COMPARISON OF NFPA AND ISO APPROACHES FOR EVALUATING SEPARATION DISTANCES

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ABSTRACT

The development of a set of safety codes and standards for hydrogen facilities is necessary to ensure they are designed and operated safely. To help ensure that a hydrogen facility meets an acceptable level of risk, code and standard development organizations (SDOs) are utilizing risk-informed concepts in developing hydrogen codes and standards. Two SDOs, the National Fire Protection Association (NFPA) and the International Organization for Standardization (ISO) have been developing standards for gaseous hydrogen facilities that specify the facilities have certain safety features, use equipment made of material suitable for a hydrogen environment, and have specified separation distances. Under Department of Energy funding, Sandia National Laboratories (SNL) has been supporting efforts by both of these SDOs to develop the separation distances included in their respective standards. Important goals in these efforts are to use a defensible, science-based approach to establish these requirements and to the extent possible, harmonize the requirements. International harmonization of regulations, codes and standards is critical for enabling global market penetration of hydrogen and fuel cell technologies.

The successful approach to risk-inform the separation distances in the NFPA standards [1] is a model for establishment of additional requirements by NFPA and other SDOs. In fact, ISO has generally adopted the same approach to determine the separation distances in ISO 20100, "Gaseous hydrogen – Fuelling stations" [2]. In addition, the data and consequence models used in the NFPA analysis have also been generally adopted for use in the ISO separation distance evaluation. However, there are some important differences in the ISO and NFPA analyses that make it difficult to compare the resulting separation distances. These differences include the scope of the application (i.e., bulk storage versus fueling station), the differences in the separation distance table format used in the specific standards (pressure ranges and exposures), the risk acceptance criteria used in the risk analysis, the utilization of component leak data in the risk assessment, and the importance placed on the risk results. This paper discusses the differences between the approaches and data utilized in NFPA and ISO assessments and their effect on the resulting separation distances.

1.0 NFPA AND ISO APPROACHES FOR ESTABLISHING SEPARATION DISTANCES

The approaches used in establishing the NFPA and ISO separation distances for gaseous hydrogen facilities are very similar but do have some important differences. Both use Quantitative Risk Assessment (QRA) techniques to evaluate the risk from unintended releases of hydrogen. The risk from the operation of a facility is the product of the frequency and consequences of all credible accidents and can be estimated using QRA. A QRA can be used to identify and quantify scenarios involving the unintended release of hydrogen, to identify the significant risk contributors, and to identify potential accident prevention and mitigation strategies to reduce the risk to acceptable levels. A key accident mitigation feature for hydrogen facilities is the use of separation distances. Under DOE sponsorship, SNL developed the data and methods that were used in quantifying both the frequency and consequence portions of the QRAs performed in both the NFPA and ISO analyses.

The separation distances in both the NFPA and ISO analysis are based on the selection of a hydrogen leak size that if ignited, would result in unacceptable risk to a person, structure, or equipment. It is generally accepted that separation distances should not be used to provide protection against rare events such as large, catastrophic ruptures. Separation distances should be selected to cover leakage events that may be expected to occur during the facility lifetime, especially small leaks that may occur frequently. It is also desirable to establish separation distances that are not too short and consequently result in unacceptable risk levels. In particular, the associated risk from leakage events that would result in consequences beyond the designated separation distances should be acceptable as determined by consensus.

The risk measure evaluated in the NFPA QRA was the frequency of a fatality to a person assumed to be constantly present at the facility lot line from an ignited hydrogen jet. The fatality risk from all possible leaks in the modeled facility was evaluated and used to help select a single leak size (expressed as a percentage of the largest flow area in the system) that was used to determine the separation distance for all exposures included in the separation table. In contrast, the ISO analysis included the frequency of exposure of structures and equipments to hydrogen jets (to prevent escalation of a leakage event into a major incident; escalation was assumed to result in a human fatality) in addition to the potential for exposure of humans that would result in fatalities. Thus, different leak diameters were evaluated for different exposures and used to establish the resulting separation distances. In both the NFPA and ISO QRAs, exposure to a hydrogen flame was assumed to result in a fatality. In addition, the ISO QRA assumed exposure to a flame, regardless of the duration, resulted in equipment and structure failure.

1.1 Comparison of Risk Assessment Approaches

A significant difference between the NFPA and ISO approaches for determining separation distances is that the NFPA approach is risk-informed while the ISO approach is more properly characterized as risk-based. A risk-informed process utilizes risk insights obtained from QRAs combined with other considerations to establish code requirements. Other considerations used in this risk-informed process include the results of deterministic analyses of selected accident scenarios, the frequency of leakage events at hydrogen facilities, and the use of safety margins to account for uncertainties in the data, methods, and scope of the risk evaluation. In contrast, a risk-based approach only utilizes risk to develop the requirements.

The risk-informed process used in the NFPA approach explicitly included consideration of both the frequency of the selected leak size and the risk from larger leaks. In contrast, the ISO approach only included the evaluation of risk from leakage events (the frequency of expected leakage events was implicitly evaluated in the risk assessment but was not used in making any decisions). It is noted that in both analyses, some of the separation distances were not based on risk arguments. For example, in the ISO analysis the separation distances for large volume systems (i.e., >100 kg hydrogen) was based on the subjective argument that the distances should be greater than for the smaller systems.

