an IRS have to carefully evaluate the benefits and costs of requiring more comprehensive information from each incident that is to be reported. A requirement for too much information will bring the system into disrepute, and too little information will mean that the results are too general to be of any real value.

Other important considerations in the design of an IRS are the data storage and analysis requirements. These need to be considered early in the design of the system if it is to be used to research and display trends effectively. For example, in addition to the answers to specific questions, the accident data analyst may wish to make use of free text descriptions of the circumstances of the accident. This implies that a text-based retrieval system will be required.

6.3.2. Near Miss Reporting Systems (NMRS)

The value of near miss reporting has been emphasized at a number of points in this book. Near misses represent an inexpensive way to learn lessons from operational experience, since they have the potential for providing as much information about the systemic causes of accidents as events with serious consequences. However, it is unusual to find an effective NMRS in the process industry. This is because the success of a NMRS depends critically on the voluntary reporting of events which would otherwise have gone unnoticed. This requires a culture which is highly supportive in terms of emphasizing the value of this type of information and minimizing the use of blame and punishment as a method of error control. Although such an approach is a fundamental aspect of modern quality assurance approaches such as Total Quality Management (TQM), it is still rare in many parts of the industry. Another factor is the need for a careful definition of exactly what constitutes a near-miss. Unless this is clearly specified, the system may be swamped with large numbers of reports which have little value in the context of establishing the underlying causes of accidents. Van der Schaaf et al. (1991) provide a comprehensive discussion of near-miss reporting systems and data collection issues in general.

6.3.3. Root Cause Analysis Systems (RCAS)

The term *root cause analysis system* is used to denote systems that are concerned with the detailed investigations of accidents with major consequences such as loss of life, or severe financial or environmental implications. These systems are characterized by the use of comprehensive, resource-intensive techniques designed to evaluate both the direct and indirect root causes. Although resource limitations are less important with RCAS, a clearly structured methodology is nevertheless needed in order to ensure that investigations are both comprehensive and consistent. The requirement for consistency is particularly important if the lessons learned from accident analyses are to be useful from a comparative basis and for evaluating trends in underlying patterns of causes over time. As with IRS, an investigation procedure based on a model of accident causation such as the systems approach (see Chapters 1 and 2) will provide a systematic framework to ensure that the right questions are asked during the investigation. Comprehensive methodologies have been developed to support RCAS, and these are explained in detail in Section 6.8.

6.3.4. Quantitative Human Reliability Data Collection Systems

There is considerable interest in developing a database on human error probabilities for use in chemical process quantitative risk assessment (CPQRA). Nevertheless, there have been very few attempts to develop such a database for the CPI compared, for example, with the nuclear industry. Some of the reasons for this are obvious. The nuclear industry is much more highly integrated than the CPI, with a much greater similarity of plant equipment and less direct competition among companies. This, at least in theory, makes it more feasible to develop shared databases of error probabilities for standardized human actions in response to specific emergency scenarios. Also, probabilistic safety analysis has been applied to a much greater extent in the nuclear industry via the regulatory process, and hence there has been a greater requirement over a long period of time for data and techniques to support these analyses. Although human reliability analyses have been performed (primarily in the offshore sector), these have mainly used extrapolated data from sources such as the THERP (Technique for Human Error Rate Prediction) database (see Chapter 5) which was largely developed in a nuclear context.

The requirements for the development of a CPI-specific quantitative human reliability data collection system are as follows:

- The users of quantitative human reliability data need to specify their needs for such data in the context of CPQRA, in terms of the types of human operations for which data are required, analytical data techniques to be used, etc..
- The PIFs that determine human reliability in these situations need to be defined.
- An industry-wide data collection effort needs to be organized that would use a common classification for human error data. This would allow a large number of errors in each category to be collected. This, together with information on the number of opportunities for errors, would allow probabilities to be estimated from the frequency of errors in each category.
- Methods for extrapolating these probabilities to specific situations, on the basis of differences among PIFs, would need to be developed (see Chapter 5).
- Where field data were unavailable, a program of experimental work (for example, based on the use of simulators for control room operations) could be implemented to generate appropriate generic data.

