THE OSHA AND EPA PROGRAMS ON PREVENTING CHEMICAL ACCIDENTS AND POTENTIAL APPLICATIONS IN THE PHOTOVOLTAIC INDUSTRY

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ABSTRACT

OSHA issued in 1992, the Process Safety Management (PSM) of Highly Hazardous Substances. This rule requires owners/operators of facilities that handle hazardous chemicals in quantities greater than the listed thresholds to establish all the elements of a PSM. EPA has issued in June 1996, the rules for a Risk Management Program which also refers to specific substances and threshold quantities. These rules are applicable to all the facilities that use or store any of 139 regulated substances at quantities ranging from 100 lb to 10,000 lb. The RMP rule covers off-site hazards, while the OSHA Process Safety Management (PSM) rule covers worker safety issues within the plant boundary. Some of the listed substances may be found in photovoltaic manufacturing facilities. This brief report presents the basic elements of these two rules and discusses their potential applicability in the photovoltaic industry.

1 INTRODUCTION

Section 112(r) of the Clean Air Act Amendments of 1990 (CAAA) includes provisions for preventing chemical accidents under Title III-Hazardous Air Pollutants. In response to this requirement, OSHA issued in 1992 the Process Safety Management (PSM) of Highly Hazardous Substances, and, on April 1996, the EPA issued the Risk Management Program (RMP). These rules are applicable to all the facilities that use or store any of about 140 regulated substances at quantities ranging from 100 to 10,000 lb. The RMP rules address potential accidental releases of certain chemical substances outside the fence of a facility, while the OSHA Process Safety Management (PSM) rules address worker safety issues within the plant boundary. Both rules are aimed at preventing accidents involving hazardous chemicals.

Some of the listed substances may be found in photovoltaic manufacturing facilities (Table 1). Consequently, OSHA and EPA provisions and associated risk prevention programs are of interest to photovoltaic manufacturing facilities that handle hazardous air pollutants. Considering these rules while designing new manufacturing facilities will minimize the costs associated with compliance.

2 OSHA Process Safety Management (PSM)

The CAAA mandated that OSHA set a chemical process safety standard to prevent accidental releases of chemicals which pose a threat to employees. In response to this requirement, OSHA issued in 1992, the Process Safety Management (PSM) of Highly Hazardous Substances, 29 CFR Part 1910.119 (1992). This rule requires owners/operators of facilities that handle hazardous chemicals in quantities greater than the listed thresholds (Table 1), to establish all the elements of a PSM.

Table 1. Compounds Listed in OSHA-PSM and EPA-RMP of Interest to The PV Industry

Toxic Substances			Flammable Substances		
Substance	Threshold Quantity (lb)		Substance	Threshold Quantity (lb)	
	OSHA	EPA		OSHA	EPA
Arsine	150	1,000	Dichloro-silane	2,500	10,000
Boron Trichloride	2,500	5,000	Hydrogen	10,000	10,000
Boron Trifluoride	250	5,000	Silane		10,000
Diborane	100	2,500	Tricloro-silane	5,000	10,000
Hydrofluoric acid (50%+)	1,000	1,000			
Hydrogen fluoride	1,000	1,000			
Hydrogen selenide	150	500			
Hydrogen sulfide	10,000	10,000			
Phosphine	-	5,000			

A PSM program is comprised of the following 14 elements.

1) Introduction to Process Safety Management
2) Employee Involvement
3) Process Safety Information
4) Process Hazards Analysis
5) Operating Procedures
6) Employee Training
7) Contractors
8) Pre-start Safety
9) Mechanical Integrity
10) Non-routine Work Permits
11) Managing Change
12) Incident Investigation
13) Emergency Preparedness, and
14) Compliance Audits

The following are highlights of compliance requirements and recommendations from Appendix C of the OSHA rule:

Introduction to Process Safety Management - An effective process safety requires a systematic approach to evaluating various levels of defense to prevent or mitigate the release of hazardous chemicals. OSHA believes that process safety management in the form of proactive hazard identification, evaluation and mitigation or prevention of chemical releases will have a positive effect on the safety of employees and also offer other potential benefits (e.g., increased productivity). For small business which may have limited resources to implement process safety management options, OSHA suggests alternative ways of decreasing the risks associated with highly hazardous chemicals at their workplaces, such as reducing the inventory of the chemical or distributing storage to several isolated locations.