The ISO risk-based approach utilizes the conceptual framework shown in Fig. 1. In this approach, the cumulative risk from different leak diameters resulting in one or more specified consequence are evaluated against the separation distances required to protect people, equipment, or structures from a specified level of harm. The ISO analysis also included risk to structures and components with the potential for structural or component damage assumed to result in a fatality. The accidental releases of hydrogen were limited to leakage events from four types of components (valves, compressors, hoses, and joints – pipes and tanks were excluded because they were not important risk contributors in the NFPA analysis). The consequences in both the ISO and NFPA analyses were limited to the effects of ignited hydrogen jets and exposure to an ignited hydrogen jet was assumed to result in harm to a target independent of the exposure period. In the ISO QRA, two selected risk acceptance criteria were used to establish the risk-based separation distances using the framework in Fig. 1. The separation distances were generated for one of two selected parameters that can result from a hydrogen jet, both of which were assumed to result in the same consequence – a fatality due to exposure to hydrogen flames: (1) the extent of the 4% hydrogen envelope which is assumed to be eventually ignited from an external ignition source or, (2) the exposure to a self-ignited hydrogen flame. Hydrogen leaks resulting in risk values equal to the risk criteria (discussed in Section 1.2) were used to select the separation distances for both consequence parameters.

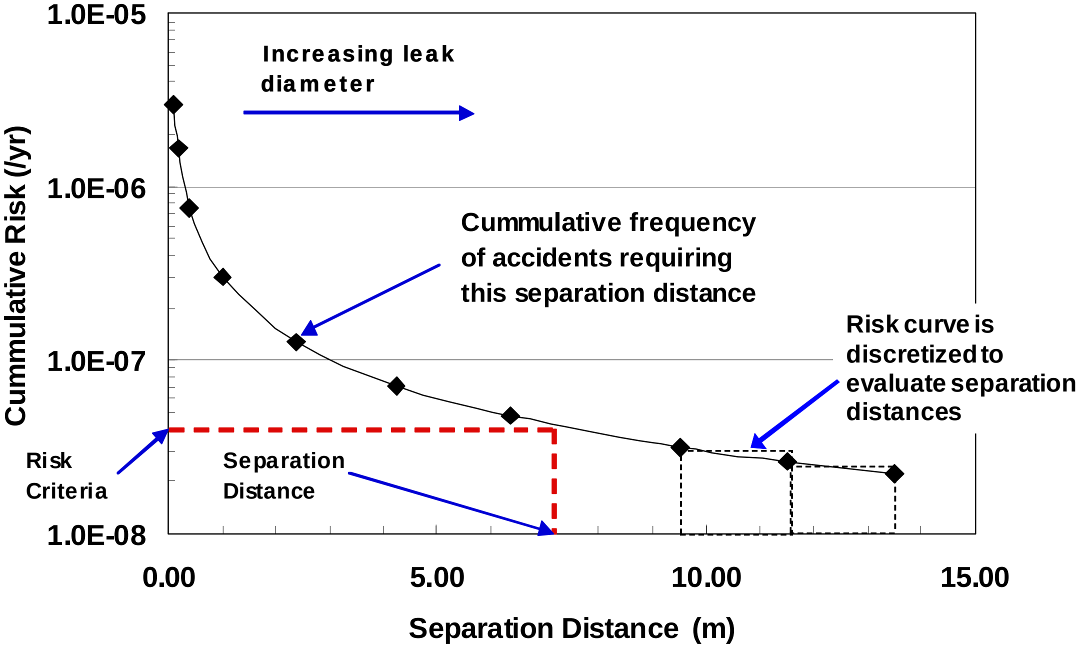

Figure 1. Risk-based approach for establishing safety distances.

In contrast, the leak size used as the basis for the separation distances in the NFPA approach was selected to encompass at least 95% of possible leakage events in typical hydrogen gas storage facilities. As a second criterion, the leak diameter was selected such that an event would not likely occur during the life time of the facility due to a low occurrence frequency (i.e., approximately 1E-2/yr). Although larger leaks would not be expected to occur, if they did, it would be desirable that the risk from these larger leaks to a member of the public standing at the selected separation distance be acceptable. Thus, the cumulative risk to the public from larger leaks was evaluated and compared to a risk guideline, as opposed to the risk criteria in the ISO approach, using the framework depicted in Fig. 1. A risk guideline is essentially a soft risk criterion that allows consideration of uncertainty in the risk assessment when selecting the separation distances using the framework in Fig. 1. The NFPA risk evaluation included separate scenarios involving both self-ignition and external ignition of a hydrogen jet and added the risk to an individual from both scenarios to determine the separation distances (the ISO analysis only included one or the other scenario to evaluate the separation distances for each target).

1.2 Risk Criteria

The performance of the QRAs in both assessments required selection of risk criteria/guidelines, establishment of needed data (component leakage frequencies and hydrogen ignition probabilities), and selection of a consequence model. Reference 1 provides a survey of fatality risk criteria that was used to select the risk guidelines utilized in the NFPA assessment. The selected fatality risk guideline of 2E-5/yr was based on three inputs: maintaining the risk at an equivalent level to gasoline stations, using a value that is consistent with countries that have established risk criteria, and limiting the risk from hydrogen releases to a fraction of the risk to an average person from accidental causes. The ISO analysis used a slightly lower fatality risk criteria of 1E-5/yr for some exposures and a lower risk criteria of 4E-6/yr for selected "critical" exposures believed to require additional protection (e.g., large volumes of flammable liquids and air intakes in occupied buildings). The 1E-5/yr fatality criterion was selected based on recommendations by the International Energy Agency Task 19 on Hydrogen Safety [3]. There is no documented basis for the critical exposure criteria.