Although the steps outlined above would in theory be capable of generating a quantitative database, it seems unrealistic to expect the degree of cooperation that would be required across the industry to develop such a resource. A more likely possibility is that large multinationals will support the development of in-house databases, possibly using the same approach as advocated here.

6.3.5. Conclusions on Data Collection System Types

The discussion of alternative types of data collection systems serves to emphasize the fact that the design of such systems needs to have very clear objectives. Although a range of data collection systems have been described as if they were independent, in fact many systems will be combinations of these types. For example, root cause analysis systems will need to consider both the technical and human causes of major accidents. A comprehensive Incident Reporting and Investigation System would probably include near misses as well as actual incident reporting.

In subsequent sections the emphasis will be on the human factors aspects of these systems. In general, the design principles which will be set out will apply to both types of system. However, distinctions will be made where appropriate.

6.4. ORGANIZATIONAL AND CULTURAL ASPECTS OF DATA COLLECTION

The first area focuses on the cultural and organizational factors that will have a major influence on the effectiveness of a human error data collection system and how well the information derived from such a system is translated into successful error reduction strategies. Regardless of how effectively the technical issues are dealt with, the system will not be successful unless there is a culture in the organization which provides support for the data gathering process. No data collection system aimed at identifying human error causes of accidents will be workable without the active cooperation of the workforce.

6.4.1. Model of Accident Causation Held by the Organization

The type of data collected on human error and the ways in which these data are used for accident prevention will vary depending upon the model of error and accident causation held by the management of an organization. This model will also influence the culture in the plant and the willingness of personnel to participate in data collection activities. In Chapters 1 and 2 a number of alternative viewpoints or models of human error were described. These models will now be briefly reviewed and their implications for the treatment of human error in the process industry will be discussed.

6.4.1.1. The Traditional Safety Engineering (TSE) View

The traditional safety engineering view is the most commonly held of these models in the CPI (and most other industries). As discussed in Chapter 1, this view assumes that human error is primarily controllable by the individual, in that people can choose to behave safely or otherwise. Unsafe behavior is assumed to be due to carelessness, negligence, and to the deliberate breaking of operating rules and procedures designed to protect the individual and the system from known risks.

The responsibility of management from the TSE perspective is to provide a safe system of work to minimize the exposure of the individual and the process system to these risks. This is achieved by technical approaches such as barriers and interlocks, and through the provision of personal protective equipment. Management also has the responsibility to inform workers of these risks and to ensure that safe methods of work are adopted by providing appropriate training. Given that management carries out these functions adequately, the main strategy for maximizing safety from this perspective is to motivate the workforce so that they do not commit deliberately unsafe acts

6.4.1.2. Implications of the TSE View for Data Collection

The implications of this approach for the data collection philosophy will be as follows:

Causal Analysis

There will be comparatively little interest in the underlying causes of errors leading to accidents. This is because the TSE view assigns virtually all errors to unsafe acts that are preventable by the individual workers concerned. There is therefore little incentive to delve into other causes.

Prevention Strategies

Emphasis for prevention will be on changing individual behavior by symbolic or tangible rewards based on statistical evidence from the data collection system. "Hard" performance indicators such as lost time incidents will therefore be preferred to "softer" data such as near-miss reports. Accident prevention will also emphasize motivational campaigns designed to enhance the awareness of hazards and adherence to rules. If a severe accident occurs, it is likely that disciplinary sanctions will be applied.

Changes in Data Collection Strategies

The TSE model of causation that accidents are primarily due to individually controllable unsafe acts is unlikely to be modified over time. This is because very little evidence on the background and conditions which led up to an accident will be collected. The data collection strategy is therefore likely to remain static, since the data collected will, by definition, not contradict the underlying assumptions.

