

Chapter 19

Barrier Analysis

19.1 INTRODUCTION

Barrier analysis (BA) is an analysis technique for identifying hazards specifically associated with hazardous energy sources. BA provides a tool to evaluate the unwanted flow of (hazardous) energy to targets (personnel or equipment) through the evaluation of barriers preventing the hazardous energy flow.

Barrier analysis is a powerful and efficient system safety analysis tool for the discovery of hazards associated with energy sources. The sequentially structured procedures of BA produce consistent, logically reasoned, and less subjective judgments about hazards and controls than many other analysis methods available. However, BA is not comprehensive enough to serve as the sole hazard analysis of a system, as it may miss critical human errors or hardware failures not directly associated with energy sources.

19.2 BACKGROUND

Because the BA technique is unique with a limited scope of coverage, it does not completely fulfill the requirements of any one of the seven basic hazard analyses types described in Chapter 3. However, BA is often used to support the system design hazard analysis type (SD-HAT), detailed design hazard analysis type (DD-HAT), or preliminary design hazard analysis type (PD-HAT) analyses. The BA technique is also known as the energy trace and barrier analysis (ETBA), or the energy trace analysis.

Many system designs cannot eliminate energy sources from the system since they are a necessary part of the system. The purpose of BA is to evaluate these energy

sources and determine if potential hazards in the design have been adequately mitigated through the use of energy barriers.

Figure 19.1 illustrates the concept of a barrier providing separation between the energy source and the target. The simple concept of barrier analysis and its graphical portrayal of accident causation is a powerful analysis tool. It should be noted that unwanted energy source from a single source may attack multiple targets. Also, in some situations multiple barriers may be required for optimum safety.

The BA technique is implemented by identifying energy flow paths that may be hazardous and then identifying or developing the barriers that must be in place to prevent the energy flow from damaging equipment or injuring personnel. There are many different types and methods of energy barriers that can be applied in a system design, that is, physical barrier (barricade), procedural barrier, or a time barrier. Barriers serve as countermeasures to control probability and/or severity of personnel injury or system damage.

Barrier analysis is a generally applicable methodology for analysis of systems of all types. It is used to ensure disciplined, consistent, and efficient procedures for the discovery of energy hazards in a system. It can also be used during accident investigations to help develop and understand damage scenarios. BA lends itself to overviews of energies in systems and guides the search for specific hazards or risks that require more detailed analysis.

Barrier analysis is capable of producing detailed analyses of hazards in new or existing systems. By meticulously and logically tracking energy flow paths sequentially, into, within, and out of a system, BA facilitates a thorough analysis for each specific energy type. A detailed understanding of energy sources in the system and their behaviors is necessary, as well as a good understanding of the system design and operation. The BA technique is uncomplicated and easily learned. Standard easily followed BA forms and instructions are provided in this chapter.

19.3 HISTORY

The BA method is based on a useful set of concepts introduced by William Haddon, Jr. [1]. These concepts have been adopted and improved upon by others until the technique has evolved into a useful safety analysis tool.

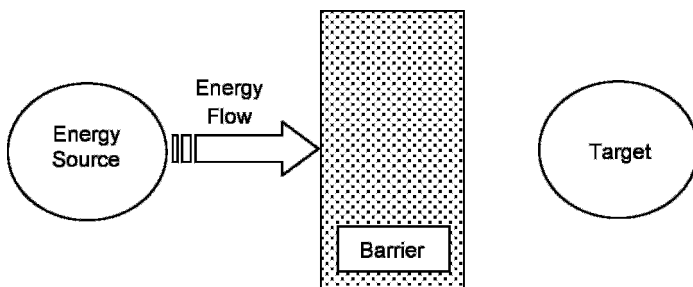


Figure 19.1 Barrier between energy source and target.

19.4 DEFINITIONS

In order to facilitate a better understanding of BA, some definitions for specific terms are in order. The following are basic BA-related terms:

Energy source Any material, mechanism, or process that contains potential energy that can be released. The concern is that the released energy may cause harm to a potential target.