1.3 Data

The component hydrogen leakage frequencies utilized in the NFPA QRA were generated using a Bayesian statistical approach [4]. A Bayesian statistical method was selected for use in the data analysis for three reasons. First, this approach allows for the generation of leakage rates for different sizes of leaks, which is a critical requirement for estimating the size of a leak to use as the basis for establishing separation distances. Second, it also generates uncertainty distributions for the leakage rates that can be propagated through the QRA models to establish the uncertainty in the risk results. Finally, it provides a means for incorporating limited hydrogen-specific leakage data with leakage frequencies from other sources (e.g., the nuclear and petroleum industries) to establish estimates for leakage rates for hydrogen components. An example of the generated hydrogen component leakage frequencies is provided in Fig. 2. The process for generating the hydrogen leak frequencies and the results are described in more detail in Reference 1.

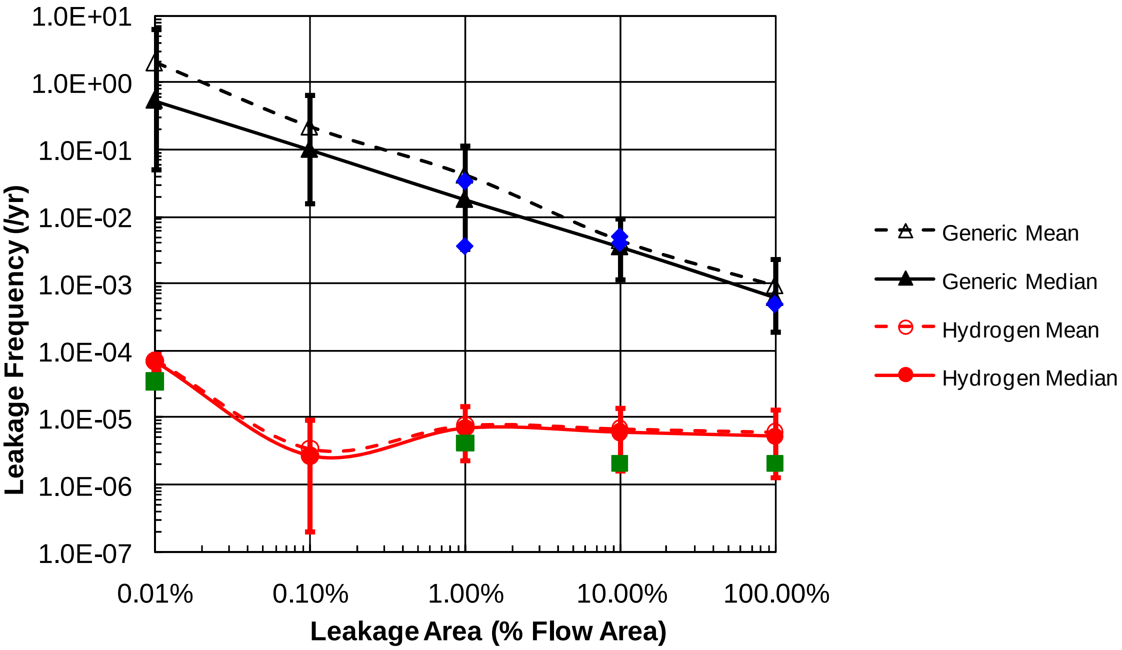

Figure 2. Results of Bayesian analysis for joint leak frequency.

There are several important points to be made about the data analysis process used in the NFPA risk assessment. First, the data in the generic sources was binned in several different approaches by the generators of each data source (the raw data is not available for review). The approaches include either specification of an exact numeric leak size (e.g., 20% of the component flow area), specification of a range in leak sizes (e.g., 1 to 50 gpm), specification of a minimum leak size (e.g., >1mm), or a qualitative description (e.g., small leak, large leak, and rupture). It is reasonable to assume that the binning of the generic data by the authors of each data source is relatively coarse and thus use of this data in a more refined binning scheme would be a further exaggeration of the uncertainty in how the raw data was binned. For example, the frequency of leaks specified as "ruptures" could actually represent leaks ranging from 10% to >100% of the component flow area even though some sources specified that ruptures were 100% of the flow area. Using the binning scheme in Cox, Lees, and Ang [5], the generic component leak data was binned into one of the three categories centered around 1%, 10%, or 100% of the component cross-sectional flow area. However, it was recognized that the actual data covers a range of leak sizes as indicated below:

- Small leaks: leaks equal to approximately 1% of the component flow area (ranging from <1% to 3%)
- Large leaks: leaks equal to approximately 10% of the component flow area (ranging from 3% to 30%)
- Ruptures: leaks equal to approximately 100% of the component flow area (ranging from 30% to >100%)

Second, the results of the Bayesian process indicated that the generic leak frequencies had an important impact for some components but not for others. This is illustrated in Figs. 2 and 3. As indicated in Fig. 2, the amount of hydrogen-specific data for joints (both the number of failures and the number of component years of operation) was relatively large. The generic data provided much higher frequencies than the hydrogen-specific data and thus had little influence on both the shape and magnitude of the hydrogen leak frequency estimate that was generated. In addition, the available hydrogen data suggested that the joint leak frequency distribution is relatively flat over a large leak size range. For valves, the story is different, as indicated in Fig. 3. The hydrogen data provided similar frequencies as was found in the review of generic data sources. As a result, the generic data influenced both the shape and magnitude of the hydrogen leak frequency estimated generated in the Bayesian analysis.

