INCIDENT REPORTING: LEARNING FROM EXPERIENCE

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ABSTRACT

Experience makes a superior teacher. Sharing the details surrounding safety events is one of the best ways to help prevent their recurrence elsewhere. This approach requires an open, non-punitive environment to achieve broad benefits. The Hydrogen Incident Reporting Tool (www.h2incidents.org) is intended to facilitate the sharing of lessons learned and other relevant information gained from actual experiences using and working with hydrogen and hydrogen systems. Its intended audience includes those involved in virtually any aspect of hydrogen technology, systems and use, with an emphasis towards energy and transportation applications. The database contains records of safety events both publicly available and/or voluntarily submitted. Typical records contain a general description of the occurrence, contributing factors, equipment involved, and some detailing of consequences and changes that have been subsequently implemented to prevent recurrence of similar events in the future. The voluntary and confidential nature and other characteristics surrounding the database mean that any analysis of apparent trends in its contents cannot be considered statistically valid for a universal population. A large portion of reported incidents have occurred in a laboratory setting due to the typical background of the reporting projects, for example. Yet some interesting trends are becoming apparent even at this early stage of the database's existence and general lessons can already be taken away from these experiences. This paper discusses the database and a few trends that have already become apparent for the reported incidents. Anticipated future uses of this information are also described. This paper is intended to encourage wider participation and usage of the incidents reporting database and to promote the safety benefits offered by its contents.

1.0 INTRODUCTION

The primary purpose of safety event reporting is the prevention and recurrence of incidents. For example, the Process Safety Incident Database (PSID) of the American Institute of Chemical Engineers' Center for Chemical Process Safety allows participating companies to collect and share safety incident experiences to enable learnings based upon the experience of others.[1] The learnings from incident investigation and analysis form the basis for many industrial process safety management systems addressing applicable OSHA standards to their facilities to ensure a safe and healthful workplace.[2,3] The magnitude of safety events can vary widely and impact personnel, equipment, business interruption and the environment. By learning about the likelihood, severity, causal factors, setting and relevant circumstances regarding safety events, one is better equipped to prevent similar incidents in the future and at other facilities.

These same principles are being applied to the hydrogen program of the U.S. Department of Energy (DOE), recognizing that safe practices in the production, storage, distribution and use of hydrogen are

an essential component of widespread acceptance of hydrogen technologies. The portfolio of projects is being conducted in various phases: laboratory-scale research, bench-scale testing, engineering development and prototype operation. Projects are being performed by many organizations ranging from universities, research institutes and government laboratories to large companies and small businesses, often requiring collaboration among these entities to be successful in achieving project objectives.

DOE requires safety plans for all funded projects [4], recognizing that safety planning and practice is principally driven by the performing organization's own safety policies and procedures, its safety culture and the priority attention given to safety at the project level. DOE requires the reporting of incidents and near-misses for all funded projects. The working definitions are as follows:

- An **incident** is an event that results in:
    - a lost time accident and/or injury to personnel
    - damage to project equipment, facilities or property
    - impact to the public or environment
    - any unintentional hydrogen release that ignites or is sufficient to sustain a flame if ignited
    - any hydrogen release which accumulates above the lower flammability limits within an enclosed space.
- A **near-miss** is an event that under slightly different circumstances could have become an incident.

A checklist [5] is used to encourage that safety plans address safety events and lessons learned through a discussion of the following topics:

- The safety event reporting procedure within the organization and to DOE
- The system and/or procedure used to investigate events
- How corrective measures will be implemented
- How lessons learned from incidents and near-misses are documented and disseminated

It is especially desired to learn from past experience and encourage the sharing of details surrounding safety events to prevent the occurrence of events that are more severe (using "lesser" events to prevent worse ones). This approach requires an open, non-punitive, information sharing environment to achieve broad benefits. Experience suggests that one is more willing to share such information on a non-attributed basis if, in turn, they may also benefit from such information reported by others.

2.0 THE HYDROGEN INCIDENT REPORTING TOOL

The Hydrogen Incident Reporting Tool (www.h2incidents.org) is intended to facilitate the voluntary sharing of lessons learned and other relevant information gained from actual experiences using and working with hydrogen and hydrogen systems. Its intended audience includes those involved in virtually any aspect of hydrogen technology, systems and use, with an emphasis towards energy and transportation applications. The vast collection of hydrogen-related safety event information available through various means is often difficult to access beyond a specific project, organization and/or collaborating partnership. A need was also identified to provide a means for being able to submit detailed information on safety events in an appropriate manner such that others might also be able to benefit from the knowledge gained.