6.4.1.3. The System-Induced Error Approach

As described in Chapters 1 and 2 the system-induced error approach comprises the following elements:

Error Tendencies and Error-Inducing Environments

Human errors occur as a result of a combination of inherent human error tendencies, and error-inducing conditions. Errors then combine with unforgiving situations (lack of recovery and the presence of hazards) to produce an accident, as illustrated in Figure 6.2. The error-inducing conditions consist of two aspects. The first of these is the presence of factors such as poor procedures, inadequate training and time stress, which mean that the worker is unlikely to have the mental or physical resources available to meet the demands arising from the job. This mismatch creates a situation of high error potential. The other aspect of error-inducing conditions is the presence of specific triggering events such as unexpected fluctuations in demand, distractions, or other additional pressures

Multiple Causation
Accidents do not arise from a single cause but from a combination of conditions which may be human caused (active or latent failures), characteristics of the environment, or operating states of the plant (see Chapter 2).

Role of Latent Failures
The systems approach emphasizes the effects of organizational and managerial policies in creating the preconditions for errors described above. In addition to the direct effects of these policies, management is also responsible for determining the culture in the organization. This may, for example, influence the choices made among profitable but possibly risky ways of working and adherence to stated safety practices (see Chapter 2, Section 2.7).

Emphasis on the Modification of System Factors as a Major Error Reduction Strategy
This emphasis replaces the reliance on rewards and punishment as a means of error control which characterizes the TSE approach.

6.4.1.4. Implications of the System-Induced Error Approach for Data Collection

Causal Emphasis
There will be strong emphasis on the collection of data on possible causal factors that could have contributed to an accident. The specific data that are collected may be based on an error model such as that shown in Figure 6.2. However, this model will usually be modified depending upon the extent to which it fits the data collected over a period of time. The systems approach is therefore dynamic rather than static.

Organizational Perspective
Monitoring and detailed accident investigation systems will attempt to address the organizational and work culture factors that influence accident causation. This will encourage the investigation of the global effects of organizational policies in creating the precursors for accidents.

Use of Near-Miss Data
The Systems Approach emphasizes the value of near-misses as a rich source of information about accident causes. This is based on the concept of accidents

