VIII.7 R&D for Safety Codes and Standards: Risk Assessment

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Project End Date: Project continuation and direction determined annually by DOE

Overall Objectives

- Establish quantitative risk assessment (QRA) as an acceptable method to assess hazards associated with widespread use of hydrogen as a fuel.
- Use hydrogen-specific QRA in a risk informed decision making process to support the development of regulations, codes, and standards for hydrogen fuel.
- Develop and support the creation of a hydrogen-specific risk assessment toolkit.

Fiscal Year (FY) 2013 Objectives

- Scope and initiate work on a quantitative risk assessment (QRA) toolkit to enable sustained use of QRA by code developers, in site-specific hazard reviews and in development of broad deployment strategies in line with project objectives.
- Participate as experts for National Fire Protection Association (NFPA) 2, International Energy Agency (IEA) Task 31 and other international programs.
- Provide QRA results for specific scenarios (e.g., indoor fueling, bulk storage, effect of passive or active mitigation features, etc.) needed for revision of regulations, codes, and standards (RCS).

Technical Barriers

This project addresses the following technical barriers from the Hydrogen Safety, Codes and Standards section of the Fuel Cell Technologies Office Multi-Year Research, Development, and Demonstration Plan:

(A) Safety Data and Information: Limited Access and Availability

(F) Enabling National and International Markets Requires Consistent RCS

(G) Insufficient Technical Data to Revise Standards

(L) Usage and Access Restrictions – parking structures, tunnels and other usage areas

Contribution to Achievement of DOE Safety, Codes and Standards Milestones

This project will contribute to achievement of the following DOE milestones from the Safety, Codes and Standards section of the 2011 Fuel Cell Technologies Office Multi-Year Research, Development, and Demonstration Plan:

- Milestone 2.4: Publish a method for estimating accident likelihood. (2Q, 2013)
- Milestone 2.8: Publish risk mitigation strategies. (2Q, 2014)
- Milestone 2.11: Publish a draft protocol for identifying potential failure modes and risk mitigation. (4Q 2014)
- Milestone 2.19: Validate inherently safe design for hydrogen fueling infrastructure. (4Q, 2019)
- Milestone 4.7: Complete risk mitigation analysis for advanced transportation infrastructure systems. (1Q, 2015)
- Milestone 4.8: Revision of NFPA 2 to incorporate advanced fueling storage systems and specific requirements for infrastructure elements such as garages and vehicle maintenance facilities. (3Q, 2016)

FY 2013 Accomplishments

- Conducted QRA for indoor fueling of hydrogen-powered industrial trucks which determined that the risk introduced by fueling hydrogen-powered industrial trucks inside of the large warehouse space does not increase the risk of the occupation and the warehouse environment.
- Documented new QRA methods and QRA needs for use in development of codes and standards requirements through the publication of a Sandia National

Laboratories report focused on indoor fueling. The new methods were used for the indoor fueling assessment.

- Created initial version of hydrogen specific QRA toolkit by integrating previously disparate activities, including manual data manipulation, under a single algorithm. Included ability to perform sensitivity analysis using the single algorithm increasing the efficiency and improving the value of the assessment to the end user.
- Hosted hydrogen QRA workshop for stakeholders. Gathered participants from industry, government, and research to determine the requirements of the next version of the QRA toolkit and to determine the applicability of such a toolkit to other flammable gas fuels such as compressed natural gas (CNG).

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INTRODUCTION

A principal challenge to the widespread adoption of hydrogen infrastructure is the lack of quantitative data regarding safety and property risks from hydrogen. To convince regulatory officials, local fire marshals, fuel suppliers, and the public at large that hydrogen refueling is safe for consumer use, the risk to personnel and bystanders must be quantified and minimized to an acceptable level. Such a task requires validated methods to assess the harm potential from credible failure modes and a good understanding of effective mitigation measures to control associated hazards.

APPROACH

Using unique skills quantitative risk assessment, Sandia and its partners are working to develop a scientific-based, hydrogen-specific, adaptable process for risk informed decision making. This process will help eliminate deployment barriers within regulations, codes, and standards to hydrogen fuel infrastructure by facilitating site-specific risk considerations for stakeholders to determine appropriate risk mitigation measures versus the traditional approach of prescriptive code requirements.

QRA can be used to identify risk drivers and the associated consequences in step-out hydrogen technologies. Sandia is developing data and tools for risk assessment of hydrogen fuel cell systems and infrastructure. This entails the development of safety scenarios, benchmark experiments, technical data, and subsequently, tools and techniques for integrating these pieces into technical data for codes and standards decision.

