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AN OVERVIEW OF SAFETY ASSESSMENT, REGULATION, AND CONTROL OF HAZARDOUS MATERIAL USE AT NREL

B. P. Nelson, R. S. Crandall
National Renewable Energy Laboratory, Golden, CO 80401

P. D. Moskowitz, V. M. Fthenakis
Brookhaven National Laboratory, Upton, NY 11973

ABSTRACT

This paper summarizes the methodology we use to ensure ~~the safe use~~ of hazardous materials at the National Renewable Energy Laboratory (NREL). First, we analyze the processes and the materials used in those processes to identify the hazards presented. Then we study federal, state, and local regulations and apply the relevant requirements to our operations. When necessary, we generate internal safety documents to consolidate this information. We design research operations and support systems to conform to these requirements. Before we construct the systems, we perform a semiquantitative risk analysis on likely accident scenarios. All scenarios presenting an unacceptable risk require system or procedural modifications to reduce the risk. Following these modifications, we repeat the risk analysis to ensure that the respective accident scenarios present an acceptable risk. Once all risks are acceptable, we conduct an operational readiness review (ORR). A management-appointed panel performs the ORR ensuring compliance with all relevant requirements. After successful completion of the ORR, operations can begin.

INTRODUCTION

NREL conducts research on virtually the entire spectrum of renewable energy technologies. A portion of NREL's internal research activities is in advanced material technologies for photovoltaic (PV) applications. The fabrication of PV devices often involves the use of materials, chemicals, and processes with intrinsic hazards.

These hazards include the use of toxic, corrosive, flammable, and pyrophoric gases, liquids, and/or solids; known as hazardous production materials (HPMs) under the Uniform Fire Code (UFC - Section 51.102) [1]. The NREL systems using these chemicals are not production-scale operations. The quantities of chemicals in use are small. However, they have one or more hazard rankings of 3 or 4 and are used directly in research processes. Therefore, they meet the definition of an HPM.

We present in this paper a methodology for ensuring the safe use of HPMs in our facilities. In the past, the elements of this methodology were applied informally. Recently, with the assistance of Environment, Safety, and Health (ES&H) experts from Brookhaven National Laboratory (BNL), we have formalized the process. Figure 1 is a flow chart that illustrates the individual steps of this methodology.

IDENTIFICATION OF HAZARDS

The first step in this process is the identification of hazards. There are basically two areas that we investigate to identify hazards. First we look at the materials involved in PV device fabrication. By analyzing the material safety data sheets and