Energy path Path of energy flow from source to target.

Energy barrier Any design or administrative method that prevents a hazardous energy source from reaching a potential target in sufficient magnitude to cause damage or injury. Barriers separate the target from the source by various means involving time or space. Barriers can take many forms, such as physical barriers, distance barriers, timing barriers, procedural barriers, and the like.

19.5 THEORY

The BA technique is based on the theory that when hazardous energy sources exist within a system they pose a hazardous threat to certain targets. Placing barriers between the energy source and the target can mitigate the threat to targets. This concept is illustrated in Figure 19.2, which also shows some example types of energy sources, barriers, and threats.

Barrier analysis involves the meticulous tracing of energy flows through the system. BA is based on the premise that a mishap is produced by unwanted energy exchanges associated with energy flows through barriers into exposed targets. The BA process begins with the identification of energy sources within the system design. Diagrams are then generated tracing the energy flow from its source to its potential target. The diagram should show barriers that are in place to prevent

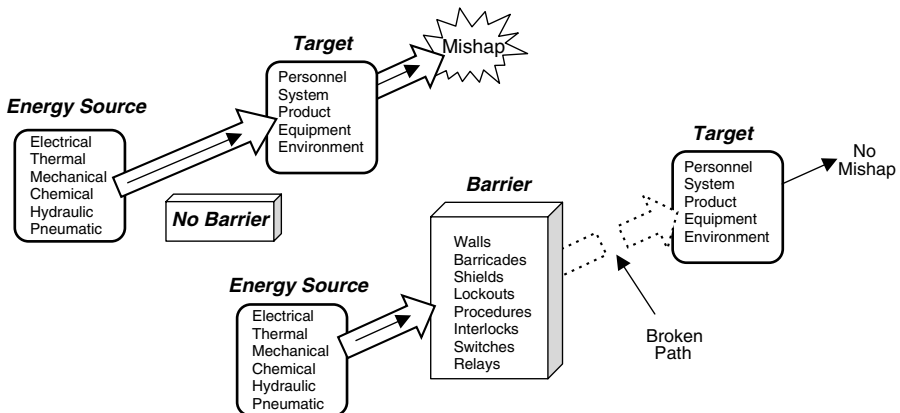


Figure 19.2 Barrier analysis concept.

damage or injury. If no barriers are in place, then safety design requirements must be generated to establish and implement effective barriers.

19.6 METHODOLOGY

Figure 19.3 shows an overview of the basic BA process and summarizes the important relationships involved.

Table 19.1 lists and describes the basic steps of the BA process and summarizes the important relationships involved. Remember that a worksheet is utilized during this analysis process.

19.6.1 Example Checklist of Energy Sources

Table 19.2 contains an example of an energy checklist. If the system design contains any energy sources in this list, then a specific energy has been identified for BA.

19.6.2 Considerations

Figure 19.4 summarizes generic components of BA: energy sources, barriers, and targets. These lists are starting points for a BA. Each component of BA must be well understood and evaluated in the system context.

After an energy source has been identified, there are a series of questions that can be answered that assist in identifying hazardous designs. Table 19.3 contains a list of some of the typical questions that must be answered by the BA.

The BA process verifies the adequacy of engineered or administrative barriers. In this context, engineered safety features are considered *hard* barriers while administrative controls such as procedures, warning signs, and supervisory checks are *soft* barriers. Because hard barriers are more difficult to bypass than soft barriers, the former is preferred. However, soft barriers may be all that can be used in some situations; therefore, an array of complementary soft barriers are often used to better ensure energy containment. Barriers may be categorized by their function, location, and/or type. Figure 19.5 provides some examples.

