8. *Rank Risks in Priority Order.* A risk-ranking system should be adopted so that priorities can be established. Since the risk assessment exercise is subjective, the risk-ranking system would also be subjective. Prioritizing risks gives management the knowledge needed on the potentials risks have for harm or damage so that intelligent resource allocations can be made for their elimination or reduction.

9. *Develop Remediation Proposals.* When the results of the risk assessment indicate that risk elimination or reduction measures are to be taken, alternate proposals for the design and operational changes necessary to achieve an acceptable risk level would be recommended. In their order of effectiveness, the actions as shown in Chapter 12, "Hierarchy of Controls: The Safety Decision Hierarchy," would be the basis on which remedial proposals are made. For each proposal, the remediation cost would be determined and an estimate of its effectiveness in achieving risk reduction given. Risk elimination or reduction methods would then be selected and implemented.

10. *Follow Up on Actions Taken.* Although a hazard analysis and a risk assessment result from applying the steps in the preceding outline, good management requires that the remaining steps in "The Safety Decision Hierarchy" be taken: Measure the effectiveness of the actions taken; determine that the residual risk is acceptable or unacceptable; and start over if the risk is unacceptable. Follow-up activity would determine that the:

- Problem was resolved, only partially resolved, or not resolved.
- Actions taken did or did not create new hazards.

If new hazards are introduced, the risk is to be re-evaluated and other countermeasures proposed.

RESIDUAL RISK

Residual risk is defined as the risk remaining after preventive measures have been taken. No matter how effective the preventive actions, there will always be residual risk if an activity continues. Attaining zero risk is not possible. If the residual risk is not acceptable, the action outline set forth in the foregoing hazard analysis and risk assessment process would be applied again.

RISK ASSESSMENT MATRICES

A risk assessment matrix provides a method to categorize combinations of probability and severity, thus establishing risk levels. A matrix helps in communicating with decision makers and influencing their decisions on risks and the actions to be taken to ameliorate them. Also, risk assessment matrices can be used to compare and prioritize risks, and to effectively allocate mitigation resources.

Definitions of the levels of probability and severity used in risk assessment matrices vary greatly. This reflects the differences in the perceptions of risk that people have. Since a risk assessment matrix is a management decision tool, management personnel at the appropriate level must agree on the definitions of the terms to be used. In so doing, management establishes the levels of risk that require reduction and those that are acceptable.

To emphasize: Safety professionals must understand that the definitions of terms for incident probability and severity and for risk levels vary greatly. Thus, they should tailor a risk assessment matrix to suit the hazards and risks and the management tolerance for risk with which they deal. Examples of the definitions used for incident probability and severity are presented here, as well as definitions for risk categories and risk assessment matrices. They are intended to provide safety professionals with a broad base of information from which choices can be made in developing the matrix considered appropriate for their clients' needs.

The breadth of possibilities in drafting a risk assessment matrix is extensive. Matrices have been developed that display only one or a combination of several of the following injury or damage classes: employees, members of the public, facilities, equipment, product, operation downtime, and the environment.

For this primer, two-dimensional risk assessment matrices are discussed. They are displays of variations for two categories of terms: the *severity* of harm or damage that could result from a hazards-related incident or exposure, and the *probability* that the incident or exposure could occur. They also show the *risk levels* that derive from the various combinations of severity and probability. A review of three- and four-dimensional risk assessment systems is given in Chapter 10, "Three- and Four-Dimensional Numerical Risk-Scoring Systems."

DESCRIPTIONS: PROBABILITY AND SEVERITY

Examples follow in Tables 1–5 to show variations in the terms and their descriptions as used in a variety of applied risk assessment processes for the probability of occurrence and severity of consequence. There is no one right method in selecting probability and severity categories and their descriptions.

TABLE 1 Example A: Probability Descriptions

Descriptive Word	Probability Descriptions
Frequent	Likely to occur repeatedly.
Probable	Likely to occur several times.
Occasional	Likely to occur sometime.
Remote	Not likely to occur.
Improbable	So unlikely that one can assume occurrence will not be experienced.