Efforts were initiated to help determine the layout, structure and content features for the database and web-based tool. Several well established incident reporting databases were reviewed [6,7,8,9,10] to form a basis for considering an appropriate layout and structure. An extended literature review was undertaken as a first step in retrieving relevant safety event record information from existing sources that could be considered for populating the hydrogen incidents database and be relevant for the intended audience. Sources included the U.S. Department of Energy and its National Laboratories, National Aeronautics and Space Administration (NASA), and the U.S. Nuclear Regulatory Commission. In general, the main criteria for consideration of any safety event record are the availability of sufficient information to establish "lessons learned" of relevance to hydrogen production, storage, transmission and use.

Some of these databases are publicly available and others have limited access restrictions. The databases were searched for hydrogen safety incidents. For example, the DOE's Occurrence, Reporting and Processing System (ORPS) database yielded more than 900 records based on a "hydrogen" search. Subsequent analysis found that approximately 40 of these records would be appropriate for inclusion in the database tool.

2.1 Hydrogen Incidents Database Structure

The database was developed with an aesthetically pleasing HTML graphical user interface, with intuitive, easy-to-use sorting and searching mechanisms. The database is structured in a fashion such that individual hydrogen incidents are initially populated on a web-based server. The incidents are then published at the H2Incidents.org website by a technical database administrator. Identifying information, including names of companies, organizations and individuals is removed to ensure confidentiality and to encourage the unconstrained future reporting of events as they occur.

The incidents are systematically organized to convey all pertinent safety related information, including ensuing lessons learned, in a format that is useful to personnel working with hydrogen within various sectors. As noted above, the incidents are also methodologically formatted to ensure that site specific information, such as location or the identity of a manufacturer of the particular piece of equipment involved, is excluded from the public record.

The H2Incidents database is an open-ended database in the sense that online users can submit incidents, which are stored on a web-based limited access server. The technical database administrator then reviews and revises the incidents and determines if the incident should be published. Once

published, the incidents can be viewed and assessed through various sorting and searching mechanisms within the database, making it easy for the user to find incidents which hold relevance to their particular need. For example, the user can search for an incident which involved a certain piece of equipment, or occurred because of a particular cause. The user also has the ability to search for key words or phrases through an automated searching mechanism.

2.2 Characterizing a Safety Event Record

The safety event record in "H2Incidents.org" is characterized in a manner that facilitates a means for users of the database tool to search and access useful safety-related information about specific records. The following categories of safety information as they are available for each record are also used for database search criteria:

- **Title** – uniquely characterizes the nature of the safety event in a shortened form
- **Severity** – identifies the event as an 'incident', 'near miss' or 'non-event' utilizing the noted definitions (a non-event is defined as a situation, occurrence or other outcome that is relevant to safety but does not involve a particular incident or near-miss)
- **Description** – describes the incident and contains any applicable information such as discussion of causes, other reports, photographs, sketches, etc.
- **Lessons Learned** – defines the lessons learned and specific suggestions for avoiding similar incidents in the future
- **Causes** – characterizes the primary cause(s) of the event, e.g., abnormal operations, laboratory experiment, routine maintenance, structural/equipment failure, etc.
- **Setting** – where the event occurred, e.g., laboratory, hydrogen production facility, hydrogen delivery vehicle, etc.
- **Equipment** – what types of equipment were involved, e.g., flexible hosing, piping/fitting, storage vessel or cylinder, etc.
- **Characteristics** – defines the hydrogen involved as high pressure (> 100 bar) or low temperature (<-100°F)
- **Discovery** – defines when the event was discovered, e.g., during operation, maintenance, or inspection
- **Hydrogen Release** – notes whether hydrogen was released during the event
- **Ignition** – notes the source of ignition, if applicable
- **Damages and Injuries** – characterizes the nature of the damage and/or injuries, if

known

- **Factors** – characterizes factors contributing to the event, ranging from human error to equipment failures
- **Recurrence** – qualitatively characterizes the likelihood of a similar event recurring
- **Frequency** – qualitatively characterizes the recurrence frequency, if applicable

Recognizing the desire for confidentiality on the part of the organizations where incidents or other safety events have taken place, all records are also "sanitized" to remove any identifying information in the event description. These sanitized, categorized records comprise the heart of the Hydrogen Incidents Reporting Tool.

The website, a screen shot of which is shown in Figure 1, displays records in a manner meant to convey information as quickly and efficiently as possible. Some relevant information is shown in an "at a glance" format across the top of the record; the record then goes on to provide a summary description of the event and any lessons learned arising from it. In some cases, photos, additional information or even full reports (though also sanitized) are available for download.

