CHEMICAL HAZARDS and methods to relate those hazards to workers, managers and designers have challenged SH&E professionals for many years. Incidents such as the catastrophe at Union Carbide’s facility in Bhopal, India, led to a strong push for what is now known as the right-to-know movement (EPA, 2006). It also prompted several regulations, such as OSHA’s Hazard Communication (HazCom) standard (29 CFR 1910.1200). Under this standard, OSHA mandates that all users of chemicals should maintain what are now called material safety data sheets (MSDS). Produced by chemical manufacturers, MSDS provide information such as manufacturer name and contacts, hazardous ingredients, physical data, fire and explosion hazard data, health hazard data, reactivity (instability) data, spill or leak procedures, special protection information and special precautions (ANSI, 1998).

Like chemicals, man/machine interactions have become more complex because of technological advances. This complexity increases the level of risk to which workers are exposed. As a result, identifying and assessing associated hazards has increased in complexity as well. To better manage these concerns, information sheets simulating MSDS for chemicals were introduced (McCabe & Lippy, 2001).

Called technology safety data sheets (TSDS), these documents aim to capture and relate a concise abstract of technical information in a user-friendly format. TSDS use information gathered through hazard analysis techniques such as job safety analysis (JSA) or failure modes and effects analysis (FMEA). Much as MSDS provide chemical hazard information to different audiences in one format, TSDS are communication tools to be used by various audiences.

According to Department of Energy (DOE) and National Institute for Environmental Health Sciences (NIEHS) (1996), a TSDS is a “technology-specific document designed to provide, among other information, the identity and relative risk of safety and health hazards associated with a technology. It can be used as a tool to manage safety throughout the technology development and implementation process, and it can provide developers with a method to collect and report hazard information in a form understood by the user community.”

**History & Origination**

TSDS was originally developed in 1994 by Matthew Fitzgerald while working under a contract for the DOE. In 1995, DOE entered into a cooperative agreement with the International Union of Operating Engineers (IUOE) to begin addressing worker safety and health considerations related to environmental technology research, development and demonstration programs (McCabe & Lippy, 2001).

In 2000, DOE’s Environmental Management Advisory Board (EMAB) recommended that a TSDS be provided for every technology at mid-stage review (EMAB, 2000). DOE then began to pilot test TSDS as a way to provide guidance on avoiding potential hazards in individual technologies (McCabe & Lippy, 2001). Although it was later reported that mid-stage review was too early for full TSDS development, it was concluded that “it is never too early for a technology developer to start considering safety and health in the research and development process” (McCabe & Lippy, 2001).

**TSDS Format**

Currently no regulatory mandate is in place for a TSDS to be developed or for the format to be used if one is developed. However, published guidelines suggest that the following elements be included: technology identity, process

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**Abstract:** New technologies and processes can pose risks to users, much like those caused by exposure to chemicals. As part of the right-to-know concept, a standardized resource such as technology safety data sheets (TSDS) can provide workers with the adequate knowledge to protect themselves from those risks. This article describes TSDS and discusses how these tools can be used to educate managers, designers, engineers and other potential users on basic aspects of safety and health.

Magdy Akladios, Ph.D., P.E., CSP, CPE, CSHM, is an assistant professor in the School of Science and Computer Engineering at the University of Houston, Clear Lake. A professional member of ASSE’s Gulf Coast Chapter, Akladios holds a B.S.M.E. from Cairo University, as well as an M.S.I.E., M.B.A. and M.S. in Occupational Safety & Health, and a Ph.D., all from West Virginia University.

Gary L. Winn, Ph.D., CHST, is a professor in the safety management program within the Department of Industrial and Management Systems Engineering at West Virginia University in Morgantown. A professional member of ASSE’s Northern West Virginia Chapter, Winn holds a B.A. from Wright State University, an M.A. from University of Dayton and a Ph.D. from Ohio State University.

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Comparing PSM & TSDS Elements