Employee Involvement Participation in Process Safety - Section 304 of the CAAA states that employers are to consult with their employees regarding the employers effort in the development and implementation of the process safety management and hazard assessment. Employers are also required to train and educate their employees and to inform affected employees of the findings from incident investigations.

Process Safety Information - Employers must provide written information regarding process technology, equipment used, and hazards posed processes utilizing hazardous chemicals. Required information includes, but is not limited to: material safety data sheets, permissible exposure limits; potential risks from inadvertent mixing of materials; process flow diagrams; safe temperature and pressure limits; and equipment design codes.

Process Hazard Analysis (PHA) - The PHA focuses on equipment, instrumentation, utilities, human actions and external factors that might impact the process. OSHA prescribes a team approach, preferably with members from various disciplines. Team must include members expert in the scientific process and methodology in use, whether or not this expertise is available on site. The team's findings must be addressed formally and resolved in a timely manner. Analyses must be updated every five years.

Operating Procedures - Operating procedures describe tasks to be performed, data to be recorded, operating conditions samples to be collected, and safety and health precautions. Operating procedures should be reviewed by engineering and operating personnel. Such procedures must be complete and comprehensive; if workers are not fluent in English, procedures need to be written in a second language understood by the workers.

Employee Training - All employees involved with highly hazardous chemicals, including maintenance and contractor employees, must be formally trained in the appropriate operating procedures. Refresher training will be required (e.g., at least every 3 years) and detailed documentation of each employee's training experience is required. Careful consideration must be given to provide current and updated training. For example, if changes are made to a process, impacted employees must be re-trained and understand the effect of the changes on their job tasks.

Contractors - This provision is basically designed to emphasize that standards are to cover all, including contract employees. Employers who use contractors to perform work in and around processes that involve highly hazardous chemicals, will need to establish a screening process for hiring contractors who accomplish their tasks without compromising safety.

Pre-Startup Safety - For new processes, a PHA is helpful in improving the reliability of design and construction of the process. The recommendations of the PHA must be addressed, and procedures and training must be completed before startup.

Mechanical Integrity - This provision sets the requirement for periodic inspection, testing and quality assurance standards for equipment used in storage, processing or handling of highly hazardous chemicals. A mechanical integrity program must be in place to assure the continued integrity of such equipment. The rule refers to primary line of defense (e.g. containment, controlled release through scrubbers or flares), and secondary systems (e.g., fire protection, water spray, dikes), systems which are discussed throughout this book. The integrity of these systems should be assured through preventive maintenance and testing.

Hot Work Permit - Non routine work which is conducted in the vicinity of covered by the standard process, has to be formally approved. The employer must issue a permit for such work and ensure that certain prevention and protection measures are satisfied.

Management of Change - Temporary changes have caused a number of accidents over the years, mainly because personnel was not fully aware of the impact such changes made to an operation. Management of change covers changes in process technology and changes to equipment and instrumentation. Employers are required to establish means and methods to detect both technical and mechanical changes and to provide written documentation and authorization of the changes.

Incident Investigation - Any incident which resulted or could have been resulted in a hazardous chemical release must be investigated within 48 hours by a team assembled by the employer. A multi-disciplinary team is better able to gather the facts of the event. A report including contributing factors and suggestions for corrective actions must be submitted. The report, its findings and recommendations are to be shared with those who can benefit from the information.

Emergency Preparedness - Employers must address what actions employees are to take when there is an accidental release of highly hazardous chemical. Employers at the minimum must have an emergency action plan which will facilitate the prompt evacuation of employees during an accident. This means that they should have an emergency action plan, including escape route, procedures and assignment. This plan will be activated by an alarm system, to alert employees when to evacuate. Employees who are physically impaired must have the necessary support and assistance to get them to a safe zone as well.

Compliance Audits - Employers must audit their operations to ensure compliance with the provisions of the rule. This self-evaluation can help employers measure the continuing effectiveness of their safety management systems. Reporting procedures must be established, the findings of the audit must be followed and deficiencies corrected.