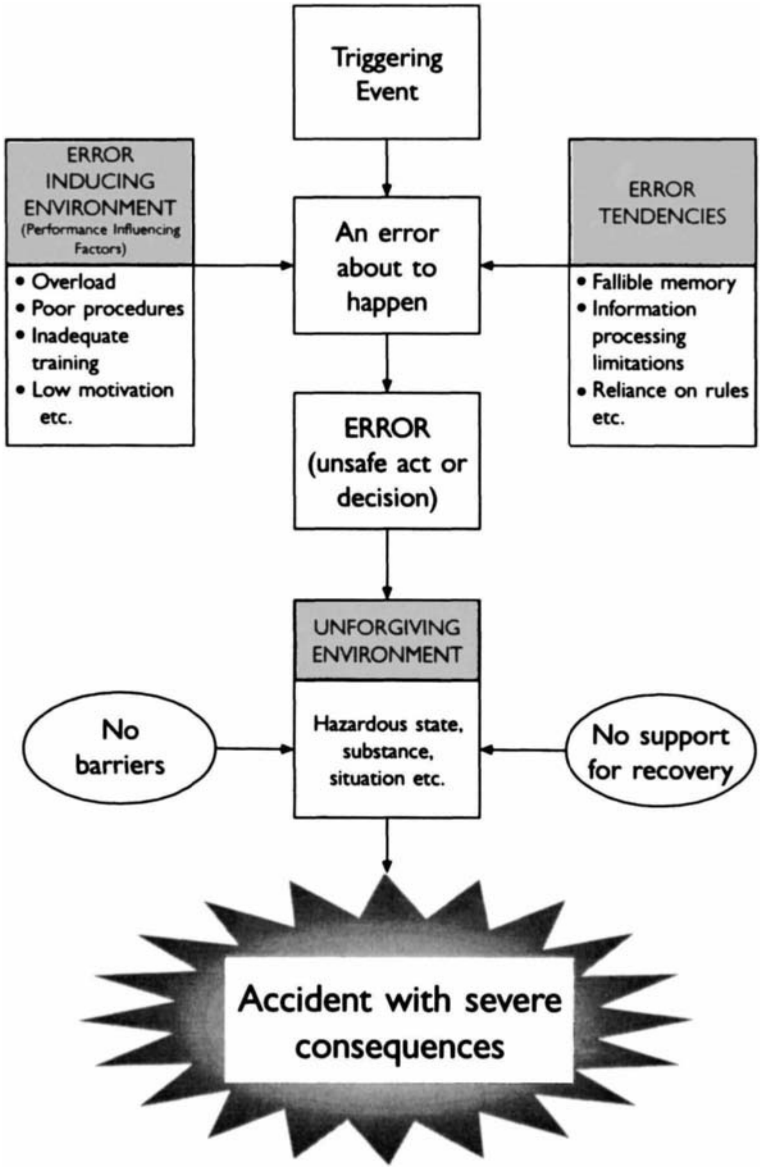

FIGURE 6.2. **Accident Causation Model (From Chapter 2).**

as resulting from combinations of conditions such as a poor safety culture, inadequate training and poor procedures, together with a triggering event (see Figure 6.2). Near-miss reporting systems are therefore important to provide early warnings of these conditions before they lead to an accident.

Changes in Data Collection Strategies

Because of the emphasis on modeling accident causation, data collection systems based on the system-induced error approach are likely to modify their data collection strategies over time. Thus, as evidence accumulates that the existing causal categories are inadequate to account for the accidents and near misses that are reported, the data collection philosophy will be modified, and a new accident causation model developed. This, in turn, will be modified on the basis of subsequent evidence.

6.4.2. Cultural Aspects of Data Collection System Design

A company's culture can make or break even a well-designed data collection system. Essential requirements are minimal use of blame, freedom from fear of reprisals, and feedback which indicates that the information being generated is being used to make changes that will be beneficial to everybody. All three factors are vital for the success of a data collection system and are all, to a certain extent, under the control of management. To illustrate the effect of the absence of such factors, here is an extract from the report into the *Challenger* space shuttle disaster:

> ***Accidental Damage Reporting.*** While not specifically related to the *Challenger* accident, a serious problem was identified during interviews of technicians who work on the Orbiter. It had been their understanding at one time that employees would not be disciplined for accidental damage done to the Orbiter, providing the damage was fully reported when it occurred. It was their opinion that this forgiveness policy was no longer being followed by the Shuttle Processing Contractor. They cited examples of employees being punished after acknowledging they had accidentally caused damage. The technicians said that accidental damage is not consistently reported when it occurs, because of lack of confidence in management's forgiveness policy and technicians' consequent fear of losing their jobs. This situation has obvious severe implications if left uncorrected. (Report of the Presidential Commission on the Space Shuttle Challenger Accident, 1986, page 194).

Such examples illustrate the fundamental need to provide guarantees of anonymity and freedom from sanctions in any data collection system which relies on voluntary reporting. Such guarantees will not be forthcoming in organizations which hold a traditional view of accident causation.

Feedback is a critical aspect of voluntary reporting data collection systems. If personnel are to continue providing information they must see the results of their input, ideally in the form of implemented error control strategies. A method for providing feedback which aims to share any insights gained from a scheme will indicate to all personnel that the system has a useful purpose. One example of an incident reporting scheme with an effective feedback channel is the Institute of Nuclear Power Operations human performance evaluation system (HPES) (Bishop and Larhette, 1988). Here a newsletter called "Lifted Leads" is used to publicize anonymous reports of incidents together with any error control strategies implemented. The newsletter is circulated to all plants participating in the HPES program. In addition, humorous posters have been developed from certain reported incidents and these are also circulated freely.

As well as a nonpunitive culture with guarantees of anonymity and feedback there are three other necessary conditions for an effective data collection system. First, it is important that the future users of the system are involved in its design and implementation. Second it is essential that those who use the system should eventually own it. Such owners should be willing to view the information in any database as a neutral commodity for all to use. Finally, it is crucial that effective training is given. This includes training in communication skills and analysis methods for the investigators of incidents, and an awareness training program for all levels of staff who will be involved.