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METHODOLOGY FLOW CHART

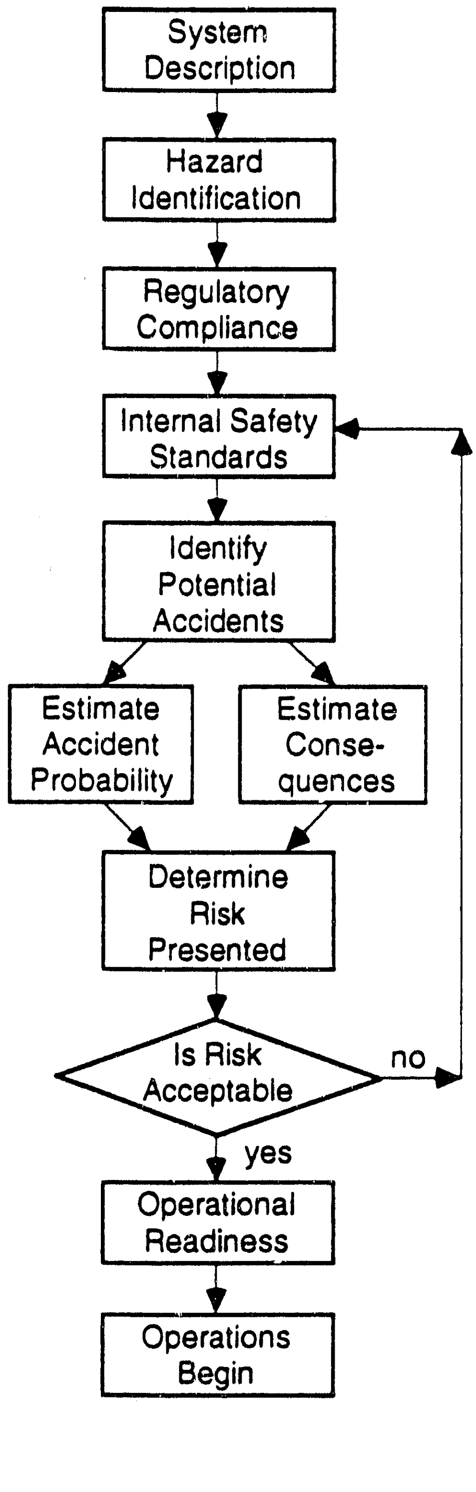

Figure 1

other information available on the materials (e.g., [2, 3, 4]), we identify the respective hazards. This includes both hazards to human health and safety and environmental impact. Then we analyze the actual system design and specifications for unusual hazards (e.g., high radio frequency fields, explosion or implosion hazards, and exposed thermal or electrical hazards).

The principal hazard associated with PV device fabrication at NREL arises from the use and handling of HPMs. Exposure to these chemicals can produce acute or chronic health problems—even death. During normal operation, the principal potential sources of human exposure to these chemicals include handling and transportation to laboratories, gas or liquid cylinder change-out, failure of the gas distribution system, ventilation failure, failure of effluent treatment, and waste disposal. Additional sources of exposure include major incidents such as fire, explosions, floods, tornadoes, and earth quakes.

REGULATORY COMPLIANCE

Once we identify the hazards associated with a particular operation, we turn to known sources of regulation and control to reduce the risks associated with these hazards. Occasionally, we generate internal documents that summarize specific requirements of regulatory agencies that apply to NREL operations. Examples of relevant internal documents are "Environment Safety and Health Policies and Procedures," "Standards for the Safe Handling, Use and Monitoring of Toxic Gases," "Emergency Response Procedures to the MDA Toxic Gas Monitor," "Laboratory Chemical Hygiene Plan," "Emergency Preparedness Manual," and the "Safety Analysis Report for the Use of HPMs in PV Applications at NREL."

At the federal level, key regulatory requirements with respect to NREL, HPM operations are as follow: Those imposed by OSHA; CFR #'s 1910.101 (compressed gases), 1910.132 (personal protective equipment), 1910.1000 (worker exposure), and 1910.1450 (laboratory chemical hygiene). Those imposed by the Environmental Protection Agency; the Resource Conservation and Recovery Act (RCRA), the Comprehensive Environmental Response, Compensation and Liability Act (CERCLA), and the Superfund Amendment Reauthorization Act (SARA) -- Title III. Those imposed by the United States Department of Transportation; especially with regard to the transportation of HPMs over public roads.

The National Fire Protection Association (NFPA) develops national consensus standards related to the protection of life and property from fire risks. Local code enforcement authorities may adopt these standards in whole or part. Relevant NFPA standards to PV operations include NFPA 101 (Life Safety Code), NFPA 70 (National Electric Code), and especially NFPA 45 (Standard on Fire Protection for Laboratories Using Chemicals).

For NREL, the local building departments and fire districts have adopted the Uniform Building Code (UBC), Uniform Mechanical Code, Uniform Plumbing Code, UFC, and the National Electric Code. Of particular importance to NREL's HPM operations are the UBC and the UFC. The basic premise of the UBC is that there must be a general correlation between the level and type of "risk" associated with activities or substances housed in a building and the level and type of safety features provided in the construction of the building. The UFC prescribes regulations governing conditions hazardous to life and property from fire and explosion, provides for the issuance of permits, and establishes a bureau of fire prevention. The Uniform Codes apply to the western portion of the United States. However, the basic requirements of the codes that apply to HPM operations are applicable to any facility as a best management practice, regardless of location.

Article 80 of the UFC provides specific requirements for the prevention, control, and mitigation of dangerous conditions as a result of hazardous material use. It is the primary article regulating operations within a B-2 occupancy under the UBC (e.g., general office buildings such as NREL's Building 16). Operations within a UBC, H-6 occupancy (e.g., the amorphous silicon deposition laboratory in NREL's Joyce Street Facility) also are subject to Article 51 of the UFC that is specific to semiconductor fabrication facilities using HPMs. Occupancy classification increases from B-2 to H-6 when the quantity of any HPM exceeds threshold values established in the UBC.

Critical to the continuing safety of personnel is an ongoing safety assessment of operations. We develop separate protocols, known as Safe Operating Procedures (SOPs), for each deposition system using HPMs. These SOPs cover all safety aspects of the operation of individual systems. In order to ensure that these SOPs remain relevant and effective, they undergo an annual review and approval by NREL line management and the NREL Safety and Security Office (SSO).

