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Norman Khumalo
Town Manager
Town of Hopkinton
18 Main Street
Hopkinton, MA 01748

March 29, 2016

Re: Technical review of Smith & Burgess report
Town of Hopkinton, MA

Dear Mr. Khumalo:

Sanborn, Head & Associates, Inc. (Sanborn Head) has per our February 25, 2016 agreement with the Town of Hopkinton (Hopkinton) reviewed the February 9, 2016 "LNG Spill Dispersion Report" prepared by Smith & Burgess. The Smith & Burgess report describes the findings of a Computational Fluid Dynamics (CFD) simulation study of the movement and dispersion of hypothetical releases of liquefied natural gas (LNG) from the Hopkinton LNG facility located near the intersection of Rafferty Road and Wilson Street. We understand that Hopkinton is concerned about hazards in areas of existing and proposed residential development that are located within the vicinity of the facility and asked Smith & Burgess to evaluate potential worst-case LNG releases irrespective of probability of occurrence.

We emphasize that the probability of an LNG storage tank failure of the type simulated is miniscule. With exception of the storage tank failure of 1944 in Cleveland that was constructed of inferior materials and did not have an impoundment, a failure of the sort considered by Smith & Burgess has never happened anywhere to our knowledge, probably largely due to the recognition of its potential consequences and implementation of mitigation programs to prevent such an occurrence. It is thus important that diligent mitigation efforts are continued at the Hopkinton LNG facility.

With reference to NFPA 59A 2013 Edition Chapter 15, the estimated annual probability for failure of a primary container (single containment failure) is 0.5 chances per million. In comparison, there is an estimated 12 per million annual chance that a magnitude 7.0 earthquake will occur in Hopkinton (Homefacts, 2016). Federal Energy Regulatory Commission (FERC) single accident release scenario criteria suggests that only failures with an annual probability greater than 30 per million should be analyzed (Kohout, 2012).

These comparisons offer perspective, but are not intended to belittle the potentially serious nature of the consequences of a significant LNG release in the unlikely event that it did occur. It is thus appropriate to consider the basis and accuracy and reliability of the Smith & Burgess report. To do so, we have reviewed the study report and additional information provided to us by Smith & Burgess in response to questions.

The Smith & Burgess technical analysis is quite complex, requiring detailed input and exercise of professional judgment. The complexity makes it impossible to discern the exact methods employed in the study without access to the CFD software and input and output files. However, there are inconsistencies apparent in the report that cast uncertainty on the accuracy of the predictions. The LNG release scenarios do not adequately account for facility-specific design considerations. Additionally, there is potentially significant overestimation of heat transfer rates to the LNG releases that results in correspondingly significant overestimation of the theoretical rate of cold vapor generation. As such, the areal extent of the projected vapor contours may be overestimated by a significant margin. Additional CFD simulations to test the sensitivity of key assumptions might help to evaluate the accuracy of the predictions. Lacking such tests, we would hesitate to rely on the study predictions to guide determinations of the extent of the region necessary to protect Hopkinton residents.

Study Design and Source Release Scenarios

A weakness of the Smith & Burgess study is the lack of a proper test case for comparison. It would have been beneficial to use one of the simple dense gas dispersion models such as DEGADIS to perform a comparable vapor dispersion simulation under simplified conditions (*i.e.*, flat, smooth terrain) to test the importance of considering topographic and land use complexities within the CFD simulations. A simple study could also be a useful check on the overall CFD estimates, and hence may still be worthy of consideration as a *post hoc* diagnostic check.

Smith & Burgess considers two release scenarios: a guillotining of an LNG transport pipe from the liquefier, and a catastrophic (complete) failure of one of the large three LNG storage tanks. Based on our process understanding, the pipe in question that runs under Wilson Street does not operate at the assumed 800 psig pressure. It operates instead at a pressure of about 110 psig. Consequently, credible CFD simulations of the pipe guillotine scenario at the location near Wilson Street would need to examine considerably lower rates of LNG release.