6.5. TYPES OF DATA COLLECTED

The types of data collected in both incident reporting and root cause analysis systems are obviously very closely linked to the particular model of accident causation which exists in the company. If, for example, the emphasis is on the underlying causes of errors, this will mean that information necessary to distinguish among different underlying causes will need to be collected (see 6.5.2.1 below). In the case of root cause analysis systems, more detailed data on indirect causes such as organizational policies will need be required (see 6.5.2.3). In both systems, information on key performance influencing factors (PIFs) will be needed. With incident reporting systems, because of the limited time available for investigations only a critical subset of the PIFs will be recorded. In the case of root cause analysis systems, a much more comprehensive PIF evaluation tool similar to the human factor assessment methodology (HFAM) tool described in Chapter 2 can be employed.

In the first of the following subsections, the data collection approaches adopted in most CPI incident reporting systems will be described. The fact that these systems provide little support for systematically gathering data on underlying causes will provide an introduction to the later sections which emphasize causal analysis techniques.

6.5.1. Data Collection Practices in the Chemical Processing Industry

The following types of information are collected in most CPI safety-related data collection systems:

Severity of the Incident

This typically considers injuries to personnel and damage to plant and equipment. In a few more highly developed systems, information on **potential** consequences is also collected. Normally the severity of the incident consequences (or in some cases its potential consequences) will determine the resources that are put into its investigation.

General Descriptive Data

This typically includes the following areas:

- Brief description of the incident in terms of when and where it occurred, etc.
- Details of any injury
- A more complete narrative description of the incident

Work Control Aspects

This describes any work permits associated with the work relevant to the incident.

Technical Information

This is mainly applicable to equipment and other technical failures. It also considers areas such as loss of containment, environmental impact, fires, and explosions.

Causal Aspects

In the majority of reporting systems this area receives relatively little attention. The user of the reporting form is asked to provide a single evaluation of the cause, with little guidance being available to assist in the process. In a few large companies, the causal aspect is addressed more comprehensively. In one multinational, for example, the form asks the investigator to evaluate both immediate and underlying causes. Guidance is also provided by providing pre-specified categories in these areas. However, information on systemic causes such as incorrect policies or discrepancies between policies and practices is rarely included in these categories.

Remedial Actions

The section on remedial actions is usually directed at preventing a recurrence of the specific accident which is the focus of the investigation. It often consists of a sequence of recommended actions linked to the causal categories identified in the previous section. Again, remedial actions directed at more fundamental systemic causes are rarely addressed.

Management of the Investigation

In some cases, the final part of the form provides a checklist which tracks the management permissions and endorsements associated with the conduct of the investigation.

Conclusions on CPI Data Collection Systems

The overall conclusion that can be drawn from a survey of CPI data collection systems is that the better systems do attempt to address the causes of human error. However, because of the lack of knowledge about the factors which influence errors, the causal information that is collected may not be very useful in developing remedial strategies. General information in areas such as severity, work control aspects and the technical details of the incident will be required in all data collection systems. However, in almost all cases a structured process for causal analysis is lacking. Some of the requirements for causal analysis are set out in the following sections.

6.5.2. Causal Data Collection

All causal data collection processes require information in the following areas:

- What happened
- How it happened
- Why it happened

As discussed earlier, most data collection systems in the CPI place considerable emphasis on the "what," but provide little support for the "how" or "why." Causal analysis methods can be broadly divided into techniques which emphasize the structure of an accident and those which focus on causes. Structural techniques provide information on the "what" and "how," and the causal techniques enable the "why" to be investigated.

The areas that need to be addressed in causal analysis can be specified by considering the contributing causal factors as a series of layers. Accident investigation can be likened to the process of peeling an onion. The onion model of accident investigation is shown in Figure 6.3. The onion analogy is not quite correct in the sense that accident investigation (peeling the onion) usually proceeds from the middle outward. However, it does provide a useful metaphor for the accident causation process.