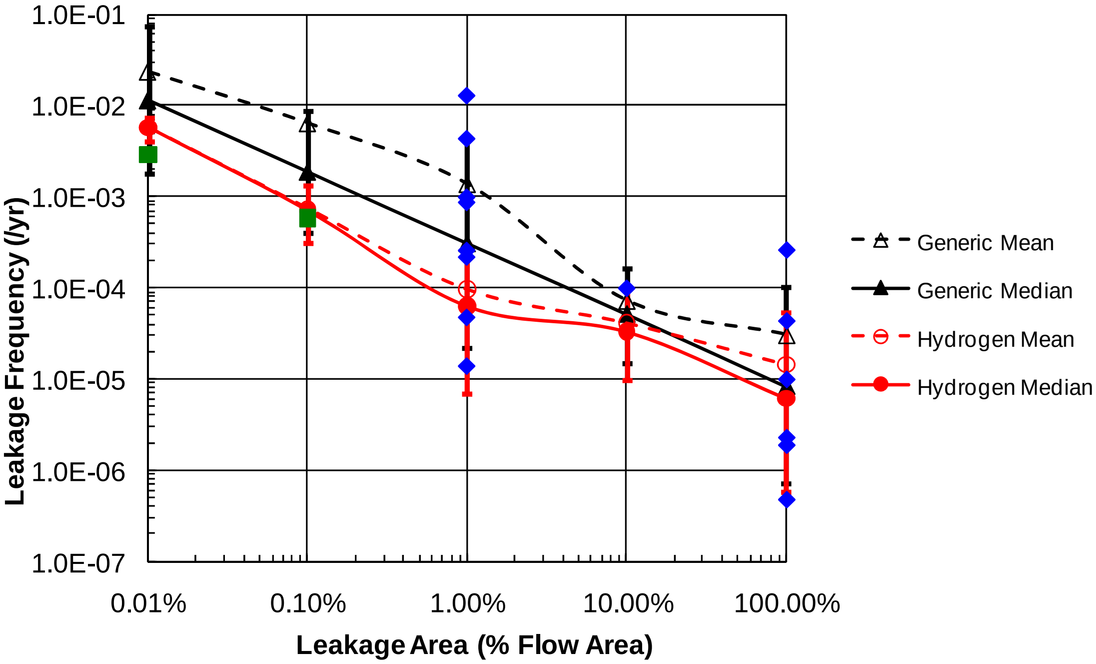

Figure 3. Results of Bayesian analysis for valve leak frequency.

The component leakage distributions utilized in the ISO analysis are linear versions (on a log-log plot) of the values generated by SNL that, as depicted in Fig. 4, are conservative over the majority of the leak size range. The linearization of the SNL data distributions was performed to simplify the ISO analysis and allow for a method to generate alternate separation distances for facilities that are substantially different than the example facility used to establish the ISO separation distance table. However, the ISO linear leak frequency distributions actually used in the risk analysis were shifted an order of magnitude when used in the ISO risk analysis (illustrated in Fig. 4). One stated purpose for shifting of the data was to discretize the leak frequency curve in to orders of magnitude bins. Instead of using the bins utilized to generate the data (discussed above), alternative bins were utilized (0.1% to 1%, 1% to 10%, 10%, to 100%). The shifting of the leak frequency distributions results in underestimating the frequency associated with each leak size and a reduction of the risk and the resulting separation distances by a factor of 3 (e.g., it uses the risk for 100% leaks to generate the separation distance for leaks in the 10%to 100% bin despite the fact that the 10% leaks are more frequent). This shifting of the data continues to be a major source of disagreement between members of the ISO working group established to generate separation distances.

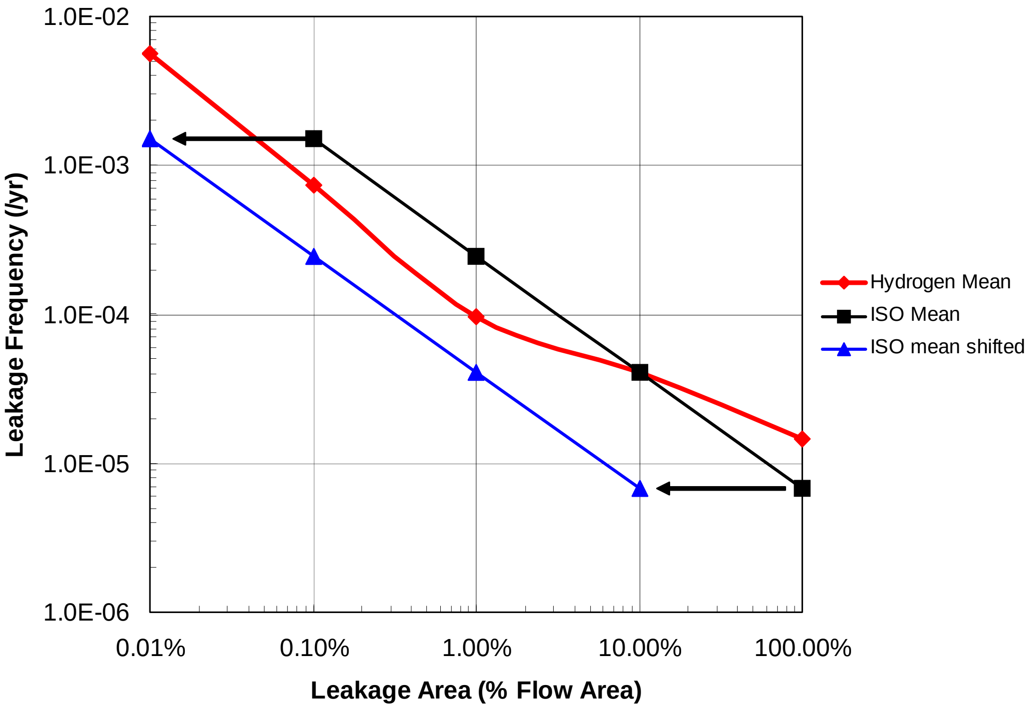

Figure 4. Comparison of valve leak frequency distribution used in NFPA and ISO analyses.

