criteria for LNG hazardous materials transportation scenarios.[3] Additionally, QRA analyses are not common regulatory requirements in the U.S. and no broadly-accepted risk criteria are employed by domestic communities or industries. The Dutch government and their respective regulatory agencies have been international leaders in utilizing QRA techniques for determining acceptability of fixed facilities and transportation routes. The approach for evaluating the risk results presented here is consistent with the Dutch guidance.

There are several foreign and several domestic examples of quantitative risk criteria.[4,5,6] Within these, there is a wide disparity in risk criteria for public exposure, with acceptable IR fatality probabilities ranging from 10^{-4} yr^{-1} (or a fatality per 10,000 years) to 10^{-8} yr^{-1} (or a fatality per 100,000,000 years). A broadly acceptable IR criterion from these international references is 10^{-6} yr^{-1}. Recommendations for QRA of LNG plants were issued in the National Fire Protection Association (NFPA) standard, NFPA 59A *Standard for the Production, Storage, and Handling of Liquefied Natural Gas (LNG)*.[7,8] In addition to including QRA as a risk assessment tool in the latest edition of NFPA 59A, the standard also includes quantitative risk criteria for fixed LNG facilities. NFPA 59A explicitly applies to LNG plants and stationary facilities; it does not apply to LNG transportation in DOT-113 tank cars. Thus, the quantitative risk criteria proposed in the standard are not directly applicable to rail shipping of LNG. However, these risk criteria are discussed here as one potential basis for quantitative risk criteria for rail shipping of LNG.

1.1.2 Individual Risk Criteria

During other rail LNG projects, the FRA requested that NFPA 59A quantitative risk criteria be used as a reference basis for the analysis. For IR, NFPA 59A identifies three "Zones" representing ranges of quantitative risk values. Each risk zone reflects general types of public occupancies recommended to be permitted within that risk zone. As the magnitude of the

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3 Strang J, "Federal Railroad Administration Risk Reduction Programs," United States Army Corps of Engineers Workshop on Tolerable Risk, March 18-19, 2008, Alexandria, Virginia.

4 Appendix B: Survey of Worldwide Risk Criteria Applications, *Guidelines for Developing Quantitative Safety Risk Criteria*. Center for Chemical Process Safety, AIChE (2009).

5 Cornwell JB and MM Meyer, "Risk Acceptance Criteria or 'How Safe is Safe Enough?'" presented at II Risk Control Seminar in Puerto La Cruz, Venezuela, October 13, 1997.

6 Ham JM, M Struckl, AM Heikkila, E Krausmann, C DiMauro, M Christou, JP Nordvik, "Comparison of Risk Analysis Methods and Development of a Template for Risk Characterisation," Institute for the Protection and Security of the Citizen, European Commission, Directorate-General Joint Research Center (2006).

7 NFPA 59A, *Standard for the Production, Storage, and Handling of Liquefied Natural Gas (LNG),* 2016 edition, National Fire Protection Association.

8 It should be noted that an older version – the 2001 edition of NFPA 59A – is one of the primary references for the requirements found in 49 CFR § 193, which provides the regulatory requirement for fixed LNG facilities operating in the U.S., and many of the 49 CFR § 193 codes reference NFPA 59A requirements directly. The 2001 edition of NFPA59A does not include requirements or suggestions for QRA.