Typically, the first phase of a comprehensive accident investigation process will involve describing the way in which the hardware, the chemical process, individual operators and operating teams are involved in the accident process. This is the domain of the structural analysis techniques and the technical analysis of the chemical process which gave rise to the accident. Analyses of human error will primarily address the interactions between hardware systems and individuals or operating teams (the first two layers

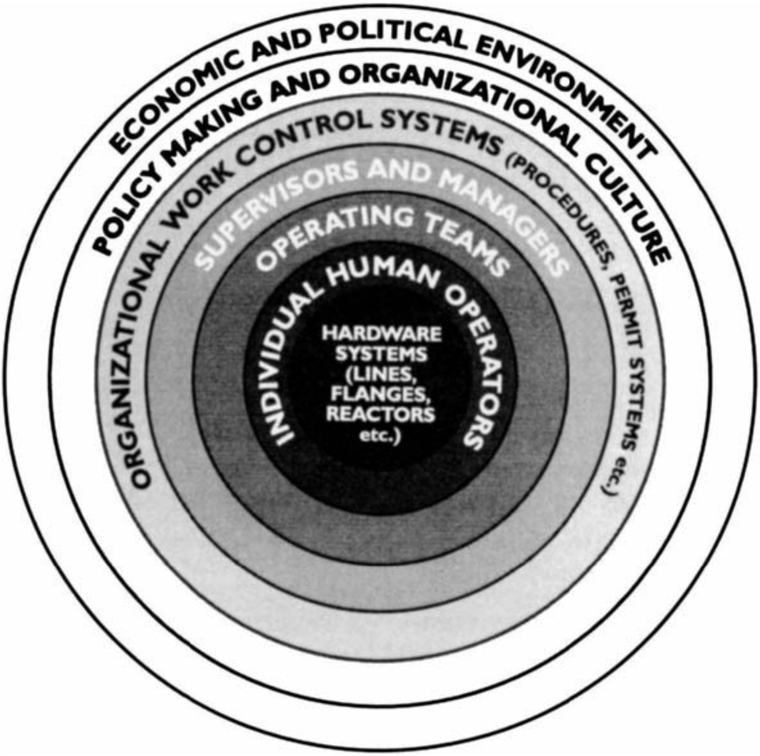

FIGURE 6.3. **Onion Model of Accident Causation.**

starting from the center of the onion). The next level of analysis is likely to address interactions between the plant operator level and the supervisory and management levels (the second and third layers). It is at this interface where communication failures or violations due to incorrect interpretations of policy are likely to occur.

The next layer contains the work control systems such as operating instructions and permit systems. Although such systems are generally executed at the operational level, the extent to which they are adhered to is strongly influenced by how they are regarded by managers and supervisors. These are in turn influenced by the general policies and safety culture that exists in the plant and the organization. Finally, these policies will be influenced by the economic and political climate in which the company operates.

6.5.2.1. Data on Event Sequence and Structure

The amount of time available for the recording of data in incident reporting systems is limited, and hence the information collected is usually confined to short descriptions of the event, its actual and potential consequences and immediate and indirect causal factors such as those discussed in the preceding section.

However, in the case of a root cause analysis system, a much more comprehensive evaluation of the structure of the accident is required. This is necessary to unravel the often complex chain of events and contributing causes that led to the accident occurring. A number of techniques are available to describe complex accidents. Some of these, such as STEP (Sequential Timed Event Plotting) involve the use of charting methods to track the ways in which process and human events combine to give rise to accidents. CCPS (1992d) describes many of these techniques. A case study involving a hydrocarbon leak is used to illustrate the STEP technique in Chapter 7 of this book. The STEP method and related techniques will be described in Section 6.8.3.