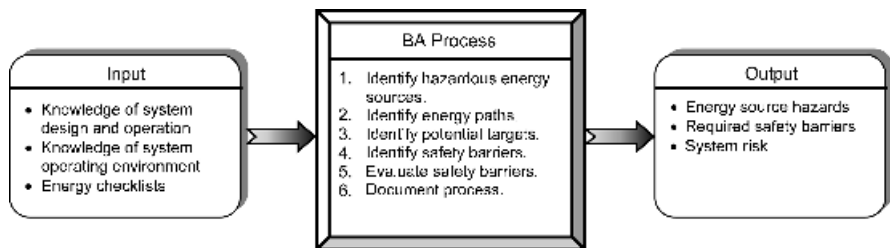


Figure 19.3 Barrier analysis overview.

TABLE 19.1 Barrier Analysis Process

Step	Task	Description
1	Identify energy sources.	Examine the system and identify all potentially hazardous energy sources. Include energy quantity and location when possible. Utilize energy source checklists. Examples include explosives, electromagnetic radiation, hazardous materials, electricity, etc.
2	Identify single energy paths.	Any potentially harmful energy flow path to the target (e.g., people, equipment, facilities, and the environment) likely to result in a mishap.
3	Identify multiple energy paths.	Multiple energy paths to the target where more than one energy path is required to reach the target and cause a mishap (e.g., both the mechanical and the electrical arm functions of a fuze).
4	Identify targets.	For each energy source, trace its travel through the system, from beginning to end. Identify all potential targets that can be injured or damaged by the hazardous energy sources. Utilize diagrams.
5	Identify the target vulnerability.	The vulnerability of the target to the unwanted energy flow. For example, an inadvertent application of +28 VDC will have little effect on a human but will destroy a microprocessor.
6	Identify safety barriers.	Identify all barriers in the path of the energy source or identify barriers that should be present. Evaluate the impact of potential failure of barriers, the lack of barriers, and/or the effectiveness of existing barriers. For example, if the heat shields on the space shuttle fall off during reentry, then the shuttle and crew could be lost.
7	Evaluate system risk.	Identify the level of mishap risk presented to the target by the energy source, both with barriers and without barriers in the system design.
8	Recommend corrective action.	Determine if the barrier controls present are adequate and, if not, recommend barriers that should be added to reduce the mishap risk. Determine if the need for more detailed analysis by other techniques (e.g., FTA) to ensure that all hazard causal factors are identified and mitigated.
9	Track hazards.	Transfer identified hazards into the hazard tracking system (HTS).
10	Document BA.	Document the entire BA process on the worksheets. Update for new information as necessary.

TABLE 19.2 Energy Checklist (Sample)

Category	Energy Sources
Acoustical radiation	Equipment noise Ultrasonic cleaners Alarm devices and signal horns
Atmospheric	Wind velocity, density, direction Rain (warm, cold, freezing) Snow, hail, sleet Lightning, electrostatic Particulates, dusts, aerosols, powders Sunshine, solar Acid rain, vapor/gas clouds Air (warm, cold, freezing, inversion) Moisture, humidity

(continued)

TABLE 19.2 *Continued*

Category	Energy Sources
Chemical (acute and chronic sources)	Anesthetic, asphyxiant Corrosive/dissolving solvent/lubricating Decomposable, degradable Deposited materials/residues Detonable Oxidizing, combustible, pyrophoric Polymerizable Toxic, carcinogenic, embryo toxic Waste/contaminating (air, land, water) Water reactive
Corrosive	Chemicals, acids, caustics Decon solutions “Natural” chemicals (soil, air, water)
Electrical	Battery banks Diesel generators High lines Transformers Wiring Switch gear Buried wiring Cable runs Service outlets and fitting Pumps, motors, heaters Power tools and small equipment Magnetic fields AC or DC current flows Stored electrical energy/discharges Electromagnetic emissions/RF pulses Induced voltages/currents Control voltages/currents
Etiologic agents	Viral Parasitic Fungal Bacterial Biological toxins
EMR and particular radiations	Lasers, Masers, medical X-rays Radiography equipment and sources Welding equipment Electron beam Blacklight (e.g., Magniflux) Radioactive sources, contamination, waste, and scrap Storage areas, plug storage Skyshine, Bremstrahlung Activation products, neutrons
Explosive or pyrophoric	Caps, primer cord, explosives Electrical squibs Power metallurgy, dusts Hydrogen and other gases

