SAND2007-4358P

Hydrogen Safety, Codes and Standards R&D

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Sandia is a multi-program laboratory operated by Sandia Corporation, a Lockheed Martin Company, for the United States Department of Energy's National Nuclear Security Administration under contract DE-AC04-94AL85000.

Start Date: FY 2002

End Date: Project continuation and direction determined annually by DOE

Efforts during this year were directed toward the following program components: (1) Scenario Analysis, Risk Assessments for Safety, and (2) Codes and Standards Advocacy.

Objectives

(1) Scenario Analysis, Risk Assessments for Safety

- Develop a scientific basis for evaluating credible safety scenarios, providing technical data for codes and standards decisions.
- Identify critical safety scenarios and gather technical data to support codes and standards decisions.
- Analyze hydrogen-related engineered systems and components for safety issues and identify probable hazards.
- Develop benchmark experiments and a defensible analysis strategy for risk assessment of hydrogen systems
- Develop engineering models for rapid scenario assessment and risk analysis.

(2) Codes and Standards Advocacy

- Provide technical program management and support for the Safety, Codes and Standards Program element within the Hydrogen, Fuel Cells and Infrastructure Technologies program.
- Participate in the hydrogen codes and standards development/change process.

Technical Barriers

This project addresses the following technical barriers from the Hydrogen, Fuel Cells and Infrastructure Technologies Multi-year Research Development and Demonstration Plan:

- F. Control and Safety (Section 3.1.4.2)
- E. Codes and Standards (Section 3.5.4.2)
- N. Insufficient Technical Data to Revise Standards (Section 3.6.4.2)

Contribution to Achievement of DOE Safety or Codes and Standards Milestones

This project will contribute to achievement of the following DOE Technology Validation milestones from the Technology Validation section of the Hydrogen, Fuel Cells and Infrastructure Technologies Multi-year Research Development and Demonstration Plan:

- Milestone 3: Complete detailed scenario analysis risk assessments. (4Q, 2007)
- Milestone 4: Complete analytical experiments and data collection for hydrogen release scenarios as needed to support code development. (2Q, 2008)

Accomplishments

- Extend the range of calculations for high-momentum leaks to pressures of 103.52 MPa (15,000 psig) and leak diameters as small as 0.25 mm.
- Completed concentration field measurements in unignited jets from slow hydrogen leaks. Use data to validate the engineering model.
- Completed engineering model for the buoyant jet from a slow unignited hydrogen leak. The model computes the hydrogen concentration along the jet trajectory.
- We initiated experimental and modeling programs to study the ability of barriers to mitigate the effects of high-pressure ignited and unignited hydrogen leaks.
- We began participating in the European Union (EU) HYPER project and developed a draft workplan for Workpages 4 and 5 of the project.
- We demonstrated a risk-informed approach for establishing safety (separation) distances for hydrogen refueling stations.
- The risk-informed approach has been presented to both national and international groups including IEA Task 19, the Tech Committee, NFPA 2 Hydrogen Technology Committee, and the NHA for comment and review.
- Sandia personnel participated in a working group chartered with the task to develop the separation distances in a new hydrogen model code, the NFPA 2.

Introduction

A major barrier to the development of a hydrogen economy and the deployment of hydrogen technologies is the lack of tested safety codes and standards. The purpose of this project is to provide the technical basis for assessing the safety of hydrogen-based systems with the accumulation of knowledge feeding into the modification of relevant codes and standards. The scenario analysis and risk assessment effort focuses on defining scenarios for the unintended release of hydrogen and quantifying the consequences through scientific experimentation and modeling. Quantitative risk assessment is used to identify risk drivers for the commercial use of hydrogen. The risk is based on the probability of occurrence and the magnitude of the event. We have developed models to quantify the hydrogen release behavior in engineered systems.