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<th>Element</th>
<th>PSM</th>
<th>TSDS</th>
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| Gather and display technology’s information | - Information pertaining to the dangers of the highly hazardous chemicals used or produced by the process.  
- Information pertaining to the technology in the process (diagrams that will help users understand the process, and maintain it under control).  
- Information pertaining to the equipment such as condition’s design must be documented (ASME, API, ANSI, NFPA codes). | - Technology identity;  
- process description;  
- process diagrams.  
These sections provide key technical information to people in order to understand the technology as is required by the standard. |
| Hazard analysis                | Based on this information, PSM will perform a PHA or safety analysis. Depending on the complexity of the process, an appropriate technique will be selected. Options include: what-if/checklist; HAZOP; FMEA; FTA. | - Safety hazards;  
- health hazards;  
- system safety analysis;  
- phase analysis.  
No decision is made on the use of any hazard analysis technique. Section 7 in the first version of TSDS describes the results of a hazard analysis, but it does not determine how to do it. The latest protocols eliminate the section and stipulate the use of these techniques to determine an appropriate assessment of the hazards. Another important point refers to the format used by TSDS. It describes the results obtained in the hazards analysis by separating the hazards descriptions in to safety hazards, health hazards, phase analysis hazards and emergency conditions. Each topic constitutes a section. |
| Operating procedures           | PSM standard requires development and implementation of written operating procedures that provide clear instructions for safely conducting activities involved in each covered process. Steps for each operating phase are initial startup; normal, temporary and emergency operations; normal shutdown; and startup following a turnaround or after emergency shutdown. | - Safety and health plan;  
- emergency condition information;  
- special considerations.  
TSDS also present a specific section, namely phase analysis, to describe the hazards involved in each life cycle phase of the technology. This concept can help developers incorporate safety aspects into designs or to final users to address hazards during the use and deployment stage in the technology. |
a person and how well a procedure is executed, they are a more viable alternative. Therefore, process safety has given way to occupational safety in the effort to produce an effective communication tool.

Sutton (2003) suggests that occupational safety and process safety are both part of an overall system, but asserts that they are separate and distinct. He also suggests a relationship between system safety, occupational safety and process safety:

Indeed, during the follow-up to serious process-related accidents, it is often observed that the facility in question had a good occupational safety record, which is one reason senior managers are often so stunned after a major incident—their good occupational safety record had led them to believe that all was well. For these reasons, the line from occupational safety to process safety is not solid, indicating a weak link. On the other hand, a facility with a good process safety program probably will do well at occupational safety, so that line is solid, indicating a stronger link (Sutton, 2003).

Since worker safety is the ultimate goal, the second-generation TSDS format illustrates and communicates safety and health information to workers and combines both approaches into one source (Table 1).

### Process Safety Management

The major objective of PSM is to prevent or mitigate the release of hazardous chemicals likely to cause serious accidents. To achieve this, PSM has three stages: identification, evaluation, and mitigation or prevention of chemical releases that could occur as a result of failures in process, procedures or equipment. To control such hazards, workers must develop the necessary expertise, experience, judgment and initiative to properly implement and maintain an effective PSM that includes gathering and displaying information, identifying and assessing hazards, and writing operating and training procedures (OSHA, 1994).

Three main sources of information are required to implement a PSM:

- information on the hazards of the highly hazardous chemicals used or produced by the process;
- information on the technology in the process (e.g., diagrams that will help users understand the process and maintain it under control);
- information about equipment conditions (e.g., pressure and temperature limits).

Based on this information, PSM uses a tool called process hazard analysis (PHA). Depending on the complexity of the process, an appropriate technique such as what-if/checklist, hazard and operability analysis (HAZOP), failure modes and effects analysis (FMEA) or fault tree analysis (FTA) is selected. Finally, the PSM standard requires development and implementation of written operating procedures that provide clear instructions for safely conducting activities involved in each covered process.

The TSDS format compiles these PSM phases and expands their application beyond preventing or mitigating the release of hazardous chemicals to use with other types of work-related hazards. The TSDS presents hazards in a clear, comprehensible format, making it an important document for communicating hazards in any type of industry.

### Proposed New Format

The lack of a standardized procedure and format has prompted the proposal of a unified approach. TSDS take advantage of hazard analysis techniques (or safety analysis methods). This systematic approach enables developers to analyze diverse objects, ranging from simple machine components to complex production processes. It also addresses ways in which operators and maintenance personnel interact with these processes. Thus, the first step in developing a TSDS is to recognize the nature of the object being analyzed. This will help to determine the approach and hazard analysis method to be used during the development of a TSDS.

### Operation Analysis

Grimaldi (1975) defined the fundamentals of operation analysis as follows:

1) Break down the job or operation into its elementary steps.
2) List them in their proper order.
3) Examine them critically.

The operation analysis technique investigates the steps of a job to identify and eliminate those that are inefficient. SH&E professionals examine each step for its accident-causing potential. Four units—dubbed the 4 Ms—should be considered when analyzing a job operation for its possible hazards:

- man: all persons related to the job;
- method: working procedures;
- machine: simple tools to complex systems;
- material: includes substances and items other than machines.

