Hydrogen Safety Review Panel: Shaping Safety Awareness

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ABSTRACT

An essential element for realizing the "hydrogen economy" is 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 (RD&D) program of the U.S. Department of Energy's (DOE) Hydrogen, Fuel Cells and Infrastructure Technologies (HFCIT) Program Office.

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 to DOE 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 introduces the Hydrogen Safety Review Panel, explores its role in the DOE program, describes how it approaches safety review site visits as one of its functions and shares specific themes and examples of those interactions and lessons learned.

1. INTRODUCTION

Hydrogen has been used in the manufacturing, chemicals, and aerospace industries for nearly a century and has enjoyed a notably high safety record. Experience with and knowledge of safe production, shipping, and use of hydrogen is therefore quite extensive. About 9.5 million tons of hydrogen are currently produced and used annually in the U.S.[2]

One reason underlying the admirable safety record achieved is the use of highly trained staff and well controlled facilities in all aspects of the industry. Hydrogen producers control the material through the point of delivery and frequently beyond, using technology that the company also controls. For example, over-the-road tube trailer and

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[2] *Hydrogen Production Overview*, National Hydrogen Association Fact Sheet Series, August 2004: http://www.hydrogenus.com/H2-Production-Overview-Fact-Sheet.pdf.

cylinder delivery trucks are operated by a gas supplier, or liquid supply is delivered by a merchant fleet from a supplier production site. Hydrogen's use inside the destination facility is controlled and monitored, again employing trained staff, so that the entire life cycle of the hydrogen from production to ultimate use is carefully managed.

The introduction of hydrogen as a commercial energy carrier in the hands of the general public promises a "whole new ballgame," however, with a host of new safety issues. Not the least of these is that the general public receives little if any official training on fuel use, at least with current fuels and fueling technologies. Another issue is that regulatory control over these technologies and products in use by the general public is somewhat limited, for example, once they have left the refueling station. Vehicles may be operated, modified, maintained (or not maintained) in a manner never intended. The mobile environment is one of admittedly harsh duty, including temperature extremes, vibration, shocks, collisions, frequent cycling, and possible long term exposure to the external environment. The expectation that the public would treat future technologies and products differently than they do currently seems unrealistic; therefore future technologies and products are going to have to increasingly rely on technological solutions, rather than regulatory and/or training solutions, to ensure safety through the most challenging of applications.

The hydrogen economy remains decades away, due in part to the physical inertia of our massive energy infrastructure and the large construction effort and economic investment that will be required to alter it. Despite the anticipated long lead time however, safety with hydrogen is as important now if not more so than when the hydrogen economy becomes a reality. The public's trust can be a fragile commodity and any catastrophic accidents may further delay or even preclude hydrogen's intended implementation.

The ability to produce, store, and use hydrogen in a manner perceived as safe by the general public will be essential to its success as a commercial energy carrier. Furthermore, when accidents do occur, as they frequently do with conventional fuels and vehicles, the demonstrated, reliable ability to respond with means that quickly contain and control damage and prevent catastrophe will be equally critical for the hydrogen economy to proceed.

2. THE HYDROGEN SAFETY REVIEW PANEL

The U.S. Department of Energy formed the Hydrogen Safety Review Panel to help the Hydrogen, Fuel Cells and Infrastructure Technologies Program Office develop and implement the practices and procedures that will ensure safety in the operation, handling, and use of hydrogen and hydrogen systems for all DOE projects. Emphasizing safety in its own program and utilizing these practices and lessons learned, the Program Office helps promote the safe use of hydrogen throughout the emerging hydrogen economy.

The Panel, formed in December 2003, brings a broad cross-section of experience upon which to build for the success of the DOE program as a whole. The experience resides in industrial hydrogen production/supply, government R&D and use, 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)

All new DOE-funded hydrogen projects are now required to submit a safety plan as an early project deliverable report. Safety plans, utilizing a DOE and Panel-developed guidance as a resource,[3] 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 and makes any needed recommendations for improvement. Some subset of projects is then selected for more in-depth review.