The shifting of the hydrogen leak frequencies was based on selected rebinning of a fraction of the generic leak frequencies. As indicated in Figs. 2 and 3, the generic data had a mixed effect on the hydrogen leak frequencies generated in the Bayesian analysis process in Reference 1. Thus, rebinning of only the generic data does not provide a rigorous and justifiable reason for modifying the leak frequencies used in the NFPA QRA. For this reason, both the generic and hydrogen-specific data was reviewed, rebinned into the alternate bins established by the ISO working group, and the Bayesian analysis was redone. The results of this effort and its impact on the ISO separation distances are discussed in Section 4.1.

The ignition probabilities used in the QRA were also different in the NFPA and ISO QRAs. The NFPA QRA utilized ignition probabilities that changed with leak size and whether the ignition occurred immediately or was delayed. The NFPA ignition probabilities are provided in Table 1. The ISO risk model included a single ignition probability of 0.04 that was independent of leak size or ignition time. Although the selected ISO ignition probability was conservative over a range of leak sizes, its use skews the actual risk profile and the resulting selection of the separation distances. This is evident in Section 4.2 which documents a sensitivity analysis where the NFPA ignition probabilities were used in the ISO QRA.

Table 1. Hydrogen ignition probabilities used in NFPA QRA.

Hydrogen Release Rate (kg/s)	**Immediate Ignition Probability**	**Delayed Ignition Probability**
<0.125	0.008	0.004
0.125 – 6.25	0.053	0.027
>6.25	0.23	0.12

1.4 Consequence Models

The consequence parameters that are important for establishing separation distances for gaseous hydrogen facilities were determined by deterministic analysis of hydrogen releases. These parameters are the unignited hydrogen jet envelope corresponding to a volumetric mole fraction of 4% and the hydrogen flame length. The models developed by Houf and Schefer [6] were used in both the NFPA and ISO QRAs to establish these parameters as a function of both pressure and leak size. The only major difference in the use of this model was that in the ISO QRA, twice the flame length was associated with causing a fatality. In the NFPA QRA, a person standing in the flame length was assumed to result in a fatality.

2. REPRESENTATIVE FACILITIES

Both the ISO and NFPA QRAs also require establishment of representative facilities for evaluating the frequencies of hydrogen leaks and the resulting risk. The NFPA analysis was focused on establishing separation distances for gaseous bulk hydrogen storage systems whereas the ISO analysis was for gaseous fueling stations. Six system/module configurations were used in the ISO evaluation while four configurations were used in the NFPA evaluation. Two operating pressures were evaluated with the ISO model while four pressures (one per model) were evaluated in the NFPA analysis. Thus, the representative facilities and pressures used in the analysis were substantially different. These differences also resulted in different separation distance table formats in the ISO and NFPA standards. A comparison of the facilities is provided in Table 2.

The NFPA example facilities had multiple components with diameters ranging from 7 mm to 52.5 mm. The ISO analysis used a single diameter for all components (8 mm) in the facility. In addition, the NFPA analysis assumed that the entire facility was co-located while the ISO analysis divided the facility into modules that were assumed to be adequately separated. The risk from leaks for each module was evaluated and compared with the risk criteria. By separating the gaseous fueling station in this fashion, the risk to an individual can be underestimated for stations that are not separated. These differences in the assumed facility separation result in significant differences in the estimated leak frequencies and associated risk for the facilities. It also makes it difficult to compare the resulting separation distances.

Table 2. Comparison of representative facilities used in ISO and NFPA risk assessments.

System	**Pressure (MPa)**	**Diameter (mm)**	**Number of Risk-Significant Components**				**LPI**[1]
			Valves	**Joints**	**Hoses**	**Compressor**	
ISO							
Very Simple Gas System (VS)- *(e.g., pressure regulator station)*	55 or 110	8	2	7	0	0	≤15 (15)
Simple Gas System (S) – *(e.g., cylinder pack)*	55 or 110	8	5	32	0.33	0	≤60 (60)
Complex Gas System (C) – *(e.g., buffer storage)*	55 or 110	8	20	55	0	0	>60 (135)
Simple Large Storage System[2] (SL) – *(e.g., larges storage system)*	55 or 110	8	NA	NA	NA	NA	≤45 (NA)
Complex Large Storage System[2] (CL) – *(e.g., tube trailer)*	55 or 110	8	NA	NA	NA	NA	>45 (NA)
Process System (A) *(e.g., compressor with connections)*	55 or 110	8	20	55	0	1	NA (>135)
NFPA							
Bulk Storage System:			36	93	17	1	-
Tube Trailer	20.7	12.7	13	38	10	0	(330)
Stanchion	20.7	18.9	4	6	1	0	(46)
Pressure Regulator Module	20.7, 51.7, or 103.4	18.97, 7.8, or 7.2	20	28	0	0	(108)
Compressor	20.7	7.8, or 7.2	0	0	0	1	(NA)
Buffer Storage	51.7, or 103.4	7.8, or 7.2	9	21	6	0	(201)

[1] Leak Probability Indicator (LPI) determined based on number of joints, valves, and hoses each multiplied by a Joint-Euivalency Ratio (JER). JER (joints)=1, JER (valves)=4, JER(hoses)=24.