A pipeline pressure as high as 800 psig is possible at the Hopkinton facility at the vaporization sendout line, which is approximately 1,600 feet from the LNG storage area. The vaporizers operate only episodically in the winter when LNG is withdrawn from the storage tanks to augment the pipeline gas supply. At these times, LNG is pumped from storage tanks at about 110 psig to the to the high pressure pump house. The liquid is then boosted to a maximum of 800 psig to the vaporizers. We note that potential LNG releases at this location have been considered in facility design and contingency planning. A guillotine failure at the high pressure pump house would by design trigger an automatic shutdown of LNG pumping from the storage tanks. Even so, regulations require the evaluation of a spill up to 10 minutes duration at the LNG pumping rate of 520 gpm (which limits the rate at which LNG can be delivered to the vaporizers).[1] If somehow this happened, 5,200 gallons of LNG may be hypothetically released, corresponding to a mass of approximately 8,100 kg. This same mass release (which is unlikely to happen) would transpire in less than 16 seconds at the 509 kg/s LNG release rate modeled by Smith & Burgess in the pipe guillotine scenario. The Smith & Burgess simulations lasted from 190 to 2,120 seconds, thus releasing more than 12 to 130 times the mass of LNG than in the worst-case (and unlikely) scenario required by regulations, thus greatly overestimating the a realistic worst-case LNG mass release from the high pressure sendout line. Moreover, any simulation of a worst-case release from the sendout line should account for the likely diversion of LNG to the sub-impoundment (approximately 20'x20' by about 6' deep) designed to contain an inadvertent LNG release.

Inaccuracies in release scenarios on the part of Smith & Burgess could have been avoided through a more detailed understanding of the design and operation of the Hopkinton facility. Additional simulations should rely on facility-specific information. Correcting to a lower operating pressure in the assumed guillotine release would result in a lower LNG release rate, and hence would decrease the extent of areas predicted to be affected by the hypothetical release. Additionally, the guillotine release scenario does not account for any shut off mechanisms that might be present in the line that would further limit the magnitude of a potential LNG release. Consequently, the CFD simulations of the guillotining scenario likely overestimate the outer geographical limits of impacts that might result from a worst-case release of the type postulated, even should the simulation refocus on the correct location of the high pressure sendout line.

Similarly, there are also various mechanisms in place that are designed to contain and limit the release of LNG from storage tank failures. As an example, the two bottom-fill LNG storage tanks have an internal shut off valve which is designed to close upon detection of excess flow such as in the case of a guillotine failure of the downstream piping. We again recommend that experts familiar with safety systems at the Hopkinton facility be consulted to determine plausible worst-case scenarios.

However, recognizing Hopkinton's desire to investigate worst-case releases irrespective of the likelihood of mechanism or probability of occurrence, the details of a particular release scenario are to first order not important. Most of the tank failure scenarios examined by Smith & Burgess assume that some or all of the stored LNG is released to the diked containment area over a relatively short period of time. The guillotine scenarios, though assumed to occur outside the containment area, also simulate the rapid release of a significant quantity of LNG (though, as detailed above, the potential mass of the release is likely greatly overstated). In such scenarios, cold LNG would be expected to spread out along the ground, form a pool, and begin to boil to natural gas vapor at the boiling temperature of about -260°F. At this temperature, natural gas is denser than air, and the cold vapor would fill the containment area and spill over (or if uncontained, simply enter the atmosphere), then remain close to the ground as it travels away from the facility and

[1] An initial depressurization of the sendout line from 800 psig to ambient pressure due to a guillotine cut might result in a short-term atomization of LNG to the air (Cleaver *et al*, 2007), but our intuition suggests that the release should rapidly revert to a liquid stream that will pool within the designed containment sump.

slowly mixes with air. The rate at which vapor is formed depends on the ability to transfer heat to it from the environment (as subsequently discussed).

Modeling Assumptions

The Smith & Burgess study is very complicated and employs a great number of assumptions. One area of potential concern is the treatment of two-phase (liquid and gas) conditions. Report figures that depict the volume fraction of liquid indicate the computational grid cells at the ground surface are large enough to contain both liquid and gas phases. In these cases, Luketa-Hanlin *et al*. (2007) suggest that the liquid phase is difficult to model in CFD simulations, as the transient LNG pool grows in extent and thickness, and suggest its separate consideration. The Smith & Burgess report does not provide details on the procedure used to model two-phase flow, but if the liquid phase is assumed to be distributed throughout the ground-based grid cell layer, the behavior of the liquid pool may be incorrectly modeled.