Development of a comprehensive QRA tool that aggregates arbitrary system failure mode analysis with quantifiable consequence modeling obtained from improved hydrogen behavior understanding of this project remains the overarching goal. Ultimately this tool would be used to improve existing codes and standards as well as provide flexibility in the application of the codes.

RESULTS

Conduct QRA for Indoor Fueling of Hydrogen-Powered Industrial Trucks

Hydrogen powered industrial trucks have gained a market foothold as a niche application of hydrogen fueled electric vehicles. The increased usage and commercial viability of these vehicles has inspired increased scrutiny of the risk of fueling these vehicles indoors. A QRA was conducted to evaluate the risk introduced by fueling the vehicles in the warehouse environment.

In order to conduct the QRA, Sandia in close cooperation with industry stakeholders, first developed a generic system model for indoor fueling equipment and the vehicle fuel system. Industry partners also participated in a generic failure modes and effects analysis for both the indoor fueling system (dispenser) and the vehicle fuel system. This project team then constructed an integrated algorithm to perform the QRA including the ability to perform sensitivity analysis.

The QRA concluded that the predicted fatal accident rate, a common measurement of risk for a specific occupation, was around 0.17. Table 1 shows the fatal accident rate values for several occupations from the Bureau of Labor Statistics, 2010. For the scenarios considered and with a large margin of error, fueling hydrogen-powered industrial trucks inside of the warehouse does not increase the risk experienced by those operators.

TABLE 1. Bureau of Labor Statistics, 2010 Fatal Accident Rate Data for Several Occupations

Occupation	FAR
U.S. workforce total	1.8
Construction and extraction occupations	5.9
Industrial machinery, installation, repair, and maintenance workers	10.4
Industrial truck and tractor operators	3.0
Laborers and freight, stock, and material movers, hand	3.1
Farming, fishing, and forestry occupations	13.5

FAR – fatal accident rate

Create Initial Version of Hydrogen-Specific QRA Toolkit

Many of the initial elements of the QRA toolkit were developed concurrently with the indoor fueling assessment effort. Using commercially available software tools (MATLAB®) an algorithm was developed that integrated multiple process steps into a single program. In addition to the evaluation of the indoor fueling scenarios, previous scenarios were evaluated to ensure the accuracy of the integrated tool.

Several elements, particularly a prediction of overpressure have not yet been incorporated into the tool. Analysis for such elements must be conducted using a separate model or program. The future work for this task will be a full integration of the elements into a single program with some functionality for sensitivity analysis.

Figure 1 is a block diagram that shows the various sub-programs used within the toolkit. The entire program is referred to as a toolkit as many of the subprogram models may function for stand-alone analysis of particular consequences, therefore the toolkit is both a single QRA program and multiple independent subprograms.

Host Hydrogen-Specific QRA Workshop for Stakeholders

The QRA Toolkit Introduction Workshop was held at Energetics on June 11-12. The workshop was co-hosted by Sandia National Laboratories and HySafe, the International Association for Hydrogen Safety. The objective of the workshop was twofold: (1) present a methodology and toolkit (currently under development) for conducting QRA to support the development of codes and standards and safety assessments of hydrogen-fueled vehicles and fueling stations, and (2) improve understanding of the needs of early-stage alternative fuel users (hydrogen, CNG, and liquefied natural gas [LNG]) and set priorities for "Version 1" of the toolkit in the context of the commercial evolution of hydrogen fuel cell electric vehicles. The workshop consisted of an introduction and three technical sessions: Risk Informed Development and Approach, CNG/LNG Applications and Introduction of a Hydrogen-Specific QRA toolkit.

Document New QRA Methods and Needs for use in Development of Codes and Standards Requirements

A report documenting the workshop and outcomes of the workshop is planned for publication in September 2013.

CONCLUSIONS AND FUTURE DIRECTIONS

Conclusion: Application of the integrated toolkit in a preliminary form was successful in performing a quantitative risk assessment of indoor hydrogen fueling activities and the results of the analysis suggest there is no additional risk for the exposed population.

- Future work: Further development of the algorithm including the incorporation of an overpressure module. FY 2014 goal of producing Version 1 of the algorithm.