OPERATIONAL SAFETY LIMITS

After the identification of all relevant regulatory requirements, we incorporate them into internal safety standards known as operational safety limits [5]. Operational safety limits are auditable boundaries of operation that are not to be exceeded during normal operation. They define the conditions, safety boundaries, and controls needed to ensure that the facility operates within the defined guidelines. This includes administrative and engineering controls and personal protective equipment standards.

We consider each of the following items when developing engineering controls for a system using HPMs: distribution systems for HPMs (gases, liquids and solid may be handled differently), reaction vessels and deposition chambers, effluent removal, exhaust systems (local and building-wide), safety interlocks, and storage facilities. NREL has internal safety standards that address the following: SOPs, responsibilities of various personnel, HPM procurement procedures, HPM transportation procedures, training, inspections and audits, and communications (e.g., signs). When necessary, we provide the following personal protective equipment: emergency response team stations, toxic gas monitoring, flammable gas (e.g., hydrogen) monitoring, corrosive gas monitoring, self-contained breathing apparatus, emergency communication stations, and oxygen (for exposure to hemolytic agents).

RISK ASSESSMENT

After identifying hazards and incorporating all required internal safety standards into system and facility design, we perform a risk analysis. It is a semiquantitative risk analysis rather than a more comprehensive probabilistic safety analysis similar to those used by nuclear power plants or large production facilities. This is because of several factors: the small scale of the research activities, the dynamic nature of the programs, and the lack of hard failure-rate data for much of the equipment used by these systems. The risk methodology presented in this section comes directly from internal safety standards at BNL [6]. As a part of Figure 1, we diagram all of the steps involved in this risk assessment.

As a first step in this risk analysis, we identify a series of potential accidents based on industry experience and the expert judgment of personnel from NREL and BNL. These potential accident scenarios must be credible, while pushing the limits of experience. It is better to analyze an accident before it occurs then after, no matter how unlikely that accident may appear.

We estimate the probability of these accidents occurring from experiences at NREL and in industry, and from failure rate data when available. We divide event probabilities into six different classes (see Figure 2): Impossible (physically impossible to occur), Extremely Remote (the probability of occurrence is indistinguishable from zero), Remote (not likely to occur in the life cycle of the system), Occasional (likely to occur sometime in the life cycle of the system), Reasonably Probable (likely to occur more than once during the life cycle of the system), and Frequent (likely to occur many times during the life cycle of the system).

In a similar way, we divide the consequences should these accidents occur into four different classes (see Figure 2): Negligible (will not result in injury, occupational illness, or system damage), Marginal (may cause minor injury or occupational illness, or minor system damage), Critical (may cause severe injury or occupational illness, or moderate system damage), and Catastrophic (may cause death or system loss). We base the estimates of potential consequences on experience, published literature, and, when appropriate, detailed numeric calculations developed for individual accident scenarios.

We then combine the accident event probabilities and consequences to determine a semiquantitative measure of risk. It is analogous to a multiplication table: risk = probability × consequence. We determine the risk of a potential accident by looking up its value based on the intersection of the probability and consequence in the risk assessment matrix provided in Figure 2. There are four final categories that describe the level of risk associated with a potential accident. They are: Routine Risk, Low Risk, Moderate Risk, and High Risk. An event with a critical consequence is a low risk if the probability of that event occurring is remote or extremely remote. Similarly, an event with a critical consequence is a high risk if the probability of that event occurring is reasonably probable or frequent.