6.5.2.2. Data on Human Error Tendencies

In order to establish the psychological causes of errors, data from accidents or near misses which are relevant to the human error tendencies discussed in Chapter 2 should be collected. These include information on the following:

- Distractions or competing activities (demand/resource mismatch). Experience or familiarity with the task (useful for identifying slips and mistakes)
- Ambiguous or difficult-to-detect information which is necessary to perform the task (possible failure to acquire critical information, see the flow diagram in Chapter 2, Appendix 2B)
- Aspects of the job requiring excessive demands on memory (task steps omitted or misordered)
- Sequences of operations in different tasks which are very similar, apart from the critical steps which could have critical consequences when performed in the wrong situation (strong habit intrusions)
- Evidence that a misdiagnosis was involved (distinction between slips and mistakes)
- Identification of possible violations

6.5.2.3. Data on Performance Influencing Factors

Another group of factors is relevant to establishing **situational causes.** Some of these will overlap with the previous group, but will include some of the PIFs considered in Chapter 3, such as:

- Quality of procedures
- Adequacy of human-machine interface or task design
- Time available
- Time of day and fatigue effects
- Environmental conditions

It should be emphasized that it is usually necessary to develop the data collection specification on an incremental basis and to utilize feedback from the system to modify the initial model relating causal factors to error types. This dynamic approach provides the best answer to the problem that no predefined error model will be applicable to every situation.

This is in contrast to many data collection systems, in which considerable efforts are expended in developing a "definitive" data collection philosophy. However, once the system is in place, there is little attempt to modify this on the basis of operational feedback.

The fact that the model connecting error types with their causes may change as a result of gaining further experience with the data collection system means that the information gathered on the PIFs in a situation may also change. For example, if incident data indicates the neglect of safety procedures because of production pressures, then the questions relating to this area will need to be extended.

In the case of root cause analysis systems, more comprehensive evaluations of PIFs will normally be carried out as part of a full-scale human factors audit. This could make use of the types of comprehensive PIF evaluation methods described in Chapter 2 (see Section 2.7.7 and Figure 2.12).

6.5.2.4. Data on Organizational Causes

The two categories of data described above relate to immediate causes of error. However, the question of how these factors came to be as they are, involves a consideration of the effects of organizational, and management and cultural issues.

An evaluation system currently being developed for process industry operations (the HFAM technique described in Chapter 2, Section 2.7) addresses organizational and work culture factors such as:

- Possible conflicts between well-established work practices and those specified in safety policy
- Policies for procedures and training
- Communications and feedback systems
- Clarity of roles and responsibilities
- Reward system
- Perceived credibility of organizational commitment to safety policy

Information on these factors is critical in establishing more general influences that impact indirectly but powerfully on the probability of an accident occurrence.

6.6. METHODS OF DATA COLLECTION, STORAGE, AND RETRIEVAL

6.6.1. Personnel Involved in Data Collection

The personnel responsible for the collection and analysis of incident data vary in different organizations. One common practice is to assign the responsibility to an investigation team which includes the first line supervisor, a safety specialist and a plant worker or staff representative. Depending on the severity of an incident, other management or corporate level investigation teams may become involved.

In some organizations, designated individuals have specific responsibility for eliciting detailed information from operational staff on the immediate and underlying causes of incidents. An example is the Human Performance Evaluation System (HPES) developed for the nuclear industry, which is described in Bishop and Larhette (1988). These coordinators provide a certain level of guaranteed immunity from sanctions which allows individuals to be frank about the contributory causes that they may not be willing to discuss in an open forum. As discussed earlier, the need for this approach is a consequence of the fact that in many organizations a blame culture exists which is likely to inhibit a free flow of information about the causes of accidents.

6.6.2. Design of Reporting Forms

The information gathered from the interviews conducted as part of the human error data collection process is entered on paper forms. In order to facilitate the ease and accuracy of data collection, the forms should be designed using human factors guidelines for written materials (e.g., Wright, 1987; Wright and Barnard, 1975).

In a data collection system that was developed in the transportation sector, the application of these principles generated the following format for a data collection form:

- Each part contains distinct sections in which related questions are grouped.
- Two types of questions predominate: simple yes/no options and multiple choice questions. For each the user is asked to tick the appropriate box.
- An indication of who is to fill in the questions is made by the use of symbols.
- For certain questions the user is provided with a "maybe" option, that is, yes/maybe/no. Much valuable information will be lost without this option.