Assuming that other stated model inputs and options have been employed correctly within the STAR-CCM+ software, there are three factors that could each serve to overestimate the outer geographical limits of vapor impacts from LNG release:

- The potential resistance to vapor transport caused by forested areas in the near vicinity of the Eversource terminal is not explicitly considered. Smith & Burgess addresses this resistance through specification of surface roughness lengths that will affect the way in which wind speed increases with height in the atmosphere, but because cold natural gas vapor stays near the ground (until it mixes with enough air), the flow around individual trees can potentially slow the progress of vapor plumes and introduce additional turbulence/dispersion. Other CFD modelers (*e.g.*, Zeleti *et al.,* 2014) have employed semi-porous elements in near-ground locations to simulate transport directly through forested areas. We recommend investigation of this method should further CFD simulations be undertaken.
- Meteorological conditions are inconsistently applied. Specifically, stable atmospheric conditions are assumed in conjunction with solar heating and an elevated ground temperature. Stable atmospheres typically occur during nighttime periods, and solar heating and elevated ground temperatures occur only during the daytime. Resolving this inconsistency in either direction will serve to decrease the extent of vapor impacts. If nighttime conditions are assumed and the solar flux and elevated ground temperature are removed, heat transfer to the LNG is reduced and cold vapor emissions are generated at a lower rate. If daytime conditions are assumed and the solar flux and elevated ground temperature assumptions are maintained, unstable atmospheric conditions should be assumed, which will increase the rate of mixing between the air and cold vapor.
- The Smith & Burgess report does not indicate whether the heat transfer characteristics of the ground were considered. Subsequent information from Smith & Burgess indicates potentially significant errors in the way in which heat transfer to the LNG was modeled. The rate at which cold vapor is generated is largely

controlled by heat conduction from the ground to the cold (-260°F) LNG. If the ground surface is assumed to be kept at a constant temperature, the rate of heat transfer, and hence LNG boiling, will be overestimated, probably by a considerable degree as the simulations proceed in time. This is in our view the most serious uncertainty of the study, and could be resolved through decoupling of the modeling of the source vapor emission atmospheric dispersion components. As an example, Luketa-Hanlin *et al*. (2007) suggest an independent model outside of the CFD environment be used to predict the pool formation and cold vapor generation from the LNG release, and the predicted mass emission rates of cold vapor be used as boundary condition inputs to the bottom (ground surface) layer of the CFD simulations.

Observations on CFD Simulation Results

The Smith & Burgess study considers different LNG release rates under different wind speeds and directions, making it difficult to compare simulations. Regardless, all of the predictions indicate vapor transport to significant distances from the point of release. As described above, there are reasons to suspect that the outer limits of these vapor transport distances are overestimated. Without investing in significant additional work, however, there is no way to tell the degree to which impacts are overestimated.

It is also worth noting, however, that the Smith & Burgess simulations (under the assumptions conducted) do not necessarily identify the greatest extent of potential impacts. To our understanding, the simulations were simply carried out to different and arbitrary times, and the results at the ending time of the simulations are presented in the maps/figures in the report Appendices. It is possible that vapor dispersion contours could grow beyond what Smith & Burgess depict if simulations are extended in time. Also, in some cases, the contours reach the edge of the computational modeling domain, indicating that the extent of potential vapor transport has not been identified.

Presentation of model predictions at only the end of each simulation does not allow for examination of the evolution of the release or dense gas plume. It would have been much more informative to provide for each simulation a time series of contour plots depicting the both the extent of the LNG pool and the methane plume at ground level.

Overall Findings and Opinion

Based on the preceding discussion, the Smith & Burgess study contains several unrealistic and potentially inaccurate assumptions that likely serve to overestimate the extent of potential impacts from inadvertent releases from the Hopkinton LNG facility. Further examination of the modeling assumptions is necessary to determine the gravity of errors that appear to have been made in the modeling of heat transfer rates to the hypothetical LNG releases. Until these potential errors can be investigated and resolved, the predicted geographic extents of vapor plumes cannot in our opinion be viewed as reliably accurate for making decisions on risk and safety.

Irrespective, if it somehow occurred, the release of the contents of an entire LNG tank could have significant consequences, especially in areas closer to the facility. The LNG industry, learning from the experience of the 1944 tank failure in Cleveland, require facilities to limit and contain potential releases, so that the chance of a total release scenario is very low. Indeed, releases of this sort have not occurred since 1944 at any of the more than 100 LNG facilities in the U.S.

Additional modeling with release scenarios based on facility-specific design factors with a likelihood of occurrence greater than the FERC 30 per million threshold could be more informative with respect to potential hazards in the vicinity of the Hopkinton LNG facility. Additionally, consideration of present inspection, auditing, and risk mitigation programs, in cooperative dialogue with the facility operator, may identify opportunities for further risk management and reduction.

References

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Closing

Our review was by necessity limited to the information provided by Hopkinton and Smith & Burgess. Based on this information, we cannot ascertain whether the inputs and assumptions were correctly considered in the STAR CCM+ CFD software used by Smith & Burgess.

Please call with any questions, and thank you for the opportunity to assist with this interesting matter.

Sincerely,

Stephen G. Zemba

Stephen Zemba, Ph.D., P.E.
Project Director