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Table 1. U.S. Department of Energy Hydrogen Safety Review Panel

Through utilization of the Hydrogen Safety Review Panel, DOE hopes to capture and capitalize on some of the established safety experience gained from the long histories with hydrogen in the industrial and aerospace arenas. This paper explores some of the lessons learned and safety discussion from the safety review site visits conducted during the first year of the Panel's existence.

3. SAFETY REVIEW SITE VISITS

One 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. Projects are performed by companies of varying size, DOE national laboratories, and academic

[3] Guidance for Safety Aspects of Proposed Hydrogen Projects, U.S. Department of Energy, August 2004: http://www.eere.energy.gov/hydrogenandfuelcells/pdfs/safety_guidance.pdf.

institutions and typically involve a number of collaborators. 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

Typically the review team consists of 3-4 members from the Panel and its support staff.

3.1 A Protocol Helps Shape the Site Visit and Discussion

Site visits are intended to focus on engagement and discussion between the review team and the contractor/project team rather than as an audit or investigative exercise. Use of a site visit protocol helps achieve that intended purpose.

Once the site visit has been scheduled, the contractor project manager (or principal investigator) provides the relevant program review presentation, annual progress report, safety plan and other literature, as applicable, to the safety review team. Background material on the Hydrogen Safety Review Panel and the two-page protocol document is provided to the contractor. An agenda is established. The contractor is asked to provide the following as part of the agenda:

- Overview of organization-wide safety policies and procedures and how these are implemented/managed for a given facility down to the project and staff levels
- Project overview
- Laboratory/facility tour of relevance to the project that includes demonstrations, if possible

Topic questions for discussion, having been submitted to the contractor/project team in advance of the site visit, are discussed. The topic questions are tailored for each site visit based in part on the provided literature and input is sought from the HFCIT staff teams on safety issues they wish to have addressed; typically all reviews will address the following items:

- What safety planning approaches and methodologies are being applied?
    - Identification and analysis of safety vulnerabilities
    - Risk mitigation plans: standard operating plans, management of change, equipment maintenance and integrity, measuring and monitoring safety performance, training
    - Communication plans for safety reviews and “incidents” reporting
- What codes and standards/regulations apply to this system, how are they being applied and what is the extent/nature of interaction with local codes and standards officials?
- How are hydrogen safety issues being addressed?
    - Hydrogen leak prevention, detection, containment/exhaust

- Hydrogen pressure
- Ignition sources: identification and control
- Materials: material properties, interaction/compatibility with hydrogen and hydrogen-containing materials

A Q&A session helps address specific questions from members of the review team. The contractor/project team is also encouraged to raise any safety issues and questions which they wish to discuss with the review team. Lessons learned from the project that relate to hydrogen safety are discussed. The safety review team also seeks input from the contractor/project team on the protocol/format used for the site visit meeting and ideas for improving the value of other such site visit meetings.

3.2 Reports Document the Discussion, Learnings and Actions

At the conclusion of the safety review site visit, two reports are prepared by the review team: (1) Site Visit Preliminary Report and (2) Safety Evaluation Report.

The Site Visit Preliminary Report (1-2 pages) is submitted by the review team to the HFCIT Program Office within 14 days of the site visit to ensure the timely dissemination of the meeting outcomes. This report briefly summarizes major areas of discussion, recommendations, lessons learned, etc. Safety-related action items and tentative recommendations from the meeting are reported even though actions, analysis and response may not be completed until after this report is submitted.

The Safety Evaluation Report is the comprehensive report of the safety review that is submitted to the Program Office on behalf of the Panel, describing the conduct of the site visit meeting, safety issues of concern, recommendations, lessons learned, etc. consistent with the purposes noted above. The draft report is sent to the contractor for comments, corrections and clarifications. The contractor's response to specific observations, questions and recommendations is included in the final report. This important feature ensures that the review team is providing DOE with the perspective of all site visit meeting participants. Regardless, the review team and the Panel retain the responsibility for making project-related safety recommendations as it feels appropriate.

The contractor is also asked to provide as much detail as is warranted on "lessons learned" to broadly benefit the DOE program. The Safety Evaluation Report is submitted to HFCIT and a copy is provided to the contractor.