TABLE 2 Example B: Probability Descriptions

Descriptive Word	Probability Descriptions
Frequent	Occurs often, continuously experienced.
Probable	Occurs several times.
Occasional	Occurs sporadically, occurs sometimes.
Seldom	Remote chance of occurrence; unlikely but could occur sometime.
Unlikely	Can assume incident will not occur.

TABLE 3 Example C: Probability Descriptions

Descriptive Word	Probability Descriptions
Frequent	Could occur annually.
Likely	Could occur once in 2 years.
Possible	Not more than once in 5 years.
Rare	Not more than once in 10 years.
Unlikely	Not more than once in 20 years.

TABLE 4 Exhibit A: Severity Descriptions for Multiple Harm and Damage Categories

Catastrophic	Death or permanent total disability, system loss, major property damage and business downtime.
Critical	Permanent, partial, or temporary disability in excess of 3 months, major system damage, significant property damage and downtime.
Marginal	Minor injury, lost workday accident, minor system damage, minor property damage, and little downtime.
Negligible	First aid or minor medical treatment, minor system impairment.

TABLE 5 Exhibit B: Severity Descriptions for Multiple Harm and Damage Categories

Catastrophic	One or more fatalities, total system loss, chemical release with lasting environmental or public health impact.
Critical	Disabling injury or illness, major property damage and business downtime, chemical release with temporary environmental or public health impact.
Marginal	Medical treatment or restricted work, minor subsystem loss or damage, chemical release triggering external reporting requirements.
Negligible	First aid only, nonserious equipment or facility damage, chemical release requiring only routine cleanup without reporting.

Table 6 shows how the severity of harm or damage categories can be related to several types of adverse consequences and levels of harm or damage.

TABLE 6 Relating Severity Categories to Kinds and Extent of Harm or Damage

Category: Descriptive Word	People: Employees, Public	Facilities, Product or Equipment Loss	Operations Down Time	Environmental Damage
Catastrophic	Fatality	Exceeds $3 M	Exceeds 6 Mos	Major event, requires more than 2 years for full recovery
Critical	Disabling injury or illness	500K to $3 M	4 Wks to 6 Mos	Significant event, requires 1 to 2 years for full recovery
Marginal	Minor injury or illness	50K to 500K	2 days to 4 wks	Recovery time is less than 1 year
Negligible	Injury requires only first aid	Less than 50K	Less than 2 days	Minor damage, easily repaired, little time for recovery

EXAMPLES OF RISK ASSESSMENT MATRICES

Five examples of risk assessment matrices follow. First, an adaptation is shown in Table 7 of the "Mishap risk categories and mishap acceptance levels" as in the working draft of MIL-STD-882E, the *Department of Defense Standard Practice For System Safety*. A comment in Appendix A of 882E is pertinent here: "A mishap assessment matrix allows classification by mishap severity and mishap probability and assists in managing the decision-making to achieve the necessary risk elimination or reduction to an acceptable level."

MIL-STD-882, first issued in 1969, is the grandfather of risk assessment matrices. All of the over 30 variations of matrices I have collected include the basics that came out of 882. They include event probability categories, severity of harm or damage ranges, and risk gradings.

This Second exhibit of a risk assessment matrix–Table 8—is a composite of matrices that include numerical values for probability and severity levels that are transposed into risk gradings. It is presented here for people who prefer to deal with numbers rather than qualitative indicators.

Take care, though–arriving at the values shown in this matrix is a qualitative exercise. And that is the case for all risk scoring systems that are not based on hard probability and severity numbers, which rarely are available

TABLE 7 Risk Assessment Matrix

Occurrence Probability	Severity of Consequence			
	Catastrophic	Critical	Marginal	Negligible
Frequent	High	High	Serious	Medium
Probable	High	High	Serious	Medium
Occasional	High	Serious	Medium	Low
Remote	Serious	Medium	Medium	Low
Improbable	Medium	Medium	Medium	Low

TABLE 8 Risk Assessment Matrix: Numerical Gradings

Severity Levels and Values	Occurrence Probabilities and Values				
	Frequent (5)	Likely (4)	Occasional (3)	Seldom (2)	Unlikely (1)
Catastrophic (5)	25	20	15	10	5
Critical (4)	20	16	12	8	4
Marginal (3)	15	12	9	6	3
Negligible (2)	10	8	6	4	2
Insignificant (1)	5	4	3	2	1

Very high risk: 15 or greater. High risk: 9–14. Moderate risk: 4–8. Low risk: under 4.