The centerpiece of the PSM standard is process hazard analysis. It offers an integrated approach to chemical safety. This standard is performance based, giving facilities some degree of flexibility in meeting their responsibilities, so that each facility can develop the most appropriate management system to meet its particular needs.

3 EPA Risk Management Program (RMP)

Under the CAAA, Section 112(r), the EPA also has specific duties relative to the prevention of accidental releases. Just recently, EPA published a list of chemicals and corresponding threshold quantities that require a Risk Management Plan (RMP). EPA's RMP is designed to reduce the risk of accidental releases of toxic, flammable and explosive substances in the environment. The final rule (June 1996) lists 78 toxic and 63 flammable substances and corresponding threshold quantities. Some of the listed substances may be found in photovoltaic manufacturing facilities (Table 1).

Current photovoltaic manufacturing facilities are not expected to have quantities in excess of threshold levels for any of the listed substances. However, even if a PV facility is not subject to the RMP rule but it handles listed hazardous materials, the CAAA General Duty clause requires that the facility owner/operator identifies hazards that may result from accidental releases, designs, operates and maintains a safe facility, and minimizes the consequences of accidental releases. Currently, EPA proposes a tiered approach that considers three types of facilities: Tier 1 facilities must simply submit evidence that no new prevention efforts are needed. Such facilities would have to prepare a "brief RMP" (probably a few weeks of effort) demonstrating that the source's worst-case release would not reach any public or environmental receptors. EPA estimates that 49,200 facilities nation-wide would qualify for Tier 1 status. The Tier 2 category requires a streamlined RMP in which facilities may implement a mini-PSM program of specific PSM and RMP elements. About 72,000 facilities would be characterized as Tier 2 facilities. Tier 3 facilities belong to specific industrial categories (e.g., pulp, plastics, chloroalkalis, chemicals and refineries) which are identified by EPA as historically accounting for most industrial accidents with potential off-site consequences. The procedure for Tier categorization is shown in Figure 1 (Sung, 1996).

Current photovoltaic module manufacturing facilities that handle listed hazardous substances will most likely qualify for Tier 1 status; larger future facilities may become subject to Tier 2 status. Currently, some electronics and semiconductor facilities are characterized as Tier 2 facilities. Photovoltaic cells are included in SIC Code 3674: Semiconductor and Related Devices. Regardless of RMP current application to the photovoltaics industry, the rule provides for a methodology to reduce hazards which is applicable to any facility handling hazardous substances. It is useful, therefore, to examine RMP programs. Section 112(r) of the CAAA states that an RMP must have 3 basic components: hazard assessment, accident prevention, and emergency

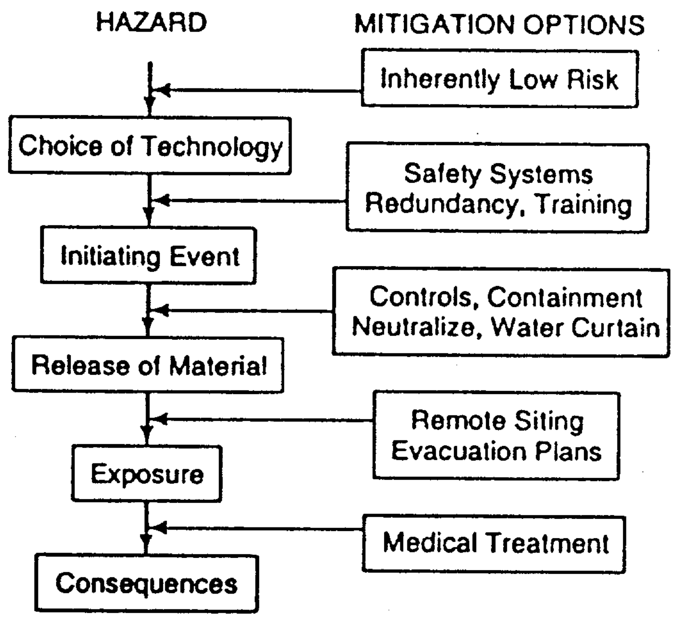

Figure 1. A hierarchial approach for managing toxic gas releases.

preparedness and response. Table 2 shows guidelines for complying with components applicable to Tier 2 and 3 facilities (Heinhold, 1996).