[2] Simple and Complex Large Storage System leak sizes are not based on risk. Leak sizes were subjectively selected.

3. COMPARISON OF SEPARATION DISTANCES AND RISK

Comparison of the separation distances generated in the ISO and NFPA analysis is not possible due to the differences in the scope of the application (i.e., bulk storage versus fueling station) and the differences in the separation distance table format used in the specific standards (pressure ranges and exposures). However, it is informative to compare the leak size, in terms of the percentage of the flow area, used to determine the separation distances. As indicated in Table 3, the fraction of the flow area used to determine the ISO separation distances for both the regular and critical exposures (i.e., based on a 1E-5/yr and 4E-6/yr risk criterion, respectively) are substantially less than the 3% of the flow area utilized by. There are several contributors to the difference including different risk criteria, different facility configurations, separation of the gaseous fueling station into separate modules, different ignition probabilities, and most importantly, the difference in the application of the hydrogen leak frequencies. However, it is important to note that in both the ISO and NFPA standards, the resulting leak sizes when expressed as a function of flow area are independent of the system pressure.

Table 3. Comparison of leak sizes used to determine separation distances in ISO and NFPA standards.

System Type	**Example Systems**	**Leak Size (% of Flow Area)**	
		Regular Exposure	**Critical Exposure**
ISO			
Very Simple Gas System (VS)	Pressure regulation module	0.03%	0.09%
Simple Gas system (S)	Cylinder pack	0.16%	0.48%
Complex Gas System (C)	Cascaded buffer storage system	0.42%	1.30%
Simple Large Storage System[1] (SL)	Large hydrogen storage (e.g., 100 m3)	0.38%	1.50%
Complex Large Storage System[1] (CL)	Hydrogen tube trailer	0.75%	3.00%
Process System (A)	Compressor plus connections	0.65%	1.81%
NFPA	Bulk storage system with a hydrogen tube trailer, pressure regulator module, compressor, and buffer storage area	3.00%[2]	

[1] The leak sizes for these systems were not evaluated using the ISO risk model. They were subjectively selected.

[2] The NFPA risk assessment used a single risk guideline of 2E-5/yr to evaluate leak sizes and resulting separation distances. This risk guideline is comparable to the regular exposure criteria of 1E-5/yr in the ISO risk assessment.

4. EVALUATION OF IMPORTANT DIFFERENCES IN NFPA AND ISO RISK ASSESSMENTS

As discussed above, major differences between the NFPA and ISO QRAs occurred due to differences in leak frequency data and how it was binned, and due to differences in the ignition probabilities that were used in the risk assessments. The impact of both of these differences is discussed in the following sections.

4.1 Component Leak Data Evaluation

As indicated previously, the modification of the hydrogen component leak frequencies from Reference 1 by the ISO working group on separation distances was not based on a rigorous or valid statistical approach. Despite these facts, the separation distances resulting from the use of this data are in the draft ISO standard [2]. In order to evaluate the significance of this action, Sandia National Laboratories reviewed the generic and hydrogen-specific data with regard to binning of the data and its impact on the estimated hydrogen leak frequencies generated using Bayesian analysis. Part of this effort included rebinning the data into the alternate bins utilized in the ISO QRA. The results for two components are highlighted in Figs. 5 and 6.

A review of the data for joints indicated that the data was correctly binned in the original Bayesian assessment documented in Reference 1. However, in order to illustrate that there was no basis for the shifting of the leak frequencies in the ISO QRA, the generic data was arbitrarily shifted an order of magnitude (i.e., 100% leaks were rebinned into a 10% to 100% leak size bin). As indicated in Fig. 5, the rebinning of the generic data lowered the mean generic leak frequency curve, however, when this revised data is used in the Bayesian process, no difference resulted in the hydrogen leak frequency estimates. The reason, as explained previously, is because the generic data (prior distribution) had little influence on the hydrogen estimate (posterior distribution).