The risk-scoring system in Table 9 appears in the American National Standard, Safety Requirements for Packaging Machinery and Packaging-Related Converting Machinery ANSI/PMMI B155.1-2006. It is shown here for two reasons. It is an indication of the validity of the concepts on which the risk assessment matrices in MIL-STD-882 are based and why so many developers of matrices use 882 as a reference. Although Table 9 is almost identical to the 882 version shown in Table 7, a slight difference exists: There is one variation for a risk severity category. As was said previously, people who develop risk assessment matrices work their own risk perceptions into them. And that is great. Table 10 shows a risk assessment matrix that combines types of severity categories and uses alpha risk gradings.

TABLE 9 Risk-Scoring System: ANSI/PMMI B155.1-2006

Probability Level	Severity Category			
	Catastrophic	Critical	Marginal	Negligible
Frequent	High	High	Serious	Medium
Probable	High	High	Serious	Medium
Occasional	High	Serious	Medium	Low
Remote	Serious	Medium	Medium	Low
Improbable	Medium	Medium	Low	Low

TABLE 10 Risk Assessment Matrix: Alpha Risk Level Indicators

Severity Categories	Probability That Something Will Go Wrong				
	Frequent (likely to occur immediately or soon: often)	Likely (quite likely to occur in time)	Occasional (may occur in time)	Seldom (not likely to occur, but possible)	Unlikely (unlikely to occur)
Catastrophic: death, multiple injuries, severe property or environmental damage	E	E	H	H	M
Critical: serious injuries, significant property or environmental damage	E	H	H	M	L
Marginal: may cause minor injuries, financial loss, negative publicity	H	M	M	L	L
Negligible: minimum threat to persons or damage to property	M	L	L	L	L

E: Extremely High Risk. H: High Risk. M: Moderate Risk. L: Low Risk.

Annex E in Z10 provides informative data concerning the standard's Assessment and Prioritization section. Table 11 is close to the risk assessment matrix shown in Annex E.

This author provided input on Annex E to the two people who drafted it: Jim Howe, vice chairman of the Z10 Accredited Standards Committee, representing the United Auto Workers International Union; and Kendall Crawford, who operates Kendall C. Crawford Associates and represented the American Petroleum Institute as a Z10 committee member. Howe and Crawford made revisions in what I provided so that its definitions and language were compatible with those of the standard itself. Crandall combined the separate risk assessment matrix and management decision levels I sent him into one matrix. Although the exhibit in Table 11 is close to the example given in Annex E, it is not an exact duplicate.

Crawford believed that my risk level categories were one step too high in two places on the bottom line of the matrix and he changed the matrix accordingly. He did not disagree with the other risk levels I suggested. What is the significance of this? Risk assessment is more art than science. Since establishing risk levels is largely a matter of judgment, people will come to different conclusions in a given

situation. Nevertheless, the ultimate goal needs to be kept in mind: satisfaction that the residual risk which exists after risk reduction measures are implemented is acceptable.

TABLE 11 Risk Assessment Matrix in Z10

Example of a Risk Assessment Matrix

Likelihood of OCCURRENCE or EXPOSURE For selected Unit of Time or Activity	Severity of Injury or Illness Consequence and Remedial Action				
	CATASTROPHIC Death or permanent total disability	Dis	CRITICAL bility in excess of 3 months	MARGINAL Minor injury, lost workday accident	NEGLIGIBLE First Aid or Minor Medical Treatment
Frequent Likely to Occur Repeatedly	HIGH Operation not permissible		HIGH Operation not permissible	SERIOUS High Priority Remedial action	MEDIUM Take Remedial action at appropriate time
Probable Likely to occur several times	HIGH Operation not permissible		HIGH Operation not permissible	SERIOUS High Priority Remedial action	MEDIUM Take Remedial action at appropriate time
Occasional Likely to occur sometime	HIGH Operation not permissible	H	SERIOUS Priority Remedial action	MEDIUM Take Remedial action at appropriate time	LOW Risk Acceptable: Remedial Action Discretionary
Remote Not likely to occur	SERIOUS High Priority Remedial action	Ta	MEDIUM Remedial action at ppropriate time	MEDIUM Take Remedial action at appropriate time	LOW Risk Acceptable: Remedial Action Discretionary
Improbable Very unlikely – may assume exposure will not happen	MEDIUM Take Remedial action at appropriate time		LOW Risk Acceptable: Remedial Action Discretionary	LOW Risk Acceptable: Remedial Action Discretionary	LOW Risk Acceptable: Remedial Action Discretionary