A facility must prepare a plan for implementing their risk management program. This plan must be given to regulators, local emergency planners and the public.

The EPA recently issued three draft guidance documents to help the implementation of RMP required analysis.[1] These three documents are:

Offsite Consequence Analysis Guidance - containing methodologies and look-up tables for developing analyses of worst case and other scenarios of accidental releases of hazardous gases.

Generic Guidance RMP for Ammonia Refrigeration Facilities - describing a model program to help facilities with ammonia refrigeration systems develop their own programs, and,

Risk Management Data Elements - lists the information that each facility subject to RMP, will be required to submit and make publicly available through the Local Emergency Planning Agencies (LEPC's).

[1] Copies of the guidance documents can be obtained through the Internet either via the EPA server **gopher.epa.gov** or through the World Wide Web site **http://earth1.epa.gov/ceppo.** Hard copies can be obtained by faxing a request to the EPA Emergency Planning and Community Right-to-Know hot line at (703) 412-3333.

Table 2. RMP Components
1. Hazard Assessment • Analyze the circumstances and transients that could result in releases of acutely hazardous substances. • Review documentation of past releases (5-year accident history). • Identify worst-case and more likely release scenarios for each substance. • Evaluate potential off-site consequences of release scenarios.
2. Accident Prevention • Evaluate safety precautions and management systems • Establish and enforce standard operating procedures. • Institute employee safety training. • Evaluate control and mitigation systems. • Investigate and report accidents.
3. Emergency Preparedness and Response • Establish emergency response procedures for all employees. • Coordinate plans with local emergency planning committee. • Develop and test public notice procedures.

The offsite consequence guidance document presents simplified approaches for consequence modeling. It contains "lookup" tables for results of dispersion and explosion modeling that allow users to minimize modeling efforts. EPA has specified some mandatory modeling parameters which, many in the industry think, are very conservative. The elements that have drawn most debates are the definition of Worst-Case Scenario and the assumptions pertaining to the flow rate of a release, the meteorological conditions for release dispersion and the exposure time. These elements are briefly discussed below.

Worst Case Scenario: EPA has defined a worst-case release as the release of the largest quantity of a regulated substance from a failed vessel or process line, that results in the greatest distance to a specified concentration. To define such quantity one should consider not only routine conditions but also process shutdown and process upsets. Administrative controls that limit the quantity of a substance in storage or process can be taken into account. Passive mitigation measures (e.g., enclosure) can also be taken into account, but active mitigation systems (e.g., flares, water curtains) are not given any credit in the analysis of the worst-case scenario. For such scenarios, the possible causes of the release, the probability of its occurrence and the reliability and effectiveness of active mitigation systems, are not considered; the release is simply assumed to happen.

Atmospheric Conditions: All releases are assumed to take place at ground level for the worst-case analysis. The meteorological conditions are defined as atmospheric stability class F and wind speed of 1.0 m/s. Two choices are provided for topography in the worst-case scenario: open (rural) conditions for a site located in an area with few buildings or other obstructions, and urban conditions for a site with many obstructions.

Toxic Gases: The toxic gases category includes all substances that are gases at ambient temperature even if they are stored as liquids under pressure or refrigeration. The total quantity is assumed to occur in 10 minutes, regardless of storage conditions. The threshold level to define hazard zone from a toxic gas release must be one of the following in order of preference: 1) the Emergency Response Planning Guideline 2 (ERPG-2),[2] developed by the American Industrial Hygiene Association (AIHA), or 2) the Level of Concern (LOC) for extremely hazardous substances (EHSs) regulated under section 302 of the Emergency Planning and Community Right-to-Know.

Toxic Liquids: For worst-case scenarios involving releases of toxic liquids, the total quantity in a vessel is assumed to be spilled onto a flat, non absorbing surface. The spill is assumed to form a pool and spread instantaneously to a depth of 1 cm in an undiked area or, if there is a dike around the vessel, to cover the diked area instantaneously.