4. EMERGING THEMES AND LEARNINGS FROM SAFETY REVIEWS

One excellent method for enabling the dissemination of hydrogen safety information among the hydrogen community and existing and potential hydrogen suppliers and users is the use of "lessons learned" and recommendations stemming from safety reviews. Over the course of the initial set of safety reviews conducted by the Panel, a few important themes have already emerged for safety planning, practices and implementation in the DOE-funded program. Issues, learnings and observations are categorized as follows:

- Design and assembly of equipment
- Operating procedures
- Equipment maintenance
- Hydrogen storage materials
- Other issues

Although not all-inclusive, the following sections reflect the meeting discussions of safety aspects of projects during the site visits.

4.1 Design and Assembly of Equipment

It goes without saying that if one designs with safety in mind, it will save time, money, and perhaps a failed system or project later on. Thus, it is always advisable to talk to safety representatives/officers both internal to the institution and in the community (e.g., fire marshals, local safety officials, etc.). The need for external involvement usually is proportional to the size of the hydrogen system, the amount of hydrogen being produced, stored, and/or used and the location of the equipment relative to other facilities and buildings. In addition, designing with versatility in mind allows one to expand and/or modify equipment more easily. Designing space rather than trying to fit into an existing laboratory or facility can reduce the associated risk.

For example, the design and siting of hydrogen storage/handling facilities may present several options. A project that uses hydrogen (perhaps a fuel cell tester, a developer of a new hydrogen compression system, or a developer of hydrogen storage systems) may go through large quantities of hydrogen in short periods of time. If the facility is not designed for handling, moving and distributing the hydrogen, one may wind up storing hydrogen in an area where safety is compromised. One might need to consider alternative supply options, e.g. an electrolyzer versus cylinder racks or tube trailers. For large quantities of hydrogen, the electrolyzer itself could have siting problems in certain circumstances.

Ideally, outdoor storage in cylinders or a tube trailer is advised, but sometimes this cannot be done. Wherever hydrogen will be stored, the questions should be asked: “What if a full tank of hydrogen or a manifold connecting several open, full tanks of hydrogen should rupture, releasing all of the hydrogen into a laboratory, storage room, or other contained space? Will the ventilation system be sufficient to keep the hydrogen concentration in that space sufficiently low to prevent a fire or explosion? If not, is the risk acceptable?

Hydrogen molecules, being small and light, have the ability to diffuse very quickly and to leak in situations where no other substance will leak. Thus, systems should be built with robust valves and a minimum number of mechanical connections. If the system is going to see large temperature/pressure cycles, compression fittings should not be used.

Although buried hydrogen pipelines are in commercial practice, one must consider that buried lines can corrode from the outside if not protected in certain types of soil. Buried lines also present the obvious challenge of leak detection.

4.2 Operating Procedures

The need for sufficient and accurate documentation has been a recurring theme of the safety reviews. Such documentation includes standard operating procedures (SOP), maintenance schedules, training schedules, warning placards, emergency call information signs, protocols, etc. While different companies or laboratories may each have their own practices and methods for documentation, the overall need for a means to disseminate knowledge to key personnel for system operations, to new employees, and to emergency responders is of utmost importance. Electronic, interactive company-wide websites are one good way of disseminating procedural and training information. Availability of hard copies of SOPs, warning placards, emergency phone numbers, and diagrams of operating systems, are needed to provide emergency call information and for first responders.

Industrial organizations typically establish policies for managing deviations from normal operations. Management of change (MOC) procedures may apply to facilities, e.g., replacing or adding a new piece of equipment, as well as abnormal situations for which there are deviations from standard operating procedures. Documented MOC policies and procedures can be tailored to apply to small laboratory-scale equipment and operations as well as larger demonstration-scale facilities. Trained and knowledgeable staff will be in a position to make informed judgments as to whether a deviation is significant enough to require application of the appropriate MOC procedures.