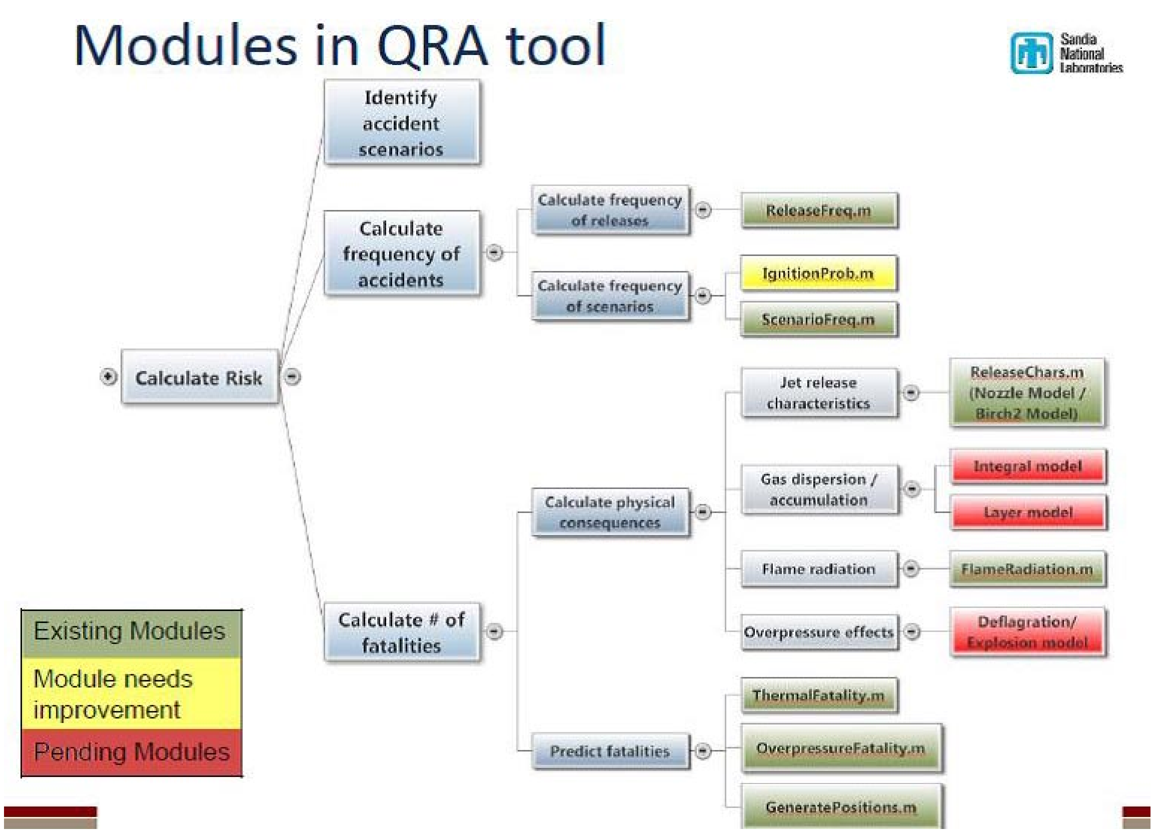

FIGURE 1. Sandia Hydrogen-Specific QRA Toolkit Block Diagram, Version 0

- Future Work: Collaborate with industry stakeholders using both the toolkit and previous risk informed decision making process concepts to validate the performance-based requirements of NFPA 2, Chapter 5 for the purpose of siting hydrogen fueling infrastructure. The requirements of this code chapter rely heavily on risk assessment. Despite publication in 2010 Chapter 5 has not yet been used for siting a fueling station.

FY 2013 PUBLICATIONS/PRESENTATIONS

1. Groth, K., Lachance, J., Harris, A. "Early-Stage Quantitative Risk Assessment to Support Development of Codes and Standard Requirements for Indoor Fueling of Hydrogen Vehicles" Sandia National Laboratories Report, SAND2012-10150.

2. LaChance, J.L.; Middleton, B. & Groth, K.M. Comparison of NFPA and ISO approaches for evaluating separation distances International Journal of Hydrogen Energy, 2012, 37, 17488-17496.

3. LaChance, J. "Risk Informed Development of Hydrogen Codes and Standards" IEA Task 31 Experts meeting, Bethesda, MD, Oct, 4-5, 2012).

4. Groth, K.M.; LaChance, J.L. & Harris, A.P. Design-stage QRA for indoor vehicular hydrogen fueling systems. Proceedings of the European Society for Reliability Annual Meeting (ESREL 2013), 2013.