(continued)

TABLE 19.2 *Continued*

Category	Energy Sources
	Nitrates, peroxides, perchlorates Carbides, superoxides Metal powders, plutonium, uranium Zirconium
Flammables	Enclosed flammable gases Chemicals, oils, solvents, grease Hydrogen (battery banks), gases Spray paint, solvent vats Coolants, rags, plastics, foam Packing materials
Kinetic—linear	Cars, trucks, railroads, carts Dollies, surfaces, obstructions Crane loads in motion, shears Presses, Pv blowdown Power-assisted driving tools Projectiles, missiles/aircraft in flight Rams, belts, moving parts Shears, presses Vehicle/equipment movement Springs, stressed members
Kinetic—rotational	Centrifuges, motors, pumps Flywheels, gears, fans Shop equipment (saws, grinders, drills, etc.) Cafeteria and laundry equipment Rotating machinery, gears, wheels Moving fan, propeller blades
Mass, gravity, height	Human effort Stairs, lifts, cranes Sling, hoists, elevators, jacks Bucket and ladder Lift truck, pits, excavations Vessels, canals, elevator doors Crane cabs, scaffolds, and ladders Trips and falls Falling/dropped objects Suspended objects
Noise/vibration	Noise Vibration
Nuclear	Vaults, temporary storage areas Casks, hot cells, reactor areas Criticality potential in process Laboratories, pilot plants Waste tanks and piping, basins, canals Sources and solutions, Skyshine Activation products, Bremstrahlung
Pressure—volume, <i>K</i> constant	Boilers, heated surge tanks Autoclaves Test loops and facilities

(continued)

TABLE 19.2 *Continued*

Category	Energy Sources
Terrestrial	Gas bottles, pressure vessels
	Coiled springs, stressed members
	Gas receivers
	Overpressure ruptures, explosions thermal cycling
	Vacuum growth cryogenic
	Liquid spill, flood, buoyancy
	Expanding fluids, fluid jets
	Uncoiling object
	Ventilating air movement
	Trenching, digging, earth moving
	Earthquake
	Floods, drowning
	Landslide, avalanche
	Subsidence
Compaction	
Thermal (except radiant)	Cave-ins
	Underground water flows
	Glacial
	Volcanic
	Convection, furnaces
	Heavy metal weld preheat
Thermal radiation	Gas heaters, lead melting pots
	Electrical wiring and equipment
	Exposed steam pipes and valves
	Steam exhausts
	Furnaces, boilers
	Steam lines
	Lab and pilot plant equipment
	Heaters
	Solar
	Radiant, burning, molten
Toxic pathogenic	Conductive
	Convective, turbulent evaporative, expansive
	Heat, cool
	Toxic chemicals, check MSDS (material safety data sheets)
	Exhaust gases
	Oxygen-deficient atmosphere
	Sand blasting, metal plating
	Decon and cleaning solutions
Bacteria, molds, fungi, and viruses	
Pesticides, herbicides, and insecticides	
Chemical wastes and residues	

Haddon [1] originated the concept that one or more barriers can control the harmful effects of energy transfer. Expanding on Haddon’s work, analysts have identified the following barrier mechanisms in order of precedence:

1. Eliminate the hazardous energy from the system (e.g., replace with alternative).

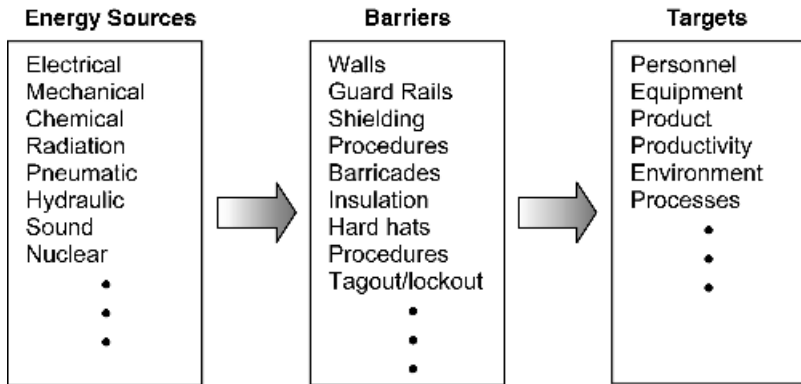


Figure 19.4 Generic BA components.