- Questions are made as short as possible and each question only asks about one aspect of the incident.
- Notes are provided to assist the user. These are compiled as a separate document and brief cross-references are given in each part of the form.

6.6.3. Data Collection Procedures for Major Incident Analysis

For a major incident investigation using a comprehensive root cause analysis system, teams will be formed to acquire information relevant to determine the structure and analyze the causes in depth. In addition to evaluations of the immediate causes, underlying causes are likely to be evaluated by investigations in areas such as safety and quality management. Both paper- and computer-based systems will be used to acquire and record information for subsequent detailed analyses.

The systems for handling the large amounts of data generated by major incident investigations need to be in place before they are called upon to be used under pressure. It is well known that the data necessary for establishing causes becomes more difficult to obtain the longer the period that elapses after the incident. There is a strong case for ensuring that any emergency response system has a built-in facility for acquiring important status information while an incident is still in progress. The robustness of data collection systems that are required to operate under conditions of high stress needs to be tested regularly, by means of frequent exercises and simulations.

6.6.4. Storage and Retrieval of Information

With the advent of notebook computers, it is feasible to use interactive software to structure the data collection process at the workplace. There are many potential advantages with this approach.

- The capability to modify the sequence of questions interactively means that the information elicitation process can home-in on particularly useful areas for establishing causes.
- The data collected on site can easily be downloaded to a central data base, thus ensuring that any significant trends in error causation could be rapidly identified and remedied.
- Individuals involved in accidents where error was a possible factor can have access to a computer which will allow them to provide information on a confidential basis. Although portable computers have not yet made a significant impact on incident data collection, there is clearly considerable potential in this area.

The databases that exist in most large companies for the accident data are usually oriented toward coded information. Each of the items on the form is keyed into a field and stored in a standard data base, where it can be interrogated to produce the familiar range of numerical and descriptive data such as bar charts and graphs. The disadvantage of the standard format for human error data is that there is usually insufficient space to allow free text descriptions of accidents to be entered in full. These descriptions are a rich source of data for the human error analyst. It is therefore recommended that the collection and storage systems for human error data provide these facilities. In order to search these free text descriptions, a database system which is capable of storing variable length records and performing text searches is desirable. Examples of database and text retrieval software which can be used for this purpose are Pagefinder® by Caere Systems (USA) and Idealist by Blackwell Software (Europe).

6.7. DATA INTERPRETATION

There is considerable overlap between the processes of data collection and interpretation as discussed in earlier sections of this chapter. The nature of the data collected will be strongly influenced by the assumed relationship between the observable characteristics of errors and their underlying causes. Similarly, the interpretation process will also be driven by the causal model.

The overall process of data interpretation and the development of suitable remedial strategies once a set of causes has been identified, is set out in Figure 6.4. The two-stage process of confirming the initial causal hypothesis is recommended to overcome the tendency to jump to a premature conclusion and to interpret all subsequent information on the basis of this conclusion.

In the following sections, a number of methodologies for accident analysis will be presented. These focus primarily on the sequence and structure of an accident and the external causal factors involved. These methods provide valuable information for the interpretation process and the development of remedial measures. Because most of these techniques include a procedure for delineating the structure of an incident, and are therefore likely to be time consuming, they will usually be applied in the root cause analysis of incidents with severe consequences.

In the case of incident reporting systems, the data interpretation process will be more concerned with identifying trends in recurrent causes for a large number of incidents than a detailed investigation of specific situations. These analyses could identify the repeated occurrence of failures arising, for example, from inadequate procedures, work systems, training, and equipment design. In addition, classifying errors using some of the concepts from Chapter 2, such as slips, mistakes, and violations, can be useful. Essentially, the interpretation process should be based upon an explicit causal model, which should specify the types of data to be collected by the incident reporting system. This causal

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