Flammable Substances: For regulated flammable substances, the worst-case release is assumed to result in a vapor cloud containing the total quantity of the substance that could be released from vessel or pipeline. The entire quantity in the cloud is assumed to be between the upper and lower flammability limits, and the vapor cloud is assumed to detonate. The threshold level for the consequence analysis of a vapor cloud explosion is an overpressure of 1 psi.

4 A PROACTIVE APPROACH FOR THE PHOTOVOLTAIC INDUSTRY

The command and control regulations we are experiencing will continue and probably increase with time. The realities of cost related to risk management have to be considered in decision making related to new technologies and facilities. The best way to minimize both the risks associated with certain chemicals and the costs associated with risk management, is to assess all alternatives during the first steps of technology development and of facility design.

For photovoltaic technologies in the first stages of development, a proactive approach on minimizing risk can start with the choice of inherently safer

[2] ERPG-2 is the maximum airborne concentration below which it is believed that nearly all individuals could be exposed for up to one hour without experiencing or developing irreversible or other serious health effects or symptoms which could impair an individual's ability to take protective action.

materials, wherever applicable. Other risk reduction options can be considered sequentially. A scheme where risk management elements are considered in five steps each comprising a more advanced (in time) protection level, is shown in Figure 2 (Fthenakis, 1993).

a) Inherently safer processes and materials.

b) Options to prevent accidental initiating events (e.g., detection and monitoring systems, and procedures for safe operation).

c) Safety systems (e.g., automatic shut-off, flow restricting valves, cooling systems and containment systems).

d) Options for control/mitigation

e) Emergency preparedness and response plans, and procedures to prevent or reduce human exposures.

Sample applications of this approach in the photovoltaic module manufacturing industry are discussed below.

4.1 Technology/System Selection

The most efficient strategy to reduce hazards is to choose technologies which do not require the use of large quantities of hazardous gases. For new photovoltaic technologies, this approach can be implemented early in development, before large financial resources and efforts are committed to specific options. The choice of inherently safer materials may not be an easy one. In addition to obvious film quality and process efficiency issues, one should consider the exposure to a certain hazard during the total life of the module and via all pathways. Some examples of likely inherently safer choices of material in photovoltaic manufacturing are: (i) trimethylarsenic instead of arsine in manufacturing gallium arsenide photovoltaics (trimethylarsenic although poisonous is liquid and far less toxic than the highly toxic arsine gas; however, its potential for carcinogenicity still exists); (ii) zinc phosphide (a solid) instead of phosphine (a highly toxic gas) in manufacturing zinc phosphide devices.

4.2 Prevent Initiating Events

Once specific materials and systems have been selected, strategies to prevent accident initiating events need to be evaluated and implemented. Administrative and engineering options should be considered e.g., remote storage, maintenance, inspection and testing, quality control and worker training, guidelines for system integrity, operating procedures, and safeguards against process deviations.