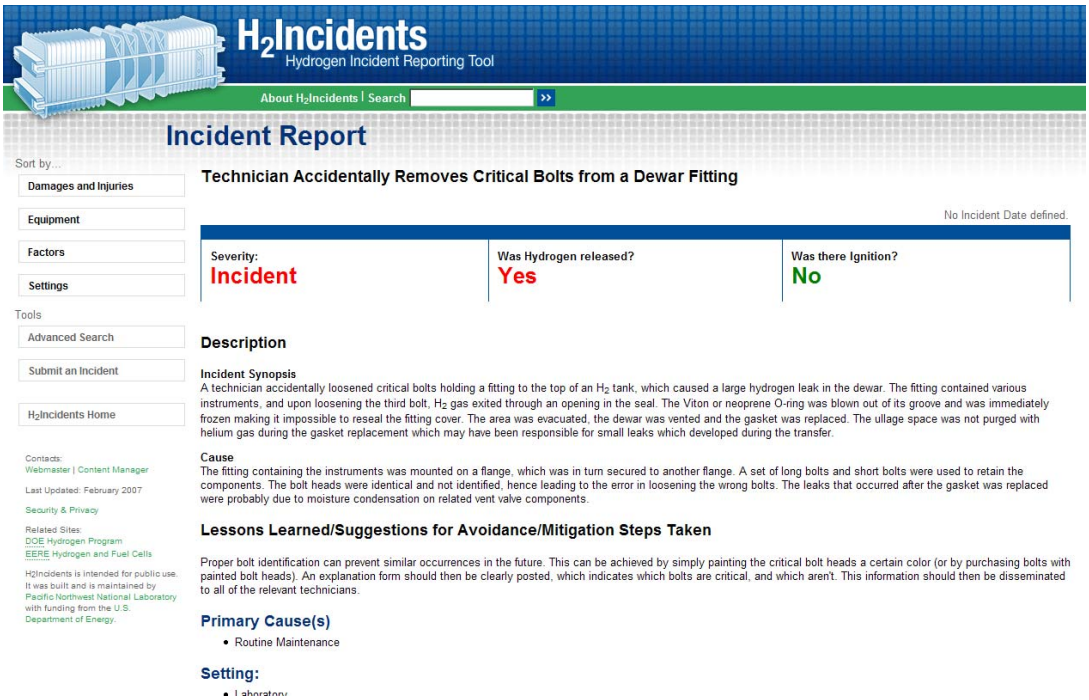

Figure 1. Partial Screen Shot of Incident Record in H2Incidents.org.

2.3 Sharing a Safety Event

In order to benefit from the experiences of relevant limited access databases in designing report submission forms, discussions were conducted with a number of hydrogen-related partnerships: California Fuel Cell Partnership, (CaFCP), Ecological City Transport System (ECTOS) and Clean Urban Transport for Europe (CUTE). The latter two initiatives are sponsored by the European Union.

The easy-to-use submission form for the Hydrogen Incidents Reporting Tool contains a comprehensive set of safety event information as noted in Section 2.2. Users wishing to submit incident reports can access an input form on the website that contains spaces for the different sections of a record, and allows them to select among the various categories. The structure of the website is dynamic in the sense that if the user inputs a submission in the 'other' category for any of the input parameters, this new input terminology is added to the main list of inputs once the safety event record is published. Thus, the database evolves to become evermore comprehensive over time.

Inputting a record requires contact information so that the technical database administrator can re-contact the submitter in the case of questions or the need for clarification. Contact information is requested on the submission form but is specifically excluded from the published safety event record itself. The administrator reviews the draft record and edits and sanitizes it, as necessary. Technical review of the record is conducted as needed prior to posting. The technical expertise of the Hydrogen Safety Panel [11] is also utilized for this purpose. The four most recently added records are highlighted on the website home page.

3.0 EMERGING TRENDS IN SAFETY EVENT RECORDS

The database currently contains over 100 incidents and near-misses, half of which have occurred in a laboratory setting. Although these safety event records represent a statistically-biased sample, and can't necessarily be extrapolated, some consistent trends are starting to emerge.

3.1 Factors Contributing to Incidents

The top two contributing factors reported in the database are "equipment" and "human error." Regardless of the setting, e.g., laboratory, production facility, etc., one would expect equipment to be one of the statistically pre-eminent contributing factors to an incident, even if not always the primary factor. One might also expect human error to be one of the top two contributing factors. Both of these factors can be addressed through appropriate mitigative steps.

Within the H2Incidents database, the equipment factor contributing to particular hydrogen incidents may be characterized by the following safety issues:

- Incorrectly sized equipment
- Inappropriate equipment applications
- Lack of and/or inferior safety equipment

- Inadequate equipment connections, i.e., fittings insufficiently tightened
- Environmentally-induced equipment failures
- Chemically-induced equipment failures
- Incorrect material selection for the application

Lessons learned suggest the need to diligently design hydrogen systems through the evaluation of potential failure modes and possible safety implications for operations. This evaluation should include environmental influences on the equipment, implications of the process chemistry/materials used and their interaction with the equipment, as well as any human factors involved.