Approach

Efforts were directed toward the following program components: (1) Scenario Analysis, Risk Assessments for Safety, and (2) Codes and Standards Advocacy. Sandia is developing benchmark experiments and a defensible analysis strategy for risk and consequence assessment of unintended releases from hydrogen systems. This work includes experimentation and modeling to understand the dispersion of hydrogen for different release scenarios, including investigations of hydrogen ignition, combustion, and heat transfer from hydrogen flames. A quantitative risk assessment approach is used to identify and grade risk drivers to help focus decision making. As part of Codes and Standards Advocacy, Sandia participates in the codes and standards development process through the Hydrogen Industry Panel on Codes (HIPOC) and the National Fire Prevention Association (NFPA). This participation ensures that standards and codes organizations have the most current technical information on hydrogen behavior.

Results

Risk Assessment: The benefit of using information from Quantitative Risk Assessments (QRA) in the development of hydrogen codes and standards was illustrated this year by applying a risk-informed approach to help establish safety distances for hydrogen refueling stations. The risk-informed approach evaluates the cumulative risk from hydrogen leaks of different diameters for various consequences compared against the separation distances required to protect people, equipment, or structures from those consequences. The availability of features to mitigate accidental releases (e.g., shutoff valves initiated by hydrogen or flame sensors) can be included in the accident frequency evaluation. A consequence of this approach is that the established separation distances will present some residual level of risk that must be acceptable by affected stake holders (i.e., the public, regulators, and facility operators). We are currently using this risk-informed approach to help establish separation distances in a new National Fire Protection Association (NFPA) model code, NFPA 2, Hydrogen Technologies.

Small Leak Scenarios: Predicting flammability envelopes for unignited leaks of various sizes is necessary to a better understanding of potential safety hazards related to unintended releases through small leaks. During the last year a new entrainment correlation was developed for the slow leak engineering model that allows it to better capture lower levels of concentration decay where the jet becomes more locally buoyant [13]. Measurements of the hydrogen concentration field in the region of a leak were carried out to characterize the extent of the flammable gas envelope for various leak rates, geometries and orientations. These results provide quantitative statistical data that can be used to validate the engineering model being developed to predict the trajectory of buoyant jets issuing from various leaks.

Barrier Wall Design: Barrier walls have been proposed as a means to reduce setbacks at hydrogen fueling stations. In January of 2007 we began a combined experimental and modeling program to develop technical data to guide decisions regarding the safety and efficiency of barrier walls. We initiated the barrier wall modeling program by performing 3-D simulations of a hydrogen jet flame impinging on a barrier wall. Figure 1 shows simulations of the steady-state temperature distribution in the flame for the impinging hydrogen jet flame test. A test plan was developed for the barrier wall experiments and the first set of tests were carried out in early June, 2007. These tests provide a direct evaluation of barrier effectiveness for mitigation of flame hazards associated with accidental hydrogen leaks as well as providing data for model validation.

70 MPa Fast-Fill Refueling: A consortium has formed to study 70 MPa fast-fill fueling requirements for the SAE J2601 standard, led by Powertech Labs. Powertech is

performing the fast-fill tests while OEM partners are contributing in-kind fueling systems (i.e., the instrumented vehicular storage tanks). Other consortium members, including Sandia, are providing funds to execute the tests. Sandia will have access to refueling trial technical data subject to approval of individual OEMs (OEM fuel system descriptions are proprietary.) We will use this data to calibrate heat transfer correlations and to build a predictive model of the fast-fill process.

Code Change Process Marty Gresho, Sandia fire marshal, is chairing the NFPA 2 Hydrogen Technology Committee. Sandia researchers, Bill Houf, and Jeff LaChance, participate in the NFPA 2 separation distances subcommittee. The separation distances subcommittee created a draft separation distances table based on the work published by Sandia [6]. Sandia researcher, Bob Schefer, was appointed to the HIPOC committee this year and coordinates lab research with code development data requirements.

