Accident Prevention and Hazard Management for Photovoltaic Manufacturing Facilities

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ABSTRACT

Photovoltaic manufacturing facilities use many chemicals that can present EH&S risks. New EH&S challenges are created as manufacturing is scaled-up to meet a growing demand. In this new environment, preserving the safe and friendly to the environment nature of the technology becomes even more important. This paper presents a strategy for multi-layer protection of photovoltaic manufacturing facilities which emphasizes proactive measures but also includes mitigation options in case, in spite of all precautions, an accident occurs. Layers of prevention and mitigation are presented in six sequential steps. As the PV industry approaches these issues and mitigation strategies in a vigilant, systematic way, the risk to the industry, the workers, and the public will be minimized.

1. Introduction

Facilities fabricating photovoltaic cells use toxic and flammable substances, which, if not handled properly, could present EH&S risks. For the most part the quantities of hazardous materials used in the PV industry are minuscule in comparison to the amounts used by the chemical industry. Nevertheless, the future of the PV industry is connected to preserving its safe and environmentally friendly nature, and it must be assured that large-scale implementation does not endanger the public or occupational health and safety. Therefore, a multilayer approach on preventing and mitigating accidents is needed to eliminate the risks associated with hazardous materials. Such an approach is based on the military concept of defense in depth; if one line of defense fails, then others are available [1].

2. The Approach

Engineering and administrative options to prevent and control accidental releases and reduce their consequences can be considered sequentially in six steps (Figure 1), each one an additional layer of protection:

1) Inherently safer technologies, processes, and materials; 2) Safer use of material; 3) Options to prevent accident-initiating events; 4) Safety systems to prevent or minimize releases at the source; 5) Systems to capture accidental releases; 6) Options to prevent or minimize human exposures and their consequences.

2.1. Selection of technology, processes and materials

The most efficient strategy to reduce hazards is to choose technologies and processes that do not require the use of large quantities of hazardous gases. This is especially important for new technologies, where this approach can be implemented early in development before large financial resources and efforts are committed to specific options. Life-cycle considerations are necessary in evaluating technology options and the associated safety and environmental control costs because some technologies present mainly occupational risks (e.g., a-Si) while others carry mainly end-of-life concerns (e.g. CdTe). Environmental, health and safety criteria at the process level include the type and physical form of material used, the rate of its use, and operation and maintenance requirements.

2.2. Safer utilization of materials

This strategy can be implemented in several ways: a) substitution (i.e., using safer materials or environmentally more benign ones), b) using a safer, source of a hazardous material (e.g., new subatmospheric pressure dopant sources and internally pressure regulated silane sources); c) reducing the quantity needed of a hazardous material; d) reducing its concentration; and e) increasing material utilization rate. The alternatives need careful evaluation because there are frequently both advantages and disadvantages associated with every option. Specific suggestions for safer material utilization can be found elsewhere [2].

2.3. Prevention of initiating events

Once specific materials and systems have been selected, strategies to prevent accident-initiating events need to be evaluated and implemented. U.S. facilities that handle highly hazardous chemicals above certain threshold quantities are required to comply with OSHA's Process Safety Management (PSM) rule and EPA's Risk Management Program (RMP). Some of the listed materials are, or have been, used in PV manufacturing (e.g., AsH_3, BCl_3, BF_3, B_2H_6, HF, H_2Se, H_2S, PH_3, SiH_2Cl_2, H_2, SiH_4, and $SiHCl_3$). Today's PV industry is not subject to compliance with these rules because the amounts used in such facilities generally are lower than the threshold quantities. Nevertheless, a proactive approach on minimizing risks is to the utmost advantage of the PV industry and, therefore, the

OSHA and EPA provisions are being used as guidance to the managers of PV facilities that handle highly hazardous materials. The most important item in the PSM rule is the Process-hazard analysis, which has to be formal and rigorous. Hazard analyses focus on equipment, instrumentation, utilities, human actions, and external factors that might impact the process and cause an accident-initiating event.

2.4. Prevention and minimization of releases

The next step is to implement safety options to suppress a hazard when an accident-initiating event occurs (e.g., inherently safer design of process, gas distribution and storage systems, early detection, flow-restricting and isolation valves, cooling systems, double-containment and adequate ventilation). Currently, most R&D and manufacturing facilities are using compressed-gas cylinders for toxic and flammable inorganic hydrides and other gases. Prevention options to enhance the safety of such systems include a) system integrity, b) outside storage, c) explosion-proof banker, d) remotely operated cylinder valves, e) automated purging, f) continuous toxic gas monitoring, g) flow restrictors, h) double containments, i) redundancy of critical systems, j) ventilation, and k) biomonitoring. Specific on these options can be found elsewhere [2].

2.5. Control and minimization of releases to the environment

If an accident occurs and the safety systems fail to contain a release of hazardous gas, then personal and engineering control systems must be relied upon to reduce or minimize environmental releases. Self-contained breathing apparatus (SCBA), spill control and other safety equipment should be available for quick use in all areas where there is the potential for an accidental release. If the release is confined and can be diverted into the control equipment, then wet scrubbers, adsorption units, and combustion devices can be used. The highly transient nature of large, accidental gas releases demands special designs and configurations for these systems. Wet scrubbers with high liquid flow and fast-reacting reagents can treat leaks from process-equipment exhaust, fume-hood exhaust and gas-cabinets vents. Adsorption units called "scrams" also can be used for accidental releases of dilute mixtures of hazardous gases.