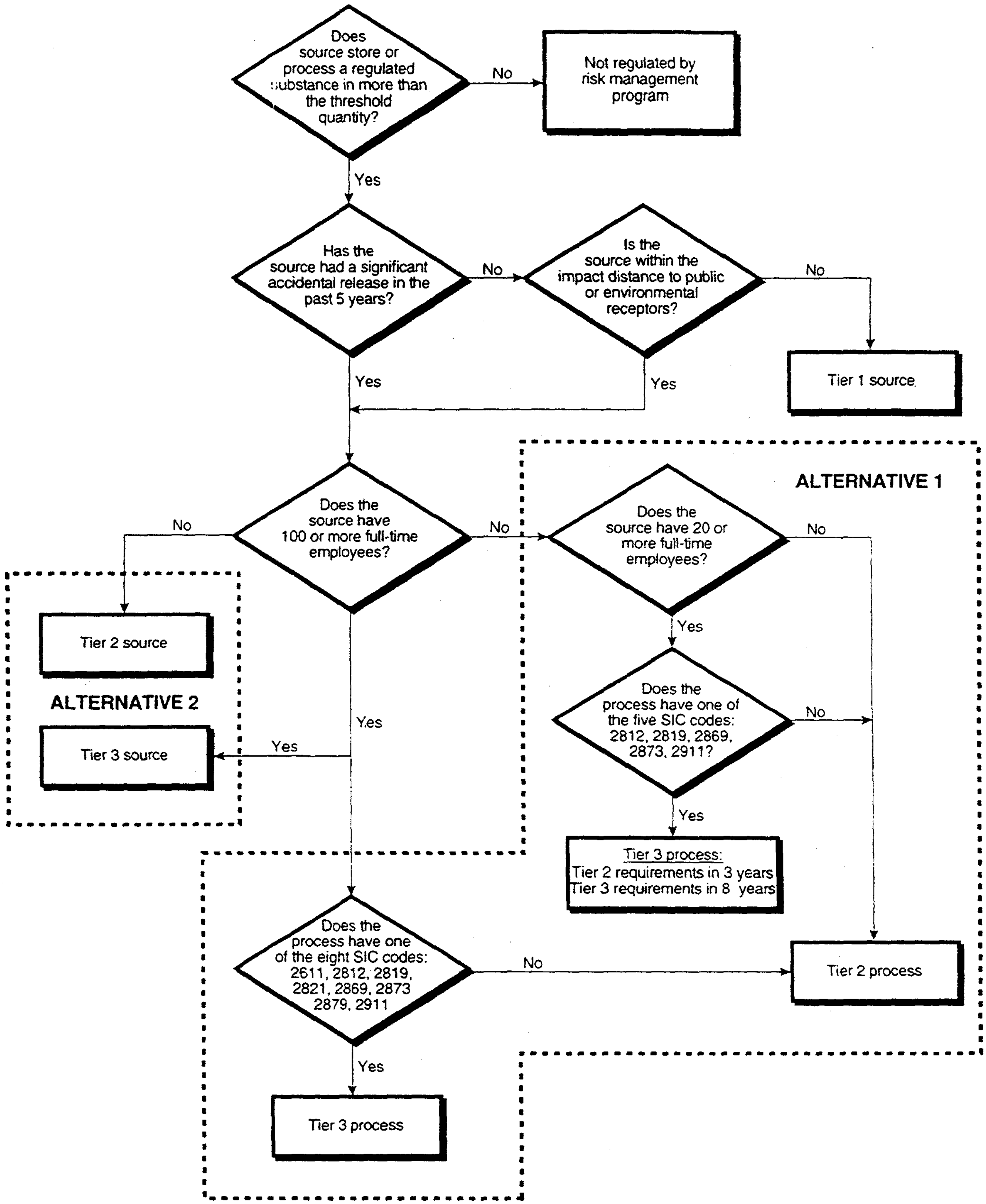

Figure 2. Procedure for Tier Categorization in EPA-RMP

Examples of such options include: outside secure storage of hazardous gas cylinders and controlled, well purged enclosures for a on line-cylinders indoors.

4.3 Prevent/Minimize Releases

The next step is to implement safety options to suppress a hazard when an accident initiating event occurs (e.g. flow restricting valves, cooling systems, double-containment with detectors and alarms, and adequate ventilation).

Releases can be prevented or reduced with fail-safe equipment and valves, adequate warning systems and controls to reduce and interrupt gas leakage. The first step in minimizing a gas release is a prompt detection of the leak. Toxic-gas detectors should be installed at critical locations inside the plant to provide prompt warning. It is very important that the detectors be placed where the maximum signal is expected. For example, a detector for a toxic gas that is heavier than air should be placed near the floor or the ground. A detector at a higher level will not produce a prompt signal because the gas may stay close to the ground for a considerable time. Monitors should be set at levels no greater than one-half the concentration level considered dangerous. If major leakage is detected, the flow of fluid to the leak point should be stopped immediately via emergency push-buttons and shut-off valves. Detector and alarm systems should be checked at every emergency drill. All personnel should be trained in what the various signals mean. All systems should have a back-up power supply (e.g., batteries), so that a power failure does not cause alarm malfunction. Emissions should be also monitored on all pollution control equipment to insure its proper performance. Ventilation exhausts should be periodically inspected for gas emissions, and scrubbers monitored for residual emissions.

