DOE Hydrogen and Fuel Cells Program Record	
Record #: 15006	**Date:** May 12, 2015
Title: Separation Distance Reduction Based on Risk-Informed Analysis	
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Approved by: Sunita Satyapal and Rick Farmer (DOE)	**Date:** May 18, 2015

Item:

Using risk-informed analysis methods, the required separation distance (also referred to as setback or safety distance) was reduced as much as 50% (with a 2 hour fire barrier wall) for bulk gaseous hydrogen (GH_2) storage at refueling stations per National Fire Protection Association (NFPA) 2 (2011 edition) compared to NFPA 55 (2005 edition). The separation distance requirement can be found in model fire codes used for constructing hydrogen fueling stations and include the International Fire Code (IFC), NFPA 2: Hydrogen Technologies Code, NFPA 55: Compressed Gases and Cryogenic Fluids Code, and International Organization for Standardization (ISO) 20100 Gaseous Hydrogen – Fueling Stations [1].

In addition, DOE-funded work established an alternative approach to code development using risk analysis to inform experts, and established a consistent, scientific approach to calculate risk with limited data from commercial hydrogen bulk storage systems.

Supporting Information:

Separation distances are used in fire codes to reduce the probable occurrence of accidents or reduce effects of accidents on people, equipment or structures. Barrier walls are considered an effective means to mitigate the effects of an accident and therefore use of barrier walls allows a reduction of separation distance for certain types of exposures. Consequence modeling and risk assessments enable the quantification of the reduction in risk provided by a barrier wall. The consequence modeling and risk assessment of the risk-informed approach provided code development experts with scientifically produced justification for reducing separation distances. The use of barrier walls, in some instances, reduced separation distances by as much as 66% [2].

Ref. [2] presents the estimated risk reductions from the use of barriers for a range of system pressures and leak diameters. The methodology developed in the presence of a barrier wall enabled the separation distance to the facility's Lot Line to be shortened from 10.4 meters (m) (the distance from Lot Lines for the largest system pressure) to approximately 3.5 m, which correlates to a 66% reduction. While the results of the DOE's Fuel Cell Technology Office R&D efforts have demonstrated up to a 66% reduction in separation distances, the revisions to the gaseous separation distance table in NFPA 2-2011 included a conservative 50% reduction (see NFPA 2 paragraph 7.3.2.3.1.1 [C]) using a science-based approach.

The risk-informed approach enabled reduction of some separation distances, such as when barrier walls are used for mitigation, and it also recommended an increase in other instances.

Development of other mitigation strategies and assessment of those strategies in future risk-informed code development activities is needed to further facilitate reduction of separation distances while maintaining consistent risk criteria. The risk informed analysis method is described in Ref. [3]. Separation distance reduction based on research at Sandia National Laboratories is found in Refs. [2, 4-7, 9].

Traditional code development relies on expert opinion and experience. However, the small number of hydrogen fueling stations that have been deployed in the U.S. and the limited hydrogen experience that code developers can rely upon has highlighted the need for a scientific approach to consequence and risk analysis. One alternative approach is quantitative risk assessment (QRA) – a combination of consequence analysis and event frequency analysis – as an accepted method for risk evaluation in other industries, including nuclear power and offshore oil and gas industries. This work established a new approach for hydrogen applications which combined expert opinion and experience with QRA. Experts from code development committees provide scenarios based on opinion and experience consistent with the traditional code development approach. A QRA is then performed on these scenarios and consequences. The results of the assessment are provided to the code development experts who then develop the code language. In this approach, the code development authority remains with the code development experts, however their deliberation on appropriate requirements, such as separation distances, is 'informed' by the results of the science-based risk assessment.

Quantitative Risk Assessment does not replace the need for relevant data. In the case of separation distances, code development experts determined that a leak and subsequent jet fire from high pressure hydrogen storage systems was the representative scenario for determining separation distances. However, the limited availability of data on hydrogen station leaks did not allow for the use of simple risk assessment methods. Instead, Bayesian statistical approaches [8] were used for the development and estimation of hydrogen leak frequencies for various components of a hydrogen storage system.