2. Reduce the amount of energy (e.g., voltages, fuel storage).
3. Prevent the release of energy (e.g., strength of containment of the energy).
4. Reduce the rate of release of energy (e.g., slow down burning rate, speed).
5. Prevent the buildup of released energy (e.g., pressure relief valve).
6. Control improper energy input (e.g., electrical energy through supercooled environment).
7. Separate in space or time the energy from the target (e.g., electric lines out of reach).
8. Interpose material barriers (e.g., insulation, guards, safety glasses).
9. Modify shock concentration surfaces (e.g., round off and make soft).
10. Strengthen the target to withstand the energy (e.g., earthquake-proof structures).
11. Limit the damage of energy release (e.g., prompt signals and action, sprinklers).
12. Train personnel to prevent energy release (e.g., warnings, procedures).

TABLE 19.3 BA Hazard Discovery Checklist

Energy Flow Changes	Changes in Barriers
1. Flow too much/too little/none at all	1. Barrier too strong/too weak
2. Flow too soon/too late/not at all	2. Barrier designed wrong
3. Flow too fast/too slowly	3. Barrier too soon/too late
4. Flow blocked/built up/release	4. Barrier degraded/failed completely/disturbed
5. Wrong form/wrong type input or flow	5. Barrier impedes flow/enhances flow
6. Cascading effects of release	6. Wrong barrier type selected
7. Flow conflicts with another energy flow	

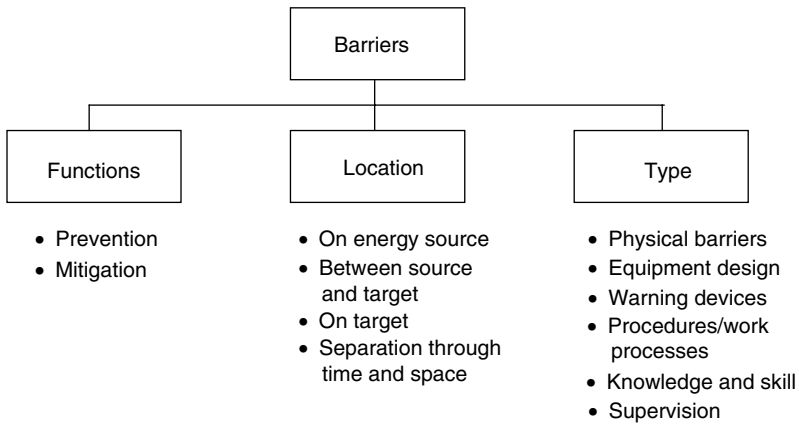


Figure 19.5 Example barrier categorizations.

These successive methods are called *energy barriers*. The energy barriers may be a physical obstruction or they may be a written or verbal procedure that is put into place as a means of separating the energy from the persons or objects in time or space. Substituting a less harmful energy may be a way to “limit the energy” or “prevent the buildup.” These 12 barrier mechanisms are expanded in Table 19.4.