RISK ASSESSMENT MATRIX

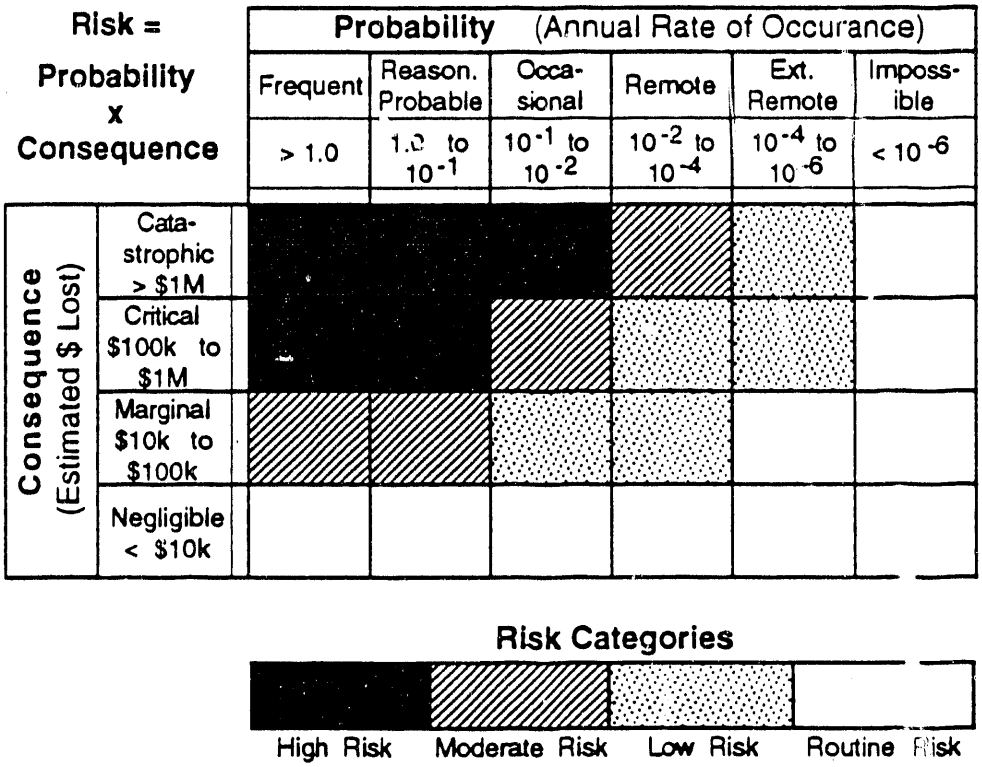

Figure 2

Events classified as "Routine Risk" are no different from those experienced by any individual in his or her daily life. "Low Risk" events are those that may have an impact within a facility and little or no impact to adjacent facilities or health or the environment. "Moderate Risk" events are those with considerable potential impacts within the facility or to people or to the environment, but, at most, only minor impact off-site. "High Risk" events are those with the potential for on-site and off-site impacts on large numbers of persons or a major impact on the environment. As the risk increases, the need for additional controls increases, and the possible acceptability of any option declines.

If a given accident scenario presents a moderate or high risk, it is unacceptable. Subsequently, we modify the system design or administrative controls to reduce either the consequences or the event probability such that the risk becomes acceptable. We incorporate these changes in both the internal safety standards and the system operation.

Once the risks presented by all foreseen, potential accident scenarios are acceptable, we construct and/or modify the systems to incorporate all the requirements of the internal safety standards.

OPERATIONAL READINESS

Before users can install the HPMs and operate systems, they must undergo an ORR by a management-assigned panel. The objective of the ORR panel is to ensure that there is compliance with all necessary ES&H requirements before HPM operations proceed. The ORR process addresses the physical and procedural requirements established in the internal safety standards for both laboratory and specific support departments. The ORR panel members do not perform reviews of research activities in which they have routine involvement.

Once an operation satisfies the established ES&H requirements, the ORR panel submits a recommendation to authorize operation to appropriate management. If, after a final review, there are open items that present an unacceptable risk, the ORR panel will submit a report of open items to the research staff and require another review. If there are open items that do not present unacceptable risks, the ORR panel will submit a conditional recommendation to authorize operation that may include operational restrictions. The Safety and Health Section retains copies of all ORR documents.

CONCLUSIONS

NREL centers its mission around research to provide a cleaner and brighter future. We can ill afford incidents that compromise ES&H. The methodology outlined in this paper is by no means a quick fix to preventing accidents. It takes a large amount of effort; from the conceptual stage through the operation of systems. Even after HPM systems are fully operational, it requires diligence to maintain the ES&H standard initiated by this process. However, the old adage, "an ounce of prevention is worth a pound of cure," is appropriate here. A poorly planned HPM system, with regard to ES&H, could result in subsequent shutdown or worse—an accident resulting in injury or death.

As the world gets more crowded, we become more aware of how everything we do affects those around us. Therefore, when we compile our list of priorities we suggest that ES&H does not always go at the top of the list, as the number one priority that many people advocate. It is better to view ES&H as the paper on which the lists of priorities are written. It must be an integral part of all that we do in the laboratory. Priorities can, and do, switch position and change.[7] With this view of ES&H, it becomes woven into all laboratory priorities as a foundational element. It is not an afterthought or a line item that is removable from the process.

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