HYDROGEN SAFETY: FROM POLICIES TO PLANS TO PRACTICES

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ABSTRACT

Safety is an essential element for realizing the "hydrogen economy" – safe operation in all of its aspects from hydrogen production through storage, distribution and use; from research, development and demonstration to commercialization. As such, safety is given paramount importance in all facets of the research, development and demonstration of the U.S Department of Energy's (DOE) Hydrogen, Fuel Cells and Infrastructure Technologies (HFCIT) Program Office. The diversity of the DOE project portfolio is self-evident. Projects are performed by large companies, small businesses, DOE National Laboratories, academic institutions and numerous partnerships involving the same. Projects range from research exploring advances in novel hydrogen storage materials to demonstrations of hydrogen refueling stations and vehicles. Recognizing the nature of its program and the importance of safety planning, DOE has undertaken a number of initiatives to encourage and shape safety awareness. The DOE Hydrogen Safety Review Panel was formed to bring a broad cross-section of expertise from the industrial, government and academic sectors to help ensure the success of the program as a whole. The Panel provides guidance on safety-related issues and needs, reviews individual DOE-supported projects and their safety plans and explores ways to bring learnings to broadly benefit the DOE program. This paper explores the approaches used for providing safety planning guidance to contractors in the context of their own (and varied) policies, procedures and practices. The essential elements that should be included in safety plans are described as well as the process for reviewing project safety plans. Discussion of safety planning during the conduct of safety review site visits is also shared. Safety planning-related learnings gathered from project safety reviews and the Panel's experience in reviewing safety plans are discussed.

1.0 THE CONTEXT FOR SAFETY AND THE HYDROGEN ECONOMY

Safety is an essential component of the emerging hydrogen economy. Hydrogen's use for nearly a century in the manufacturing, chemicals and aerospace industries provides valuable experience and knowledge in its safe production, shipping and use. At this moment, there are numerous small demonstration projects around the world with hydrogen vehicles and refueling stations, stationary and mobile applications, as well as substantial research activity in hydrogen production, storage, fuel cells and related technologies. The Hydrogen Program of the U.S. Department of Energy encompasses this breadth to support efforts to ultimately realize hydrogen as a commercial energy carrier.

Demonstration projects are believed by many to be the first step towards realizing a hydrogen economy. In this early stage, it is important to assess and implement plans for mitigating unintended safety events, determine the cause of the events so that lessons can be learned and evaluate automated systems to mitigate potential high risk incidents. The seamless coordination from suppliers to original equipment manufacturers in such projects is essential to realizing these safety learnings.

The public's perception of hydrogen and safety also needs to be addressed. Education at all levels – from the general public to consumers to emergency responders – is essential to improve the awareness and understanding of hydrogen properties and its differences from current conventional fuels. For example, since hydrogen is the lightest element, it is very buoyant and disperses readily in air. It behaves very differently from the gasoline used to power the conventional vehicles of today.

We are currently in the “learning phase” of the hydrogen economy – researching, developing and demonstrating technologies to proof-of-concept of the fuel cells in vehicular, mobile and stationary applications. Safety data, information and lessons learned will be invaluable for realizing these applications. Collecting, analyzing and disseminating the safety knowledge gained is an imperative toward getting the hydrogen economy moving forward.

2.0 THE HYDROGEN SAFETY REVIEW PANEL

The Hydrogen Safety Review Panel, formed in December 2003, brings substantial experience in industrial hydrogen production/supply/use, government R&D, industrial liability and facility insurance, risk analysis, accident investigation and fire protection and is backed up with technical support from the National Laboratories. The Panel members are noted in Table 1; Edward Skolnik, Energetics, Inc., and Steven Weiner, Pacific Northwest National Laboratory, provide technical and management support to the Panel whose activities are focused on several key objectives:

- Provide expertise and guidance to the DOE and assist with identifying areas of additional research necessary to fill safety information gaps

- Integrate safety procedures into all DOE project-funding procurements to ensure that all projects incorporate hydrogen safety requirements.

- Publish a handbook of “Best Management Practices for Safety” (2007)

The Panel has undertaken a number of specific initiatives. DOE-funded hydrogen projects are required to submit a safety plan as an early project deliverable. Safety plans, utilizing DOE and Panel-developed guidance as a resource [1], focus on the identification and analysis of safety vulnerabilities, mitigating the associated risks, ensuring an effective communications plan and other information. The Panel reviews each safety plan utilizing a checklist they have developed and makes any needed recommendations to DOE for improvement.