2.6. Prevention and minimization of exposures

As a final defensive barrier, human exposures must be prevented if a hazardous gas is released. This barrier includes storing the gas in a remote location, having exclusion zones adjacent to plant boundaries, and having early warning systems, emergency preparedness, and response and evacuation plans, to prevent the public's exposure. It is essential that such plans are 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. Quick response and medical preparedness is essential to reduce consequences if exposures occur.

3. DISCUSSION

Accidental releases of hazardous gases and vapors can cause significant occupational risks. It is of the utmost importance for the future of the PV industry to prevent and minimize accidental releases of hazardous gases by choosing safer technologies, processes, and materials, using materials more efficiently and in safer forms, using reliable automated gas-handling-systems, and emphasizing employee training and safety procedures.

REFERENCES

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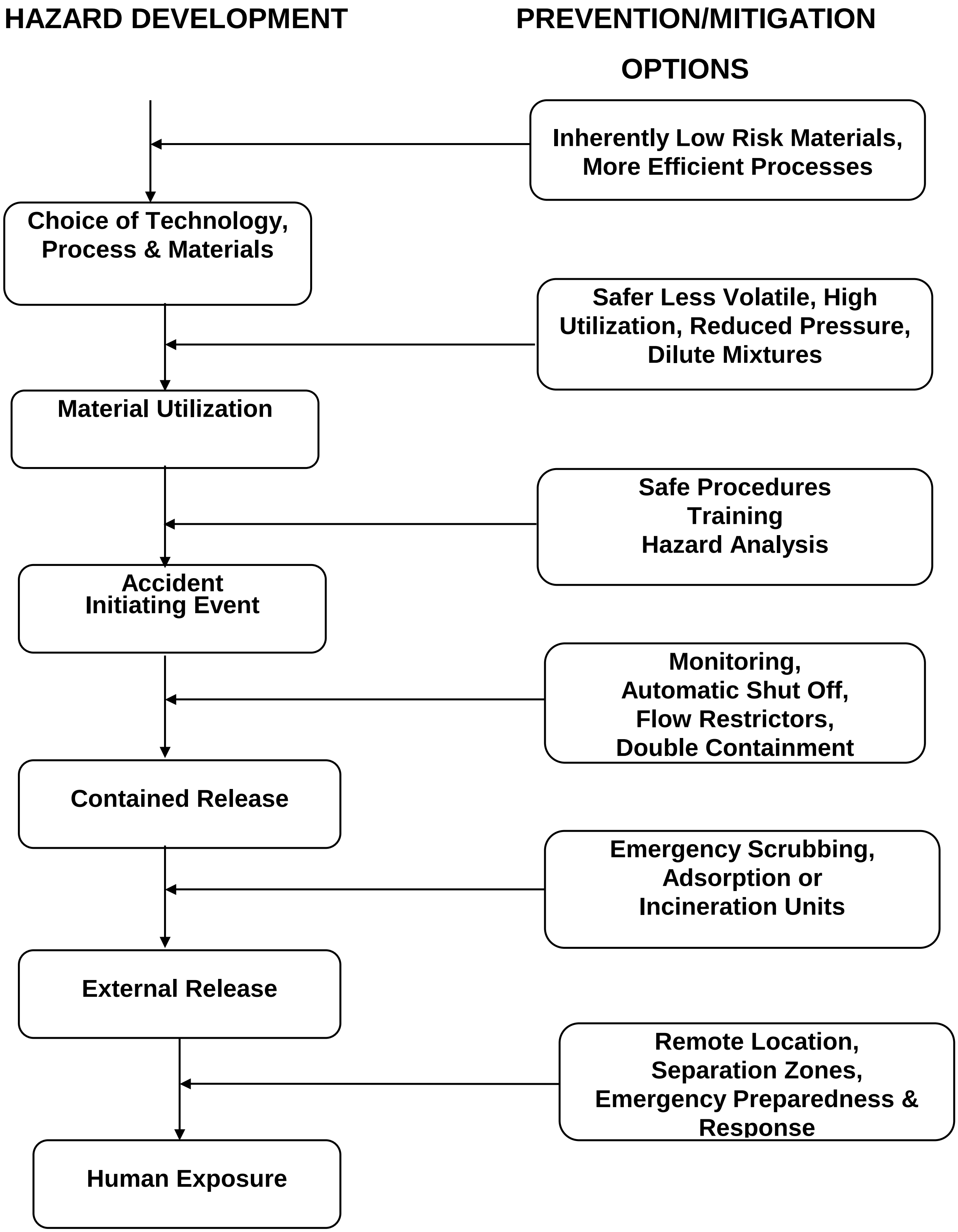

Figure 1. Prevention and Mitigation of Accidental Releases of Hazardous Gases