Within the H2Incidents database, the human error contributing to particular hydrogen incidents is typically due to one or more of the following factors:

- Lack of personnel training on specific equipment, systems and operating scenarios
- Personnel inadequately trained on hydrogen properties and potential consequences of their actions
- Inattentive and complacent actions by personnel operating hydrogen and related equipment
- Personnel not following written procedures

The fact that the human error factor is frequently seen within this group of over 100 incidents, might be attributed to the fact that laboratory-scale work is often not guided by specific and written operating procedures for the experimental work being conducted and the equipment being used. Diligent maintenance of that equipment through the use of written procedures and the logging of maintenance/calibration information may also be a factor [12].

3.2 Equipment Types Involved in Hydrogen Incidents

Perhaps not surprisingly, piping/fittings and hydrogen storage equipment contribute to more incident occurrences than all of the other pieces of equipment noted in the database although there is a wide-range of causes in both cases. These two pieces of equipment are common to nearly all hydrogen and related systems in one way or another and should receive particular attention to their design, safe and reliable operation and regular maintenance.

Within the H2Incidents database, the hydrogen storage incidents are predominantly caused by the following:

- Hydrogen storage burst disk failures
- Hydrogen storage pressure relief valve or pressure transducer failures

- Hydrogen storage vessel vacuum jacket failures
- Over-pressurization of hydrogen storage tanks by operators
- Oxygen/air infiltration of hydrogen-containing vessels leading to flammable range conditions and potential for explosions
- Over-pressurization due to chemical reaction, heat generation and/or excessive external temperatures

The hydrogen storage system failures within the current set of incidents are primarily caused by improper maintenance of hydrogen storage system components and the lack of secondary safety equipment. For example, recognizing that pressure transducers and pressure relief valves can fail can be mitigated by ensuring proper maintenance and appropriately considering secondary safety valves or transducers built in the system design phase.

Within the H2Incidents database, piping/fitting incidents are predominantly caused by the following:

- Improperly labeled piping/fittings leading to operational errors
- Fitting leaks due to inadequate inspection and maintenance
- Improperly installed piping/fittings
- Incorrectly sized piping/fittings
- Material deficiencies in piping/fitting design
- Incorrect work orders associated with installing and maintaining piping/fittings

Hydrogen system designers and maintenance technicians need to be properly trained on how to design, install and maintain hydrogen piping/fittings. Many of the incidents currently in the database might have been avoided if the systems were properly designed, and the maintenance technicians were properly trained on the properties of hydrogen.

4.0 NEXT STEPS AND FUTURE PLANS

Capturing lessons learned from safety events in a database such as H2Incidents.org serves as a reference to help prevent the recurrence of similar events elsewhere. An additional effort is in progress to develop a hydrogen safety best practices database/website which DOE plans to release in 2008. Like H2Incidents.org, this database will be publicly available via an electronic format on the Internet, taking the form of a companion, closely-linked website. A best practice can be defined as the means used to accomplish a task or perform some action that is based upon knowledge learned and experience gained, e.g. lessons learned from safety events. The best practices database will be based on both lessons learned from incidents contained in H2Incidents.org, as well as knowledge found elsewhere.

Improvements to H2Incidents.org will help enhance its utility. For example, graphical features can display some of the trends in the database records mentioned above, e.g., pie charts showing the distribution of contributing factors across sets of safety event records. Also, the website is to be updated to facilitate capture of other knowledge by allowing users to submit comments on individual pages directly to the technical database administrator. The ease of accomplishing this is intended to encourage further sharing of valuable experience among members of the broader hydrogen community.

A number of hydrogen incident collection and reporting efforts are underway around the world. Establishing a means of integrating and linking all these activities would increase their usefulness to the global hydrogen community. One can envision having the ability for users themselves to improve on the existing available information. Users with years of safety related experience, for example, may recognize additional lessons to be learned from existing safety event records.

5.0 CONCLUDING THOUGHTS

There are currently more than 1,000 unique visitors accessing the database every month, a number that continues to grow. It is the intent of the developers and those with technical oversight responsibility to make the database tool ever more useful and comprehensive, as needed.

One can envision the enhanced utility of the database as ever more safety event records are added. Those working with hydrogen and hydrogen-related equipment and systems will be increasingly able to draw parallels in their own work to the lessons learned that are noted in the database. Those lessons learned may run the gamut from equipment design issues and failure modes to personnel training issues and more.

In the end, the database underscores the importance of establishing, conducting and maintaining safe practices while providing a mechanism for sharing safety knowledge and learning from the experience of others.

6.0 ACKNOWLEDGMENTS

The authors wish to thank the U.S. Department of Energy's Hydrogen, Fuel Cells and Infrastructure Technologies Program Office (Mr. Patrick B. Davis, Acting Program Manager/Manager, Safety Codes and Standards) for their support of this work.

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