Heinrich, Petersen and Roos (1980) explain how a production system should be divided into units to facilitate the identification of hazards. The same concept is presented by Harms-Ringdahl (2002) when describing a modern production system where the simple machine has been replaced by a production system. In this context, a production system “can be seen as a number of elements that must interact for a desired result” (Harms-Ringdahl, 2002).

The main components of a production system include technical equipment and physical conditions; individuals within the company; organization and activities; surroundings, including society.

**Hazards are best controlled before they are created. However, if a designed system goes to market, worker behavior can be modified to avoid accidents. Therefore, a TSDS may be used with designers and/or workers and safety managers in mind.**
Developing a TSDS: What Works Best

More than 50 hazard analysis methods are available. Harms-Ringdahl (2002) describes 10 select methods based on the belief that these techniques are simple to apply and suitable for use in the work-

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**Table 2**

<table>
<thead>
<tr>
<th>Technique</th>
<th>Applications</th>
<th>Pros</th>
<th>Cons</th>
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</thead>
<tbody>
<tr>
<td><strong>Technical (T)</strong></td>
<td></td>
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<tr>
<td>Energy analysis</td>
<td>All types of systems</td>
<td><em>Can give “strict” results</em></td>
<td><em>Human/organization missed</em></td>
</tr>
<tr>
<td>HAZOP</td>
<td>Chemical installations</td>
<td>Simple method, quick, gives an overview</td>
<td>Limited analysis of causes.</td>
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<tr>
<td>FMEA</td>
<td>Mechanical and electrotechnical systems; can be widened</td>
<td>Well known, many manuals, straightforward to use.</td>
<td>Time-consuming.</td>
</tr>
<tr>
<td>FTA</td>
<td>All types of (technical) systems</td>
<td>Well established, international standard.</td>
<td>Time-consuming. Many possible failures.</td>
</tr>
<tr>
<td>Event tree analysis</td>
<td>All types of (technical) systems</td>
<td>Well established. Provides a clear picture of sequence of events after a failure. Basis for probabilistic calculations.</td>
<td>Rather difficult. Binary (yes or no).</td>
</tr>
<tr>
<td><strong>Human (H)</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Action error method (several similar ones)</td>
<td>People’s actions in systems</td>
<td><em>Human actions are essential</em></td>
<td><em>Difficult to model and predict</em></td>
</tr>
<tr>
<td>a) Hierarchical task analysis</td>
<td>Well-defined procedures in process industry, for example</td>
<td>Straightforward use, rather simple.</td>
<td>Focus on normal process. Many possible failures.</td>
</tr>
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<td></td>
<td>Map out the task of an individual, all types of systems</td>
<td>Goal oriented, well structured description. A basis for further analysis.</td>
<td>Does not support identification of risks (not a real safety analysis method).</td>
</tr>
<tr>
<td><em><em>System (THO</em>)</em>*</td>
<td>Also organization oriented</td>
<td><em>Organizational activities are decisive</em></td>
<td><em>Difficult to model and predict</em></td>
</tr>
<tr>
<td>Job safety analysis</td>
<td>Defined work procedure for an individual worker or a team</td>
<td>Simple to learn/apply; similar to traditional safety thinking.</td>
<td>Too traditional, new hazards not found; not suitable in automatic systems.</td>
</tr>
<tr>
<td>Deviation analysis</td>
<td>All types of systems</td>
<td>Generic; works on most systems, simple flexible principle.</td>
<td>Sensitive to structuring, many deviations at different levels.</td>
</tr>
<tr>
<td>Safety function analysis</td>
<td>All types of systems</td>
<td>Generic; works on most systems; focus on safety, making it right from the beginning.</td>
<td>Rather difficult, results can be presented in different forms.</td>
</tr>
<tr>
<td>Change analysis</td>
<td>All types of systems</td>
<td>General; simple principle.</td>
<td>Based on occurred accidents; assumes that the original system is safe enough.</td>
</tr>
<tr>
<td>a) Audits (in general)</td>
<td>Check of (safety) management; all types of systems</td>
<td>Essential to check that SM works. With a suitable checklist, it can be rather easy.</td>
<td>Depends much on the checklist; can be an empty formality; difficult to apply on flat organizations.</td>
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*THO = technical, human and organizational aspects.*

According to Harms-Ringdahl (2002), these four elements constitute a method of separating a job or operation, when analyzed, into simple compounds. Literature related to hazard analysis techniques offers a broad range of names for these techniques. While many of these techniques are similar, they may have different naming conventions due to lack of standardization of safety terminology and communication. The three basic thought processes by which hazards may be identified are:

1) deductive: based on a list of undesired events;
2) inductive: based on physical part failure modes;
3) inductive: based on human failure modes.
know what protective measures to use to guard against these hazards. TSDS also provide information to designers to help them control hazards via design modifications. Not only is this important for the technology in question, it also provides subtle knowledge and helps educate non-SH&E professionals on the basic aspects of safety and health issues and the different ways to mitigate these risks.