Future Directions

- Expand safety distance analysis to include the risk associated with on-site hydrogen gas generation and additional risk drivers such as fast deflagration, and taking into account event mitigation design features at the refueling station.
- Perform risk assessments on remaining elements of hydrogen infrastructure to identify important safety drivers. Integrate risk assessment as a formal element in hydrogen codes and standards development.
- Develop a QRA software package to support the permitting of hydrogen fueling stations and to educate permitting authorities on potential accident scenario risks.
- Investigate and characterize flame behavior and heat transfer in release scenarios involving flame impingement on barrier walls. Define wall configurations required to safely deflect unignited jets using computational parameter studies.
- We will begin to assess what issues are important for safety codes and standards involved with liquid hydrogen.
- Experimentally determine ignition limits for lean hydrogen/air mixtures for sustainable flames in turbulent jets and plumes.

FY 2007 Publications/Presentations

1. LaChance, "Risk-Informed Safety Distances for Hydrogen Refueling Stations", IEA Task 19 Hydrogen Safety Experts Meeting, Vancouver, Canada, September 6, 2006.
2. LaChance, "Risk-Informed Safety Distances for Hydrogen Refueling Stations", NFPA Hydrogen Technology Technical Committee meeting, Golden, CO, Nov 2006.
3. LaChance, "Risk-Informed Separation Distances for an Example Hydrogen Refueling Station", IEA Task 19 Hydrogen Safety Experts Meeting, Tsukuba, Japan, Jan 2007 .
4. LaChance, "Risk-Informed Separation Distances for Hydrogen Refueling Stations", NHA Annual Conference, San Antonio, Texas, March 20, 2007.
5. LaChance, "Risk-Informed Separation Distances for Hydrogen Refueling Stations", NFPA Hydrogen Technology Technical Committee meeting, Detroit, MI, April 2007.
6. Houf and Schefer, “Predicting Radiative Heat Fluxes and Flammability Envelopes from Unintended Releases of Hydrogen,” International Journal of Hydrogen Energy, Vol. 31, No. 1, January, 2007, pp. 136-151.
7. Schefer, Houf, Bourne, and Colton, “Spatial and Radiative Properties of an Open-

Flame Hydrogen Plume," International Journal of Hydrogen Energy, Vol. 31, No. 10, August, 2006, pp. 1332-1340.
8. Schefer, Houf, San Marchi, Chernicoff, and Englom, "Characterization of Leaks from Compressed Hydrogen Dispensing Systems and Related Components," International Journal of Hydrogen Energy, Vol. 31, No. 9, August, 2006, pp. 1247-1260.
9. Molina, Schefer, and Houf, "Radiative Fraction and Optical Thickness in Large-Scale Hydrogen Jet Flames," Proceedings of the Combustion Institute 31, 2, 2007.
10. Houf and Schefer, "Radiative Heat Flux and Flammability Envelope Predictions from Unintended Releases of Hydrogen," Proceedings of the 13th International Heat Transfer Conference, Sydney, Australia, August13-18, 2006.
11. Schefer, Houf, Williams, Bourne, and Colton, "Characterization of High-Pressure, Under-Expanded Hydrogen-Jet Flames," International Journal of Hydrogen Energy, In Press, October, 2006.
12. Houf and Schefer, "Investigation of Small-Scale Unintended Releases of Hydrogen," SAE World Congress, Detroit, MI, April 16-19, 2007.
13. Houf and Schefer, "Small-Scale Unintended Releases of Hydrogen," National Hydrogen Association Meeting, San Antonio, TX, March 19-22, 2007.
14. Houf, Evans, and Schefer, "Analysis of Jet Flames and Unignited Jets from Unintended Releases of Hydrogen," 2nd International Conference on Hydrogen Safety, San Sebastian, Spain, September 11-13, 2007.
15. Houf and Schefer, "Analytical and Experimental Investigation of Small-Scale Unintended Releases of Hydrogen," Submitted to International Journal of Hydrogen Energy, May, 2007.
16. Angers, Benard, Chen, Evans, Hourri, Houf, Schefer, and Tchouvelev, "High Pressure Hydrogen Jets in the Presence of a Surface," 2nd International Conference on Hydrogen Safety, San Sebastian, Spain, September 11-13, 2007.
17. Schefer, and Houf, "Investigation of Small-Scale Unintended Releases of Hydrogen: Momentum–Dominated Limit", Submitted to International Journal of Hydrogen Energy, May 2007.
18. Schefer, Houf, and Evans, "Hydrogen Safety Codes and Standards: Unintended Releases," Hydrogen Codes and Standards Tech Team Meeting, Sandia National Laboratory, Livermore, CA, January 2007.
19. Houf, Schefer, and Evans,"Research and Development for Hydrogen Safety Codes and Standards," Hydrogen Codes and Standards Tech Team Meeting, Sandia National Laboratory, Livermore, CA, January 31, 2007.
20. Houf and Schefer, "Research and Development on Unintended Releases for Hydrogen Safety, Codes and Standards," NFPA Hydrogen Technology Technical Committee Meeting, Golden CO, November 2-3, 2006.
21. Houf, Evans, and Schefer, "Validation of CFD for Hydrogen Release Scenarios," CFD Working Group Meeting, San Antonio, TX, March 19, 2007.
22. Houf and Schefer, "Small-Scale Unintended Releases of Hydrogen," Tri-Lab Engineering Conference, Albuquerque, NM, May 7-10, 2007.
23. Houf and Schefer, "Research and Development on Unintended Releases for Hydrogen Safety Codes and Standards," PG&E Hydrogen Safety Meeting, San Ramon, CA, April 2, 2007.