Table 1. U.S. Department of Energy Hydrogen Safety Review Panel (as of June 1, 2005)

Addison Bain, Chair	NASA (ret.)
Carol Bailey	Sentech
Harold Beeson	NASA White Sands
William Doerr	FM Global Research
Don Frikken	Becht Engineering
James Hansel	Air Products and Chemicals
Richard Kallman	City of Santa Fe Springs, CA
Harold Phillippi	ExxonMobil Research and Engineering
Jesse Schneider	Daimler Chrysler
R. Rhoads Stephenson	Jet Propulsion Laboratory (ret.)
Robert Zalosh	Worcester Polytechnic Institute

Another important effort of the Panel is conducting site visits to perform safety reviews of DOE-funded projects that cover R&D in hydrogen production, storage and fuel cells, as well as demonstration projects that include hydrogen refueling stations. Site visits are an opportunity for the contractor/project team and the Panel review team to:

- Share and discuss new insights that bear on safety
- Address project-specific safety issues
- Identify project-specific findings that can have a broader benefit in the DOE program.

A meeting template helps shape the site visit and is intended to focus on engagement and discussion rather than as an audit, investigative or regulatory exercise. The conduct of these site visits and emerging themes and learnings have been recently presented in more detail.[2] Topics and learnings that focus on safety planning are addressed later in this paper.

In a third initiative of the Panel that bears on safety planning, all DOE project teams are currently responding to a safety questionnaire (see Appendix I). The responses will be analyzed to suggest what benefits might be derived and learnings brought to the DOE project portfolio as a whole.

The following sections of this paper address various aspects of project-specific safety planning for the DOE Hydrogen Program.

3.0 GUIDANCE FOR SAFETY ASPECTS OF PROPOSED HYDROGEN PROJECTS

The "Guidance for Safety Aspects of Proposed Hydrogen Projects" [1] was developed to aid DOE project teams in developing a comprehensive safety plan and program. The document defines the safety plan requirement, provides details as to what must be included in a safety plan and gives examples of methodologies which may be utilized.

3.1 Identifying and Analyzing Safety Vulnerabilities

The foundation of any risk mitigation plan is the identification of safety vulnerabilities (ISV) within the system. The ISV may be accomplished by a number of different methodologies, all with the same goal: to systematically identify potential weak points within the system being analyzed. Common techniques include Hazard and Operability Analysis (HAZOP), Failure Modes and Effects Analysis (FMEA), "What-if" Analysis, and Checklist Analysis. There are other techniques that may be utilized as well, each with their own strengths and weaknesses and rationales for application. In order to perform a comprehensive study, it is critical that the assembled team consists of personnel knowledgeable on the system being analyzed. If teams are comprised of less experienced individuals, they may fail to identify hazards or they may generate recommendations where none are warranted. Typical composition of the team includes a team leader/facilitator, process engineer and individuals representing operations, maintenance, instrumentation (this can vary based on the size of the system being assessed), and an individual that acts as the team scribe. Additionally, a person representing management who is empowered to make decisions on recommendations is of critical importance. The ultimate success (or failure) of the assessment is highly dependent on the ability of the leader. The leader must spend a significant amount of time preparing for the study and must facilitate discussion amongst the team members.

A great deal of documentation must be developed prior to the study. Piping and instrumentation diagrams (P&ID) must be drawn; safe upper and lower process limits for parameters such as temperature and pressure must be identified; operating procedures must be written; datasheets for equipment must be available. Without all of these items, the team will not be productive as too many undefined parameters will slow the team's progress. Additionally, it must be recognized that the ISV may be a long, time consuming process (depending on the size of the system), and personnel may be committed for an extended period of time.

There are a number of pitfalls that must be avoided when conducting these technical studies. Some common issues that arise are identified below.

- **Lack of understanding by management of the time commitment needed to produce a successful study.** As previously stated, the ISV can consume a significant amount of time and resources which may take personnel away from other tasks they normally perform.

- **Lack of experience by the team leader.** If the team leader is not technically strong and cannot facilitate productive discussion between the team members, the ISV may not adequately address all vulnerabilities.

- **Use of outdated documents.** Studies are sometimes performed without first checking to ensure that P&IDs and other documents are up to date. For example, if valves have been removed or control instrumentation has been changed, recommendations may be made that are no longer valid or may be detrimental to the operation.

- **Addressing all aspects of the operation.** Normal start-up and shut-down, as well as emergency start-up and shut-down procedures, should be included.