To reach the level of standard communication tool, additional concepts must be described as well. For example, it is critical to clearly describe the technology, process or task (e.g., an entire installation, type of machine, specific machine, part or workplace as a production line or production process, transportation system, specific type of work, organizational routines) in which the engineers, worker or SH&E professional will be involved. Important issues related with this aspect are:

- display of information related to the technology, such as flow process diagram, schemes of different systems, and pictures and diagrams showing the steps to perform a task;
- use of brief operation description to understand the object or task.

A worker’s risk perception as a consequence of hazard assessment will help modify his/her behavior. The worker can better visualize how risky a given technology or task is and his/her perception helps the SH&E manager to rank hazards and make appropriate decisions.

Since each organization has a unique way of char-
acterizing the degree of hazard, there is no standard methodology in this area. Another consideration is the life cycle of the technology and all the different states that can occur from cradle to grave. These safety considerations apply during planning, design, production start, operation and decommissioning. MIL-STD-882B specifies general system designs requirements: Eliminate identified hazards or reduce associated risk through design, including material selections or substitution, and select those with least risk throughout the life cycle of the system when potentially hazardous materials must be used (DOD, 1984).

Selecting the Development Team

According to Harms-Ringdahl (2002), composition of the TSDS development team depends on what is to be studied, not necessarily the knowledge of the hazard analysis methodology. “An important advantage in creating a team lies in the way the analysis can be rooted at company levels. Through a stage-by-stage process of clarification and adjustment, results can become broadly accepted within the company” (Harms-Ringdahl, 2002).

Several problems can arise if just one person conducts the entire analysis (Harms-Ringdahl, 2002). Therefore, a multidisciplinary team must perform the hazard analysis that leads to the preparation of a TSDS; this team should include an expert in the technology under investigation; a potential user(s) of the technology such as a worker(s) with the skills needed to operate the technology; and experts with knowledge of the specific hazard analysis methodology to be used. In addition, if the technology poses a hazard that requires specific knowledge, an expert in that field must be present as part of the team (IUOE, 2002).

TSDS in Practice

One effective approach developed by IUOE (2002) arises from an adaptation of MIL-STD-882D (DOD, 2000). This method considers both probability and severity in a quantitative way. Simply, the standard requires that risk assessment be used in formulating decisions related to resolving identified hazards (Brauer, 1994).

Another approach was developed by the Indiana University of Pennsylvania’s National Environmental Education Training Center (IUP-NEETC). This method evaluates probability as the chance of the hazard occurring only when the technology is in operation or under maintenance.
This technique also has a color-coded numerical rating that indicates the potential severity of injury and/or illness due to existing hazards. An important contribution to the TSDS format is the added visualization of the hazard assessment in an easy-to-understand color matrix.

Figures 1 through 6 provide examples of a TSDS for a thermal desorption technology at McClellan Air Force Base in Sacramento, CA (IUP-NEEC, 2003). This example shows the additions of hazard color-coding, which directs the reader to focus on the most important hazards first. Less-hazardous situations are also summarized, but are given secondary importance. The quantitative risk valuation and hazard rating is calculated based on the following formula:

\[
\text{Risk} = \text{Probability of Occurrence} \times \text{Severity}
\]

The five possible probabilities are:
- A = Improbable
- B = Remote
- C = Occasional
- D = Probable
- E = Frequent

The four possible levels of severity are:
- I = Negligible
- II = Marginal
- III = Critical
- IV = Catastrophic

The resulting four possible levels of risk are low (indicated by white), medium (indicated by yellow), serious (indicated by orange) and high (indicated by red).

Conclusion

While no standardized format is currently available to document and communicate technology-related hazards to workers, SH&E professionals, engineers or other personnel involved in the use of a given technology, such documentation is needed. A standardized TSDS can provide a clear description (both verbally and visually) of the technology, process or task in which the worker will be involved; incorporate hazard assessment information; and describe various situations arising throughout a system’s life cycle.

When a multidisciplinary team is created to develop a TSDS, the analysis can be rooted at different company levels. Through a stage-by-stage process of clarification and adjustment, results can become broadly accepted within a given company.

The ultimate goal of a TSDS is to identify key hazards and suggest solutions to mitigate them. As the examples show, TSDS
provides “recommended controls” for each hazard identified. Ultimately, if all these recommendations are followed, the risk chart should be moved from the red zone (high risk) to the white zone (low risk).

References