Acronyms

ICC – International Code Council
IEA – International Energy Agency
FY – fiscal year
HIPOC – Hydrogen Industry Panel on Codes
MPa – Megapascals
NFPA – National Fire Protection Association
NHA – National Hydrogen Association
NREL – National Renewable Energy Laboratory
OEM – Original Equipment Manufacturer
QRA – quantitative risk assessment
R&D – research and development

Figure Captions

Figure 1. Fuego 3-D Navier-Stokes simulation of hydrogen jet flame impinging on a barrier wall for conditions corresponding to planned Sandia/SRI barrier experiments.

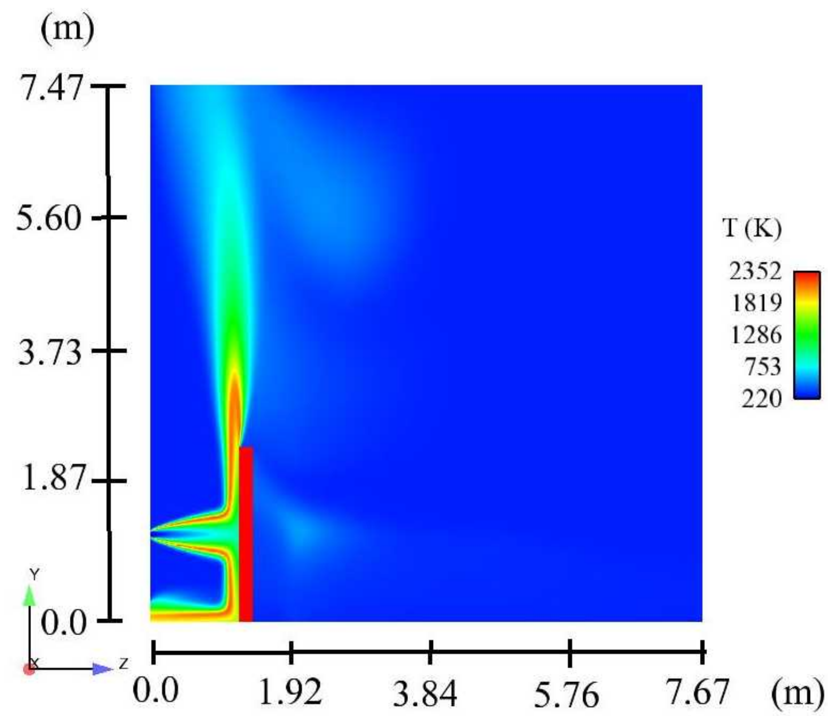

Figure 1.