- **Failure to consider existing safeguards.** Many processes have existing safety systems. When an ISV is performed, scenarios are typically identified based on the lack of any system safeguards. Subsequently, scenarios should be analyzed taking into consideration any existing safety equipment (provided the equipment will survive the initiating event). Failure to consider these safeguards may generate recommendations that are unnecessary and potentially take away resources from other more relevant scenarios.

Once the ISV has been completed, the “risk” of the potential accident scenarios must be analyzed. In order to characterize the risk associated with a project, two elements are examined: the likelihood of the event occurring, and the potential consequences associated with the scenario. A “score” is established for each of the scenarios, and potential safeguards are proposed to mitigate the risk to an acceptable level. A degree of difficulty is encountered during this phase of the analysis, as the team must determine what level of risk is acceptable. There is no way that all risk can be eliminated as there are simply not enough resources available to design a system that is completely void of risk. Team members can have very different views of what is acceptable depending on their background and involvement in a project. Management may have one opinion on what is acceptable, while individuals performing work on the system may have a completely different assessment. If an accident scenario can impact the surrounding community, local politics may influence these decisions.

3.2 Mitigating Risk

Once all the risks identified in the ISV have been ranked, the mitigation process begins. During the ISV study, it is important not to have the ISV team get bogged down by the details of how to manage the risk. The team’s job is solely to identify the weak points within the system. Subsequently, decisions take place on the best course of action to mitigate a potential release. Engineering controls, personnel training, personal protective equipment (PPE), maintenance programs, and operating procedure modifications are just a few of the strategies that can be utilized to aid in the mitigation of the identified risks.

In most instances, engineering controls are the preferred method to mitigate risk. Both active and passive engineering controls should be considered. These types of controls often take the “human element” out of the equation. For hydrogen related projects, examples of active controls may include sensors, interlocks, ventilation systems, and excess flow valves. A canopy of a given shape over a hydrogen dispensing system is an example of a passive engineering control. In the engineering design stage, it is important to design the canopy such that hydrogen cannot accumulate and become trapped underneath the cover. While engineering controls may be the preferred method of risk mitigation, they are not always feasible. In many instances, releases have occurred due to improper employee action. Failure to implement an effective training program could have major impacts on the safety of a project (even with the best engineered control system). Training programs must be regularly evaluated to determine their effectiveness. With hydrogen's unique properties, specific training related to hydrogen should be mandated for all projects that deal with this material. Employees should be provided with an initial training program and should have refresher training when new job tasks are assigned or at intervals determined to be appropriate related to the employee's experience and assignments.

A final element related to risk mitigation which bears discussion is the development of an emergency response plan and coordination with emergency responders. Facilities which utilize hydrogen must determine how they wish to handle emergencies. Are they going to evacuate the area and call for local responders? Do they plan to take offensive action to mitigate a release? Is there a coordinated response effort between facility personnel and local responders? If a facility decides to have their own response team, they must ensure that the team is appropriately trained (there are many OHSA requirements related to emergency response) and has the necessary equipment to effectively respond to an emergency. If the facility plans to evacuate and let local emergency responders handle the incident, it is imperative that the local responders are familiar with the facility and the hazards associated with the site. If there is a coordinated effort, drills must be held to enable the teams to practice together. Otherwise, there will not be any familiarity between the teams and the coordinated response may be ineffective.

It is important to realize that there are many ways to mitigate risk. An effective risk mitigation program may be comprised of many different elements to ensure that safety is maintained. Risk mitigation should be an iterative process in which releases or threatened releases are evaluated and any lessons learned are fed back into the ISV process for assessment.

3.3 Communicating Safety

Communication plays a very important role in the life cycle of risk mitigation. Different target audiences must be addressed based on the scope of the project. Facilities working on similar projects should be able to learn from incidents that occur at other sites. In this way, the "sharing" of information can create a safer environment for all involved. The development of a repository for hydrogen safety data and information and the publication of a database is one of the technical tasks in the DOE Multi-Year Research, Development and Demonstration Plan (MYPP).[3] The information contained within the database should be accessible to anyone working with hydrogen so that safety data and information and incident learnings can be shared across the breadth of the DOE Hydrogen Program. Through site visits and safety reviews, the Hydrogen Safety Review Panel has already documented learnings and incident information that is relevant to numerous projects.