There are no restrictions or rules with respect to the terms used to establish qualitative risk levels. But a matrix, as a minimum, should illustrate probability and severity categories and risk gradings. Tables 7–11 show a general acceptance of a group of terms for incident probability and severity, and for risk categories. However, I repeat: Safety professionals should draft matrices with which they are comfortable. Since risk assessment matrices are valuable communication tools, the terms used in them must be agreed on and the education time necessary to achieve an understanding of them must be allocated.

ON ACCEPTABLE RISK

In Chapter 6, "Achieving Acceptable Risk Levels: The Operational Goal," I wrote that as every element of Z10 is applied, the outcome would be the achievement of acceptable risk levels so that the risk of harm remains at a practicable minimum. I also said that the risk assessment matrices in this chapter and the discussion of risk categories here will help in determining acceptable and tolerable risk levels.

The concept of As Low as Reasonably Practicable (ALARP) was recognized as a valuable tool in determining acceptable risk levels. However, a word of caution was offered: On occasion, achieving risk levels as low as reasonably practicable will not be acceptable. Prior to presenting the following definition, I said that a workable and sound definition of acceptable risk must encompass hazards, risks, probability, severity, and economics:

> Acceptable risk is that risk for which the probability of a hazards-related incident or exposure occurring and the severity of harm or damage that may result are as low as reasonably practicable, and tolerable in the situation being considered.

Thus far, this chapter has dealt with hazards, risks, probability, and severity. In applying the ALARP concept, economics is brought into the decision making. ALARP may be defined as follows: ALARP is that level of risk which can be further lowered by an increment in resource expenditure that cannot be justified by the resulting decrement of risk.

MANAGEMENT DECISION LEVELS

Remedial action or acceptance levels must be applied to the risk categories to permit intelligent decision making on the part of management. The remedial action levels shown in Table 12 served as the basis from which Ken Crawford, Jim Howe and I agreed on the entries to be made in the example of a risk assessment matrix included in Z10. Table 12 provides a basis for review and discussion. Others who craft risk assessment matrices may have other ideas about acceptable risk levels and the management actions to be taken in a given risk situation. Going through the exercise of creating and reaching agreement on a risk assessment matrix and the management decision levels adds to a safety professional's effectiveness in communicating about risks and obtaining consideration of the remedial actions recommended.

TABLE 12 Management Decision Levels

Risk Category	Remedial Action or Acceptance
High	Operation not permissible.
Serious	Remedial action to have high priority.
Medium	Remedial action to be taken within appropriate time.
Low	Risk is acceptable; remedial action discretionary.

In the discussion that follows of acceptable and tolerable risk levels and the management actions to be taken to achieve them, the Example of a Risk Assessment Matrix given in Table 11 serves as the foundation. Keep in mind that:

- An acceptable risk level must be tolerable in the situation being considered.

- Although economic co siderations are part of the decision making, the risk level is to be as low as reasonably practicable and acceptable.
- Extra special considera on should to be given to preventing incidents resulting in serious injuries and i lnesses, and fatalities.
- What follows is this au hor's opinion; others may have different views.

If the risk category for w rker injury or illness is High, the risk is unacceptable and the operation should be s opped immediately. If it is determined that the cost to reduce the risk to a tolerably l ower level is excessive in relation to the risk reduction benefit to be achieved, the o eration should cease in all but rare situations (e.g., society accepts the risks of d ep sea fishing, a high-hazard occupation).