Excess-flow valves and flow-limiting valves can increase the margin of safety by cutting-off the flow, and reducing the maximum flow through the valve, correspondingly. Flow-restricting valves currently are used for highly toxic gases (e.g., AsH_3, PH_3) in the photovoltaics industry. For a cylinder on 2000 psig pressure, the initial flow out of a wide open cylinder valve (e.g., opening of 0.25" diameter) will be approximately 2500 lpm; a 16 kg cylinder will be emptied in about one minute. A flow restricting valve with an orifice of 0.006" reduces the flow out of this cylinder to about 30 lpm which can much more easily controlled.

Isolation valves should be operated from a safe, remote location (e.g., a control room having a reliable fresh-air supply). Isolation valves generally should be "fail-safe" (e.g., closing on loss of instrument air or electric power). Check valves can also be used to prevent back-flow from a larger container to avert a leak. To assure reliable operation, these check valves should be checked periodically. Operating push buttons for actuating isolation valves and shutting off pumps should be located in the prevailing upwind direction, not far away from the equipment they control. A second emergency push-button should be located in the control room.

Double containment, in the form of either double wall storage tanks or double co-axial distribution lines and raceways, is an important measure against leaks of toxic gases into occupational space. Adequate ventilation also ameliorates the potential of dangerous exposures of workers to hazardous gases. A well designed ventilation system can protect employees from small leaks indoors. The system must be designed so that the hazardous gas is not directed past the workers. Thus, the system should provide air circulation to draw in hazardous emissions and direct their flow away from the workers' breathing zone. The system should draw in fresh air, not air from another section of the plant. Cooling systems (e.g., sprinklers in gas cabinets and raceways) must be used to suppress fire/explosion hazards if there is a leak or an abnormal increase of temperature in the gas system.

4.4 Control/Minimize External Release

If an accident occurs and safety systems fail to contain a hazardous gas release, then engineering control systems will be relied on to reduce/minimize environmental releases. If the release is confined, and can be diverted into the control equipment, chemical scrubbers, combustion chambers or adsorption columns (for low concentrations) can be used. Such systems are effective in controlling routine emissions of toxic gases, but their application in accidental large gas releases is not straightforward. The highly transient character of such releases demand special designs and configurations. As a general guideline, systems designed to control massive transient releases should meet the following criteria:

- They should be mechanically simple with a minimum number of moving parts and connections;
- they should operate under a wide range of conditions, given the uncertainty of release conditions; and
- they should assume fail-safe operation to the highest degree possible, through passive functioning and redundancy of components.

4.5 Prevention/Minimization of Human Exposures

As a final defensive barrier, the prevention of human exposures is needed if a hazardous gas is released, in spite of previous strategies. This barrier includes remote location of gas storage, exclusion zones adjacent to plant boundaries, early warning systems, emergency preparedness, response, and evacuation plans to prevent exposures to the public. Evacuation planning requires the formulation of plans and liaison with outside authorities, including emergency service personnel, appointment of key personnel and defining their duties, setting up emergency control centers, development of site action plans including fire-fighting procedures and rescue systems, and plant shut-down procedures.

4.6 Reduce Consequences

Prevention of consequences forms the final defensive barrier. Medical facilities near by that can accommodate victims of the worst accident, can reduce the consequences of personnel exposure to hazardous gases. Plant managers should provide local health agencies and hospitals with information about the materials which could be released offsite. These groups should work together, well in advance of any incident, to identify the appropriate medical treatments required to mitigate exposures to the public. Subsequently, appropriate medical personnel (e.g., fire department paramedics, and hospital emergency room staff) should be trained to respond to such incidents; specialized medical equipment and antidotes may be required. Experience has shown that in real emergencies, there is often much confusion. Hence, it is essential that such plans be regularly rehearsed and practiced under simulated emergency conditions to test the response of personnel, increase their base of experience, and evaluate the effectiveness of equipment.

The importance of the administrative options and procedures should be emphasized. In the chemical industry many accidents have happened not because safety engineering systems were lacking, but because safe procedures and preventive strategies were not followed. Management should show great vigilance in promoting safety and industrial hygiene in the work place and frequently reward employee contributions for a safer and cleaner environment.

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