Another critical element related to risk communication is involvement of the public when a project has the potential to impact the community. Although this aspect of communication is not currently discussed in the guidance document, there are projects that have faced opposition from public groups that do not want hydrogen in their community. There is a great deal of public concern related to hydrogen due to lack of information and outreach. Through education and communication, these fears can be overcome and projects can proceed. It is critical that project teams partner with community leaders where the public is involved. By establishing and maintaining dialogue with community members, the risks associated with a project can be discussed and there is an opportunity to provide information on safeguards that are being implemented to reduce the risks to the community. There are many guidance documents available on this important topic.[4,5] If risk communication is not handled properly, political pressure can cause a project to fail regardless of how safe the project may be.

4.0 SAFETY PLANNING – THE PROCESS AND THE OUTCOME

As noted previously, the HFCIT Program Office requires all newly-funded projects to submit a safety plan. The safety planning process highlighted here consists of collecting, evaluating, and providing feedback in the early stages of a project to encourage practices and awareness that will result in an environment where safety is an integral component of all funded projects.

4.1 Collecting and Reviewing Safety Plans

Safety plans are submitted to the DOE contracting office through a Web-based interface. The safety plan is date-stamped and forwarded to both the technology development manager (TDM) responsible for safety as well as the TDM responsible for overseeing the project as a whole. The safety TDM is the responsible party for initiating the review process.

Concurrently with DOE's evaluation of the safety plan, the Hydrogen Safety Review Panel coordinator and 1-2 members provide review, comments and recommendations on whether to accept or reject each plan. In evaluating the plan, the emphasis is placed on bringing the expertise of individual Panel members to bear on safety aspects of the project. Although a formal scoring system for evaluation is not utilized, some of the factors that Panel members consider are as follows:

- Does the plan provide a good sense of how the policies and procedures of the organization are implemented down to the project and staff levels for this specific project?

- Does the plan reflect the key areas of sound and thoughtful identification and analysis of safety vulnerabilities, risk mitigation and communications as noted in the guidance document?[1]

- Does the plan reflect a desired nature that it be a "living document" and, therefore, discuss safety considerations relevant to the course of the project, e.g. management of change, dissemination of learnings, etc.?

Emphasis is placed on performing these reviews in an efficient and timely manner so an online review tracking database for safety plans, review schedules, status notes, reviewer assignments and other pertinent information is maintained. Good communication is an essential ingredient for the process to work effectively.

4.2 Feedback and Recommendations

The HFCIT Program Office exercises the responsibility of collating DOE's review comments with those of the Panel and providing DOE's recommendation to the performing organization. In some cases, follow-up meetings via telephone, e-mail or in person may be needed to guarantee that all recommended safety issues are fully discussed and resolved. It is important to note that a safety plan review may also conclude with recommendations for change or corrective action required for continuing execution of a project.

5.0 SAFETY PLANNING – LEARNINGS AND OBSERVATIONS

At this writing, only a limited number of safety plans have been fully developed, reviewed and implemented under the previously mentioned guidance document. However, safety planning has been an integral part of project safety review site visits and part of the meeting template which has included Q&A discussions on this subject. In conjunction with the safety plan review, the Panel site visits are very important as simply reviewing a safety plan may not yield an accurate assessment of the safety practices at a facility.

5.1 The Template for Safety Planning Q&A

The meeting discussion on safety planning during the project safety review site visits is focused on the three topics discussed in Section 3.0: (1) identification and analysis of safety vulnerabilities, (2) risk mitigation plans, and (3) communications plans. This discussion supplements the project team's presentation(s) that provide an overview of the project as well as the organization-wide safety policies and procedures. Particular emphasis is placed on the latter as to how these policies and procedures are implemented and managed for a given facility down to the project and staff levels. The Q&A format takes the following approach:

- Safety Vulnerabilities – How do you assess the safety risks that are/will be present during the implementation of your project? Do you use established qualitative or quantitative measures or one(s) of your own design?

- Risk Mitigation – What approaches and methodologies are used to reduce the identified risks?

- Communications – How are safety reviews conducted during the design, development and operating phases of the project? How are safety incidents and "near-misses" documented and reported and the resulting "lessons learned" shared.

For example, a number of risk mitigation topics are addressed during the Q&A: personnel training, management of change, measuring/monitoring safety performance, standard operating procedures and equipment maintenance and integrity.

5.2 Safety Review Site Visit Observations and Learnings

To date, the Hydrogen Safety Review Panel has conducted 11 safety review site visits, covering projects in each of the four focus areas of the DOE portfolio – production, storage, fuel cells and technology validation and demonstration. Emerging themes and learnings have been presented recently in detail.[2] Examples of additional observations and learnings are noted here.