The example in Table 1 is one of numerous examples and shows a highly successful specific case in which the separation distance area was reduced from 12,480 ft^2 to 5,304 ft^2 (i.e., 58%).

Table 1 - Comparison of separation distances in NFPA 2 (2011) and NFPA 55 (2005) for gaseous hydrogen [9]

Separation Distance Comparison NFPA 2 (2011) "science based" vs. NFPA 55 (2005) "expert opinion and experience" Fueling System Description: Gaseous Hydrogen (GH_2): 12,500 psi storage, 100 kg, 0.4 inch ID tubing with a barrier wall *Note: there has been no change in separation distances or approach to separation distances for liquid hydrogen due to a lack of data on liquid hydrogen release behavior*		NFPA 2 (2011)	NFPA 55 (2005)
		GH_2 ft (wall)*	GH_2 ft (wall)*
Group 1	Lot Lines	24	0
	Air Intakes (NFPA 55-2005 includes air compressor intakes - i.e. pneumatic safety systems included)	24	50
Group 2	Ignition sources such as open flames and welding	24	0
	Exposed persons other than those servicing the system	13	*nd*
	Places of public assembly	*nd*	50
	Parked Cars	13	15
	Public Sidewalks and Parked Cars	*nd*	15
Group 3	Un-openable openings in building and structures	10	*nd*
	Not above any part of the system	*nd*	10
	Above any part of the system	*nd*	25
	Utilities overhead including electric power, building services or hazardous materials piping systems	10	*nd*
	Horizontal distance to the vertical plane below the nearest overhead electric wire of an electric trolly, train or bus line	*nd*	50
Required area for sample installations considered (sites requiring lot line separation of 50 ft rather than 0 ft)		5,304 ft^2	12,480 ft^2

Note: *nd* = not defined
*Refers to the required distance (in number of feet) from the outer edge of the gaseous hydrogen storage system to the exposure specified when a fire barrier wall – with minimum fire resistance rating of 2 hours – is located between the system and the exposure.

Peer Review: This record was peer reviewed by Jay Keller – a consultant to the DOE Fuel Cell Technologies Office's Safety, Codes and Standards program; Technical Program Director for the Built Environment on ISO Technical Committee 197; and member of the Technical Advisory Board – and a team of experts at Sandia National Laboratories.

Reference(s):

[1] ISO/CD 20100, "Gaseous hydrogen – Fuelling stations," International Organization for Standardization, August 12, 2008.

[2] J.L. LaChance, J. Phillips, W.G. Houf, "Risk Associated with the Use of Barriers in Hydrogen Refueling Stations," World Hydrogen Energy Conference, Essen, Germany, May 16-21, 2010.

[3] J.L. LaChance, W.G. Houf, B. Middleton, L. Fluer, "Analysis to Support Development of Risk-Informed Separation Distances for Hydrogen Codes and Standards," Sandia Report SAND2009-0874, March 2009.

[4] R. Schefer, E. Merilo, M. Groethe, W.G. Houf, "Experimental Investigation of Hydrogen Jet Fire Mitigation by Barrier Walls," *International Journal of Hydrogen Energy*, Vol. 36, Issue 3, pp. 2530-2537, Feb., 2011.
[5] W.G. Houf, G. Evans, R. Schefer, E. Merilo, M. Groethe, "A Study of Barrier Walls for Mitigation of Unintended Releases of Hydrogen," *International Journal of Hydrogen Energy*, Vol. 36, Issue 3, pp. 2520-2529, Feb., 2011.
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[8] C.L. Atwood, J.L. LaChance, H. F. Martz, D. J. Anderson, M. Englehardt, D. Whitehead, and T. Wheeler, "Handbook of Parameter Estimation for Probabilistic Risk Assessment," NUREG/CR-6823, U.S. Nuclear Regulatory Commission, Washington, D.C. (2003).
[9] A.P. Harris, D. E. Dedrick, C. LaFleur, C. San Marchi, "Safety, Codes and Standards for Hydrogen Installations: Hydrogen Fueling System Footprint Metric Development," Sandia Report SAND2014-3416, April 2014.