19.7 WORKSHEET

The BA process is a detailed hazard analysis of energy sources and their potential effect on system personnel and/or equipment. It is desirable to perform the BA using a form or worksheet to provide analysis structure, consistency, and documentation. The specific format of the analysis worksheet is not critical. Typically, columnar-type worksheets are utilized to help maintain focus and structure in the analysis. As a minimum, the following basic information should be obtained from the analysis worksheet:

1. System energy sources that provide a threat
2. Targets within the system that are susceptible to damage or injury from the energy sources
3. Barriers in place that will control the energy hazard
4. Barriers that are recommended to control the energy hazard
5. System risk for the energy–barrier hazard

The recommended BA worksheet is shown in Figure 19.6. This particular BA worksheet utilizes a columnar-type format. Other worksheet formats may exist because different organizations often tailor their analysis worksheet to fit their

TABLE 19.4 Barrier Mechanisms

Barrier Mechanism Strategy for Managing Harmful Energy Flow	Implementation of Mechanism
Eliminate the energy source <ul style="list-style-type: none"> • Exclude (remove) energy concentration 	<ul style="list-style-type: none"> • Eliminate from design • Replace with alternate design
Reduce the amount of energy <ul style="list-style-type: none"> • Limit quantity and/or level of energy 	<ul style="list-style-type: none"> • Store heavy loads on ground floors • Lower dam height • Reduce system design voltage/operating pressure • Use small(er) electrical capacitors/pressure accumulators • Reduce/control vehicle speed • Monitor/limit radiation exposure • Substitute less energetic chemicals
Prevent release of energy	<ul style="list-style-type: none"> • Heavy-walled pipes/vessels • Interlocks • Tagout-lockout • Double-walled tankers • Wheel chocks
Reduce the rate of release of energy <ul style="list-style-type: none"> • Modify rate of release of energy 	<ul style="list-style-type: none"> • Flow restrictors in discharge lines • Resistors in discharge circuits • Fuses/circuit breakers • Ground fault circuit interrupters
Prevent the buildup of released energy	<ul style="list-style-type: none"> • Use pressure relief valves • Control chemical reactions
Control improper energy input <ul style="list-style-type: none"> • Keep energy source within specifications • Prevent the combining of energy sources 	<ul style="list-style-type: none"> • Separate hyperbolic fuel sources
Separate energy from target in time and/or space	<ul style="list-style-type: none"> • Evacuate explosives test areas • Impose explosives safety quantity—distance rules • Install traffic signals • Use yellow no-passing lines on highways • Control hazardous operations remotely
Isolate by interposing a material barrier	<ul style="list-style-type: none"> • Concrete road barrier • Safety eyeglasses • Rounded corners • Padding
Modify shock concentration surfaces <ul style="list-style-type: none"> • Modify target contact surface or basic structure 	<ul style="list-style-type: none"> • Earthquake-proof structure • Nuclear reaction containment facility
Strengthen potential target to withstand the energy	<ul style="list-style-type: none"> • Building sprinkler systems • Aircraft fire suppression systems
Limit the damage of energy release	<ul style="list-style-type: none"> • Warning notes • Special procedures • Safety training
Train personnel to prevent energy release	

Barrier Analysis						
Energy Source	Energy Hazard	Target	IHRI	Barrier	FHRI	Comments
1	2	3	4	5	6	7

Figure 19.6 Recommended BA worksheet.

particular needs. The specific worksheet to be used may be determined by the system safety program (SSP), system safety working group, or the safety analysis customer.

The following instructions describe the information required under each column entry of the BA worksheet:

1. *Energy Source* This column identifies the hazardous energy source of concern.
2. *Energy Hazard* This column identifies the type of energy-related hazard (i.e., the energy path) involved with the identified energy source. The hazard should describe the hazard effect and mishap consequences and all of the relevant causal factors involved. All possibilities of hardware faults, software errors, and human error should be investigated.
3. *Target* This column identifies the target, or targets, that can be adversely affected by the energy source if barriers are not in place and a mishap occurs.
4. *Initial Mishap Risk Index (IMRI)* This column provides a qualitative measure of mishap risk for the potential effect of the identified hazard, given that no mitigation techniques are applied to the hazard. Risk measures are a combination of mishap severity and probability, and the recommended values from MIL-STD-882 are shown below.