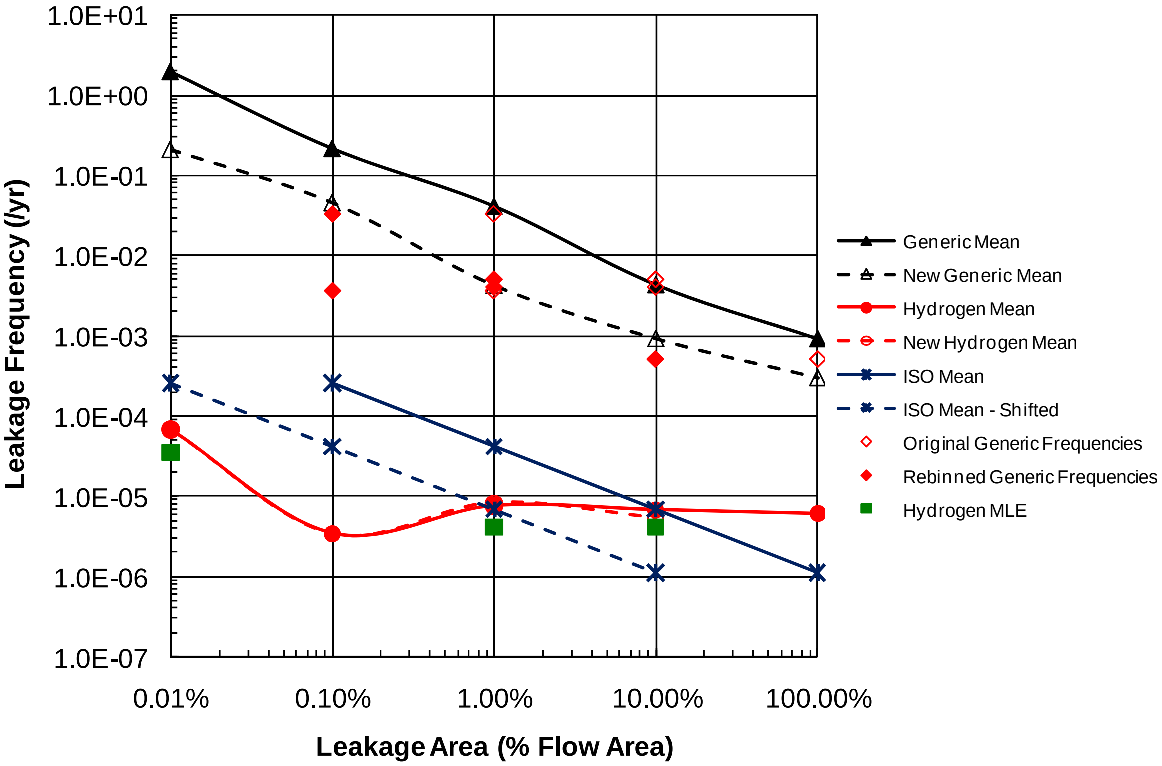

Figure 5. Results of Bayesian analysis with joint data shifted one order of magnitude.

A review of the generic leak frequencies for valves indicated that some of the data had been conservatively binned in the initial Bayesian analysis. As indicated in Section 1.3, the actual leak size represented in this data is uncertain. However, some of the data was rebinned into lower leak sizes, especially the data points identified by the ISO working group. In particular, many of the data points initially binned as ruptures (30 to 100% leaks) were rebinned into smaller leak categories. However, several data points remained as 100% leaks. A Bayesian analysis was performed using this revised data. As illustrated in Figure 6, the resulting hydrogen generated mean leak frequency curve has lower frequencies than those reported in Reference 1. However, the frequencies are not substantially less (less than a factor of 2 different) which does not justify using the 100% leak size frequency as representative of leaks in the 10% to 100% range (results in non-conservative results). It would be conservative to utilize the leak frequency for 10% leaks to represent the leaks in that range. A more realistic result would occur if the original leak size bins from Reference 1 were utilized (i.e., leaks between 30% to 100% of the flow area are better represented by the leak frequency estimate for a 100% leak).

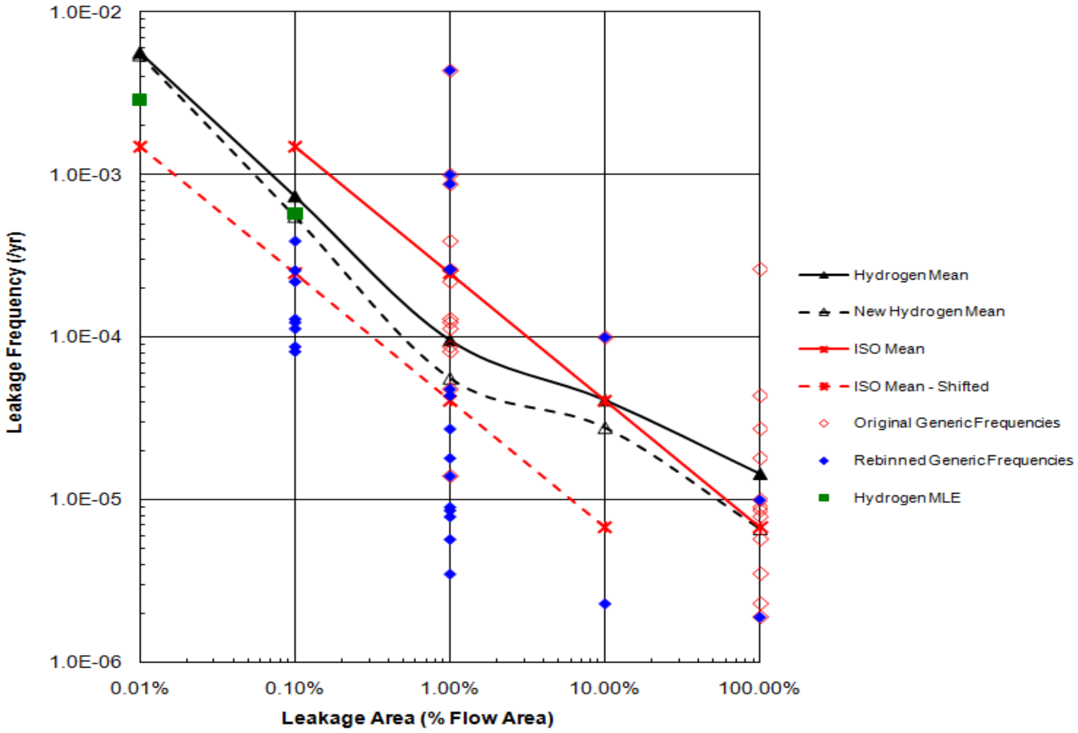

Figure 6. Results of Bayesian analysis with valve data rebinned.