As might be expected for such a portfolio for which projects are performed by small and large companies, universities and government laboratories, and at varying stages of technology development, a variety of techniques have been utilized to identify and analyze safety vulnerabilities. Often, a combination of techniques is utilized consistent with the policies and procedures of the performing organization. The safety guidance document [1] suggests that *Guidelines for Hazard Evaluation Procedures*, a publication of the American Institute of Chemical Engineers (AIChE) Center for Chemical Process Safety, can serve as a reference for discussion and worked examples for specific vulnerability analysis techniques.[6] For projects performed at universities, project personnel are generally undergraduate and graduate students as well as post-doctoral fellows. The Panel has also recommended that this reference may be utilized as an excellent teaching/learning tool.

Discussion of management of change (MOC) is included in site visit discussions of risk mitigation. The project teams are queried as to what methods and procedures are used to analyze, validate and document safety vulnerabilities arising from major changes in items such as laboratory location, new/different equipment, process configuration and operating conditions /procedures, personnel, etc. MOC is an integral part of the OSHA (Occupational Safety and Health Administration) Process Safety Management of Highly Hazardous Chemicals standard (29 Code of Federal Regulations Section 1910.119) to help assure safe and healthful workplaces.[7] In 2001, The U.S. Chemical Safety and Hazard Investigation Board issued a safety bulletin to focus attention on the need for systematically managing the safety effects of process changes in the chemical industry.[8] Although the example cited in the safety bulletin is that of a major oil refinery fire in 1998 that caused six fatalities, the lessons learned are directly responsive to hazardous work being performed at much smaller scales and different environments from an oil refinery. The referenced safety bulletin encourages systematic methods for handling change and notes attributes of an effective MOC system. For example, training personnel to recognize change combined with their knowledge of standard operating procedures at any scale of operation will enable those personnel to activate an MOC system when appropriate.

Several aspects of a communications plan that a project manager will develop and implement during the course of a project are discussed: (1) communication/discussion of safety reviews and learnings during the design, developmental and operational phases of a project; (2) safety event and "near-miss" reporting, documentation and learning. On the latter subject, the Panel has observed that the organizations for which site visits have been conducted each have their own safety event reporting system in place. The Panel is working with DOE to develop a safety event reporting system for the program broadly so that learnings from past experience can help prevent the occurrence of events that are more severe (using "lesser" events to prevent worse ones). Any system to receive, process, record, analyze and act on safety event information requires a great deal of information sharing as openly and thoroughly as possible, some degree of confidentiality to deter punishment of personnel, and a commitment to creating higher learning value.

6.0 SUMMARY

Identification and analysis of safety vulnerabilities, risk mitigation, and communication are the critical topics that should be addressed within an effective safety plan. The safety plan should be a comprehensive study that is meant to be a "living" document. It should not be a plan that is placed on a shelf and forgotten. It must be periodically reassessed and as changes to projects occur, the safety plan should be updated accordingly. The plan is a tool that facilities should utilize to make sure their overall safety practices are in order and that safety is a priority. The development and implementation of a comprehensive safety plan will greatly aid facilities in ensuring their overall safety programs are effective.

7.0 ACKNOWLEDGMENTS

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APPENDIX I – SAFETY QUESTIONNAIRE FOR HYDROGEN PROJECTS

1. **What is the most significant hydrogen hazard associated with this project? Please be specific in your answer.**
   The most significant hazard is one that you believe is credible and could pose the greatest potential impact to personnel, and/or destruction or loss of equipment or facilities.

2. **What are you doing to deal with this hazard? Please list pertinent safety measures you are implementing and/or plan to implement.**
   Cite specific standards, special measures, special operating procedures focused on this hazard, limits on personnel access, etc. that you are using to mitigate the potential impact posed by the specific hazard.

3. **What is the most likely hydrogen accident scenario associated with this project?**
   This accident scenario should represent a hazard that you believe has a relatively high probability of occurring sometime during the life of the project. If it does occur, it should have less of an impact than the hazard you discuss in response to Questions #1 and #2.

4. **What are you doing to reduce the risk associated with this most likely accident scenario?**
   The guidance provided for Question #2 above also applies for Question #4.

5. **What other serious safety concerns do you have in working on this project?**

6. **Do you have significant safety concerns that you would like to discuss with the Safety Panel? Please explain.**