Severity	Probability
1. Catastrophic	A. Frequent
2. Critical	B. Probable
3. Marginal	C. Occasional
4. Negligible	D. Remote
	E. Improbable

5. *Barrier* This column establishes recommended preventive measures to eliminate or control identified hazards. Safety requirements in this situation

generally involve the addition of one or more barriers to keep the energy source away from the target. The preferred order of precedence for design safety requirements is as shown below.

Order of Precedence

1. Eliminate the hazard through design measures or reduce the hazard mishap risk through design measures.
 2. Reduce the hazard mishap risk through the use of safety devices.
 3. Reduce the hazard mishap risk through the use of warning devices.
 4. Reduce the hazard mishap risk through special safety training and/or safety procedures.
6. *Final Mishap Risk Index (FMRI)* This column identifies the final mishap risk given that the barriers or safety features are in place to mitigate the hazard. This risk assessment will show the risk improvement due to barriers in the system. The same risk matrix table used to evaluate column 4 is also used here.
 7. *Comments* This column provides a place to record useful information regarding the hazard or the analysis process that are not noted elsewhere.

19.8 EXAMPLE

In order to demonstrate the BA methodology, the hypothetical water heating system shown in Figure 19.7 will be analyzed for energy–barrier hazards. Table 19.5 contains a list of system components and establishes if they are energy sources of safety concern.

Figure 19.8 contains a diagram of the energy path for the propane energy source. This diagram shows all of the energy barriers in the system design.

Tables 19.6 and 19.7 contain the worksheets for a partial BA of this example system. Two of the system components, propane and water, were selected for demonstration of the BA technique.

19.9 ADVANTAGES AND DISADVANTAGES

The following are advantages of the BA technique:

1. BA is simple to grasp and use.
2. BA has a pictorial benefit that aids analysts in visualizing hazards.
3. BA is a relatively inexpensive analysis tool.
4. Most energy sources are easily recognized (e.g., explosives, electricity, springs, compressed gas).

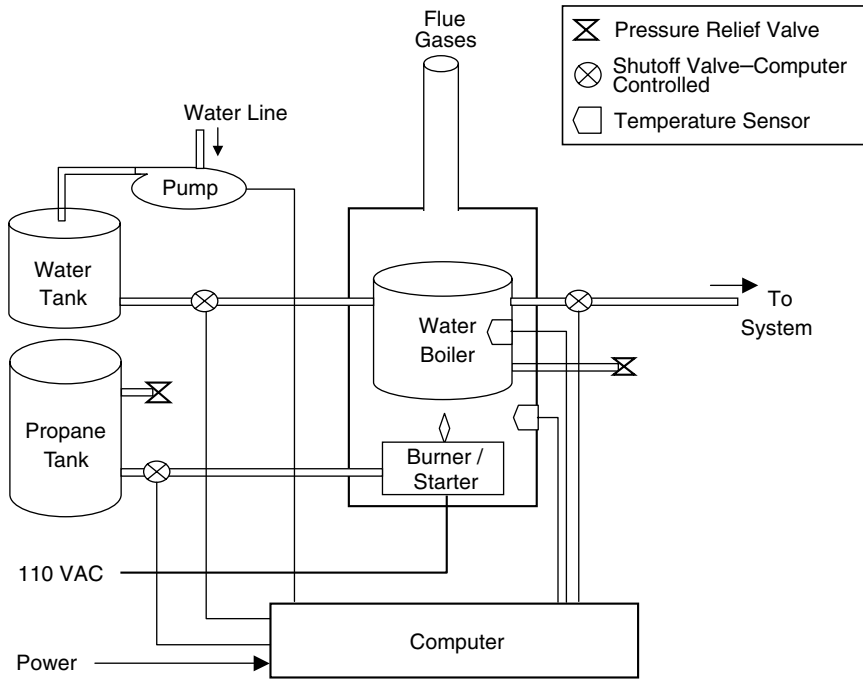


Figure 19.7 Example water heating system.

The following are disadvantages of the BA technique:

1. BA is limited by the ability of the analyst to identify all the hazardous energy sources.
2. BA does not identify all system hazards, only those associated with energy sources.
3. Not all sources of harm to targets are readily recognizable as energy sources (e.g., asphyxiate gases, pathogenic organisms).