The results of the rebinning of data and Bayesian analysis for hoses and compressors resulted in similar results as for the joint and valve components, respectively. Based on this more rigorous evaluation, the rebinning of selected generic data performed by the ISO working group does not provide an adequate basis for shifting the hydrogen leak frequencies reported in Reference 1. The impact of this on the ISO risk results is discussed in the following section.

4.2 Leak Frequency and Ignition Probability Sensitivity Study

The impact of using the same component leak frequencies and hydrogen ignition probabilities as was used in the NFPA QRA was evaluated using the ISO risk models. The results are shown in Fig. 7 for four systems/modules that are defined in Table 2.

As indicated in Fig. 7, the resulting risk profiles are very different than from the ISO QRA and result in generally higher risk estimates for a person standing at a specified distance. Although the risk is higher for most of the systems/modules, the risk is acceptable over a range of separation distances. For example, the highest risk level is associated with the complex gas system (C). Using the ISO risk criteria of 1E-5/yr and 4E-6/yr, the associated separation distances are approximately 5 m and 9 m, respectively. The risk estimate for both of these distances using the NFPA data is 2E-5/yr. However, for the very simple gas system (VS), the ISO risk estimate is nearly identical to that predicted using he NFPA data.

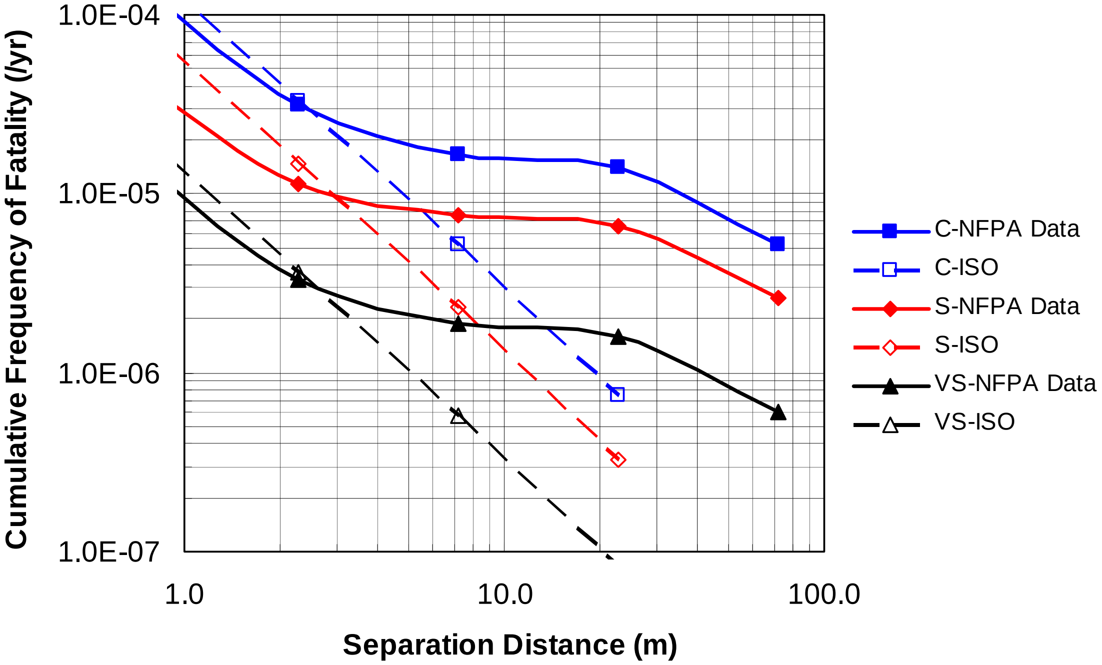

Figure 7. Results of requantification of ISO QRA using NFPA leak frequency and ignition probabilities.

5. CONCLUSIONS AND FUTURE DIRECTIONS

As indicated above, the efforts to harmonize the ISO and NFPA approaches to determine separation distances was generally successful as both used essentially the same risk approach for evaluating separation distances. Similarly, the SNL consequence models and the hydrogen leak data generated by SNL using Bayesian analysis were used in both evaluations. However, the SNL leak frequency data was modified in the ISO analysis based on a non-rigorous analysis which involved a cursory rebinning of only the generic data utilized in the SNL Bayesian process. A more detailed assessment of the data by SNL that involved rebinning of the generic and hydrogen-specific data and re-performance of the Bayesian analysis indicates that the modification of the SNL data in the ISO QRA was not justified. The application of the ISO leak frequency distributions in the QRA under estimates the risk and associated separation distances. In addition, the use of a constant ignition probability in the ISO QRA is non-mechanistic and results in a skewed risk profile that contributes to smaller separation distances. However, sensitivity studies performed using both the component leak frequencies and hydrogen ignition probabilities used in the NFPA QRA indicates the resulting risk associated with the ISO separation distances is acceptable.

International harmonization of Regulations, Codes and Standards enables global market penetration of hydrogen and fuel cell technologies. Toward this end, efforts will continue to evaluate the effect of other differences (e.g., risk criteria) between the NFPA and ISO analyses in order to harmonize the methodologies and the resulting separation distances to the greatest extent possible. In addition, harmonization of the example facilities and separation distance table format should be pursued.

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