Numerous organizations are doing developmental work on fuel cells and/or hydrogen storage systems and require significant amounts of compressed hydrogen onsite. For many, the movement of hydrogen cylinders within a facility and changing hydrogen cylinders is an important consideration. One company, which must constantly move large quantities of hydrogen, designed and built an ergonomic hydrogen cart with which one can transfer two hydrogen cylinders at once on a hand-cart designed with a large platform to ensure tank stability, and with a configuration to take pressure off the workman's back. They use long, flexible-hose tubing to ensure quick and safe replacement of empty cylinders with full ones. Other hydrogen cylinder-related issues include (1) a logical (but not always followed) caveat of always moving a cylinder with the cylinder cap in place; (2) the tendency for hydrogen cylinders to leak slightly through the lead seal on the tank valve. Sound protocols should cover all aspects of cylinder transport and use.

Another emerging theme, and one that is not always obvious, is to ensure that labels on purchased materials accurately reflect content. Some larger facilities will have a central storage area from which materials are delivered. It is possible that the storage area personnel deliver the wrong material. Checking the labels should be a necessary step that is reflected in SOPs or protocols before using materials.

4.3 Equipment Maintenance

Proper and timely equipment/sensor maintenance is key to ensuring this aspect of a good risk mitigation plan. Large pieces of equipment may have service contracts and be handled accordingly, but that may not be the case routinely. An electronic spreadsheet can assist in scheduling and tracking equipment maintenance and sensor calibration requirements that might be noted in SOPs.

A strong valve maintenance and replacement program is also an important consideration. Hydrogen leaks can occur either out of the valve or through the valve. The former could be detected by a sensor near the valve, but the latter, especially if it is small, may be more difficult to detect, and result in a hydrogen presence where unexpected.

4.4 Hydrogen Storage Materials

A significant amount of hydrogen research is now centered on the storage of hydrogen in complex metal hydrides. Some of these storage materials are dangerous in their own right. Sodium alanate ($NaAlH_4$) is usually considered the typical material of this type, and is used for much of the testing. Hydrogen is recovered from sodium alanate in a two-step process:

$$3NaAlH_4 \rightarrow Na_3AlH_6 + 2Al + 3H_2$$

$$Na_3AlH_6 \rightarrow 3NaH + Al + 3/2H_2$$

Sodium alanate itself, the intermediate product Na_3AlH_6, and the byproduct NaH are all very reactive in the presence of either oxygen or moisture. For example, they are pyrophoric in moist air. The fact that there is likely to be some free hydrogen present as well exacerbates the issue. Great care is needed throughout the manufacturing and testing of these compounds to keep them in an inert atmosphere.

The disposal of these materials is an important consideration in metal hydride handling safety. Spent (oxidized) materials may contain pockets of active alanate or an active intermediate may be present, and the mix might be shock-sensitive. Thus, it is recommended that even supposedly fully oxidized alanates be treated as hazardous materials.

4.5 Other Issues

Although not directly involving hydrogen, oxygen depletion leading to asphyxiation is a serious issue discussed during several safety reviews. For example, laboratory work is often performed in a glove box, under a nitrogen or argon atmosphere. If the glove box develops a large leak, it may not be obvious when the inert gas leaks into the room itself, depleting oxygen. Asphyxiation by oxygen depletion in a facility where an inert gas is being used or is being piped through is an often overlooked danger that costs several lives each year. Methods of prevention include oxygen level sensors in the room itself, flow rate sensors on the inert gas feed, and adequate ventilation in the room to overwhelm any large inert gas leak.

Performing safety-based site visits has also revealed that even though large demonstration-sized hydrogen projects carry the larger risks, even small, laboratory-scale hydrogen production projects can evolve sufficient hydrogen to be a potential hazard. Personnel should calculate the worst-case scenarios for possible hydrogen buildup and ventilate the area adequately.

Two different facilities reported that some electrochemically-based sensors may mistake hydrogen for carbon monoxide, suggesting they not be used in a hydrogen-containing application.

The safety review site visit can be an effective mechanism for engaging organizations and project teams to bring learnings to the DOE program and help shape safety awareness. Even the importance of accepted safety practices as standard as the use of safety glasses in research laboratories can be reinforced. Site visits have already proven their value in tapping the expertise of the Hydrogen Safety Review Panel and providing broad benefit to the DOE program.

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