TABLE 19.5 List of Energy Sources for Water Heating System

System Component	Hazardous Energy Source	Hazard Potential	Barrier
Propane tank	Yes	Yes	Yes
Propane gas	Yes	Yes	Yes
Water tank	Yes	Yes	Yes
Water	Yes	Yes	Yes
Water boiler	Yes	Yes	Yes
Electricity	Yes	Yes	Yes
Gas burner	Yes	Yes	Yes
Computer	No	Yes	Yes

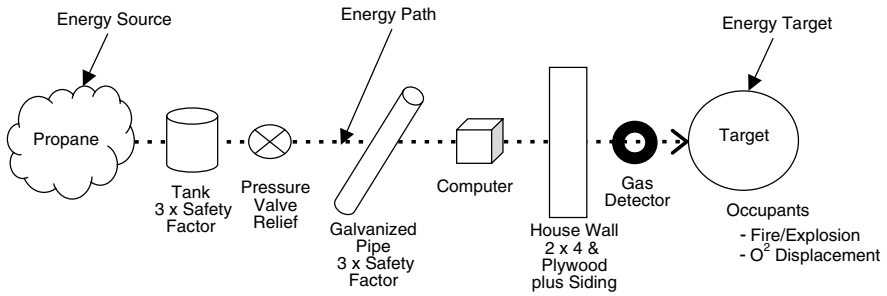


Figure 19.8 Propane energy path with barriers.

19.10 COMMON MISTAKES TO AVOID

When first learning how to perform a BA, it is commonplace to commit one or more of the following errors:

1. Not identifying all of the energy sources within the system
2. Not evaluating the potential failure of energy barriers
3. Not evaluating the possible cascading effects of energy sources
4. Not identifying/understanding all of the energy paths
5. Not considering the complete system (i.e., taking too narrow a view of energy paths)

TABLE 19.6 Example BA—Worksheet 1

Energy Source	Hazard	Target	IHRI	Barrier	FHRI	Comments	
Propane	Fire/explosion causing death, injury and/or damage	Personnel/facility	1C	<ul style="list-style-type: none"> • Isolate tank safe distance from facility • Use protected lines • Minimize ignition sources 	1E		
	High-pressure release causing death, injury, and/or damage	Personnel/facility	1C		<ul style="list-style-type: none"> • Isolate tank safe distance from facility • Use protected lines • Isolate lines from personnel • Use pressure relief valve 		1E
	Oxygen replacement causing death	Personnel	1C		<ul style="list-style-type: none"> • Use propane with smell detection (e.g., mercaptan) • Use gas detector 		1E

TABLE 19.7 Example BA—Worksheet 2

Energy Source	Hazard	Target	IHRI	Barrier	FHRI	Comments
Water	High temperature causing tank explosion, which results in death, injury, and/or damage	Personnel/facility	1C	<ul style="list-style-type: none"> • Isolate boiler tank • Use protect lines 	1E	
	High pressure causing tank explosion, which results in death, injury, and/or damage	Personnel/facility	1C	<ul style="list-style-type: none"> • Isolate tank safe distance from facility • Use protected lines • Isolate lines from personnel • Use pressure relief valve 	1E	
	Flood causing damage	Facility	2C	<ul style="list-style-type: none"> • Isolate tank safe distance from facility • Use water detector 	2E	

19.11 SUMMARY

This chapter discussed the BA technique. The following are basic principles that help summarize the discussion in this chapter:

1. BA involves detailed focus on potentially hazardous energy sources within the system design and intentional barriers for mitigating the energy hazards.
2. BA should be a supplement to the PD-HAT, DD-HAT, and SD-HAT.
3. Some hazards identified through BA may require more detailed analysis by other techniques (e.g., FTA) to ensure that all hazard causal factors are identified and mitigated.
4. The use of worksheets provides structure and rigor to the BA process, and energy flow diagrams aid the analysis.

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