If the risk category is Se ous, the risk is not acceptable and action should be undertaken on a high-priorit y basis, meaning very soon, to lower the risk to a tolerable level. While arran ements are made to reduce the risk, an extra heavy application of the lower level in the hierarchy of controls (warning systems, blocking off work areas, administ ative controls, personal protective equipment) is in order. If it is determined that the cost to reduce the risk to a tolerably lower level is excessive in relation to th risk reduction benefit to be achieved, the operation should cease in all but rare s tuations.

When the risk category i Medium, even though the probability ratings for severe injury or illness are " mprobable" or "Remote," and the probability rating for minor injury is "Occasio al," and the probability ratings for negligible injury are "Frequent" or "Probable." remedial action should be taken, in good time, to reduce the risk in accord w h good economics. This is the risk category where the lower levels in the hiera chy of controls, if more extensively and effectively applied, may be sufficient to achieve acceptable and tolerable risk levels.

When the risk category is Low, the risk is considered acceptable. Nevertheless, there will be times when it i good business management and employee relations if attention is given to Low risks, if they are perceived to be more serious than they actually are. Remember, an employee's perception is his or her reality.

Some of the risk assessm nt matrices shown in this chapter combine elements pertaining to personal injury with the financial impact of an incident represented by the amount of property dama e, business downtime, and time to recover from an environmental incident. Safet professionals who have made such combinations in their risk assessment matrice insist that they receive better management response to their proposals for risk re uction if they tie the severity of injury to avoiding operational property damage downtime, business interruption, and environmental damage. That has been this a thor's experience.

DESCRIPTIONS OF HAZA RDS ANALYSIS AND RISK ASSESSMENT TECHNIQUES

Over the past 40 years, a lar e and unwieldy number of hazard analysis and risk assessment techniques have b en developed. For example, Pat Clemens gives brief

descriptions of 25 techniques in "A Compendium of Hazard Identification and Evaluation Techniques for System Safety Applications." In the *System Safety Analysis Handbook*, 101 methods are described. Brief descriptions will be given here of purposely selected hazard analysis techniques. If a safety professional understands all of them and is capable of bringing them to bear in resolving hazards and risk situations, he or she will be exceptionally well qualified to meet the risk assessment requirements in Z10.

As a practical matter, having knowledge of three risk assessment concepts will be sufficient to address most occupational safety and health risk situations: Preliminary Hazard Analysis, the What-If Checklist Analysis Methods, and Failure Mode and Effects and Analysis. It is important to understand that each of these techniques complements, rather than supplants, the others. Selecting the technique or a combination of techniques to be used to analyze a hazardous situation requires good judgment based on knowledge and experience. Qualitative rather than quantitative judgments will prevail. For all but complex risks, qualitative judgments will be sufficient.

Sound quantitative data on incident probabilities are seldom available. My associates skilled in system safety, a field in which quantitative risk assessments are routine, are not overly pleased when I say that most quantitative risk assessments are really qualitative risk assessments because so many judgments have to be made in the process to decide on the probability levels to be selected.

PRELIMINARY HAZARD ANALYSIS: HAZARD ANALYSIS AND RISK ASSESSMENT

The original use of the preliminary hazards analysis (PHA) technique was to identify and evaluate hazards in the early stages of the design process. However, in actual practice the technique has attained much broader use. The principles on which preliminary hazards analyses are based are used not only in the initial design process, but also in assessing the risks of existing products or operations.

For example, a European standard adopted by the International Organization for Standardization (ISO) requires that risk assessments be made for all machinery to go into a workplace within the European Community. That standard is ISO 12100-1, Safety of Machinery—Basic Concepts, General Principles for Design; Part 1, Basic Terminology, Methodology. The risk assessment process is outlined in ISO 14121, Safety of Machinery—Principles for Risk Assessments. These risk assessment requirements have been met in some companies by applying an adaptation of the PHA technique.

In reality, the PHA technique needs a new name, reflecting its broader usage. At A-P-T Research, Inc., the process is called Hazard Analysis and Risk Assessment, a designation they say is coming into greater usage since it is more descriptive of its purpose. (Also, take note of the following to avoid confusion: in the *OSHA Rule for Process Safety Management of Highly Hazardous Chemicals* and the EPA's *Risk Management Program for Chemical Accidental Release Prevention*, PHA stands for Process Hazard Analysis.)