Geotechnical Consultant **Professional Engineer**

D. J. HAGERTY

May 8, 2017

Frost Brown Todd LLC
Attn: Mr. Glenn Price
400 West Market Street, 32^{nd} Floor
Louisville, KY 40202

RE: Evaluation of Noise Effects from Propane Tank Explosions
River Metals Recycling, Inc.

Dear Mr. Price:

In accordance with DJH Proposal No. 17C-11, and your authorization on April 7, 2017, of work under that proposal, I undertook the first phase in an evaluation of noise effects from explosions of propane tanks surreptitiously sequestered in scrap vehicles when those vehicles were being shredded at the River Metals Recycling, Inc., (RMR) recycling facility on Metals Lane at River Road. According to information provided by you and Mr. Chris Bedell of the David Joseph Company, owners of the RMR facility, conditions during crushing of the scrap vehicles had caused propane to escape from hidden tanks and explode, damaging the shredder equipment. I had proposed providing a preliminary opinion based on my education and experience in evaluating the effects of explosions on residential structures, incorporating an analysis of published information about air overpressures generated by explosions. Since the authorization of that work, I have been provided data from a noise monitoring device located at the RMR facility so I can include an analysis of data from the recorded events in forming a preliminary opinion.

Air overpressures from explosions have been studied by many government agencies, university scientists and other individuals. Fundamental studies of air overpressure generation and propagation have concluded that the intensity of effects from a release of energy in air depends on two principal factors: the degree to which the release is contained or confined; and the distance between the point of energy release and the person or structure affected by the overpressure. If the energy release were to occur in a perfect, ideal non-yielding container, then no energy would be transmitted to the surrounding air and the overpressure (pressure about atmospheric pressure) would be zero. Perfect confinement is not encountered in most explosions even when those explosions occur in boreholes drilled into rock, with pieces of rock packed into the holes over the explosive that is detonated. At the extreme end of the confinement spectrum is an energy release in air, with no confinement. **To estimate an overpressure generated by an energy release when propane gas escaped from a metal tank inside a scrap vehicle, the most conservative approach, used to estimate the maximum probable air overpressure, is to assume that the gas explosion is unconfined.** The effect of the leaking tank, the scrap vehicle and the shredder in which the event occurs can be ignored, if a conservative prediction is desired. In such a case, the energy release from the gas is not an explosion but a deflagration, or very rapid burning.

The second factor that is important in determining the effect of a gas deflagration on a structure or object is the distance between the energy release point and the receptor (the structure that is affected). A shock wave is produced by rapid energy release and that wave moves out from the energy release point so that the released energy is spread over a greater and greater area (the surface of the wave). As the distance from the energy release point increases, the intensity of the air overpressure that impacts any structure along the wave path decreases drastically.

The effect of distance on air overpressure from unconfined explosions has been studied for many years. One of the earliest studies that has been cited consistently through the years was a research effort at the Ballistic Research Laboratories from which the results were published in 1964 (Perkins, B. Jr., and W. F. Jackson, *Handbook for Prediction of Airblast Focusing*, Ballistic Research Laboratories, Aberdeen, MD, Report No. 1240, 100 p.) The equation published in that Handbook for prediction of airblast overpressure (AB), in pounds per square inch, described the overpressure as a function of distance in feet between the energy release point and the affected structure to the -1.38 power:

$$AB \text{ (in psi)} = F(\text{distance})^{-1.38}$$

That equation can be used to predict the generated air overpressure at a given distance from a given energy release if the air overpressure is known at a second point. For example, if the air overpressure from a given energy release were 1.0 psi at a distance of 300 feet from the energy release point, the air overpressure at a second point at a distance of 2,800 feet from the energy release point would be approximately 0.046 psi, or 4.6 percent of the pressure at the nearer point. In terms of decibels, the pressure of 1.0 psi is equivalent to 170.8 dB and the pressure of 0.046 psi is equivalent to 144 dB.

In recent years, the effects of air overpressure from explosions has gained immense importance because of terrorist bombing attacks on structures such as the Murrah Federal Building in Oklahoma City, Oklahoma. Protection of buildings against bombing attacks has become the focus of coordinated efforts by federal agencies; the best single reference on the effects of air overpressures on buildings, and how overpressure changes with distance from an energy release point is *FEMA 426 Reference Manual to Mitigate Potential Terrorist Attacks Against Buildings*, FEMA 2003. The term used in the FEMA Manual to signify the distance between the energy release point and the affected building is the "Stand-off Distance." An example of the effect of increasing stand-off distance is shown in Fig. 4-10 from Chapter 4 of the FEMA Manual. For an assumed energy release equivalent to that from 1,000 lbs of TNT, increasing the stand-off distance by a factor of approximately 5.3 decreases the air overpressure on an affected building by a factor of ten. For example, increasing stand-off distance from roughly 85 feet to 450 feet will reduce the air overpressure from 10 psi to 1 psi; see Fig. 4-10, next page. The same result would be obtained by using the Perkins and Jackson equation cited previously.

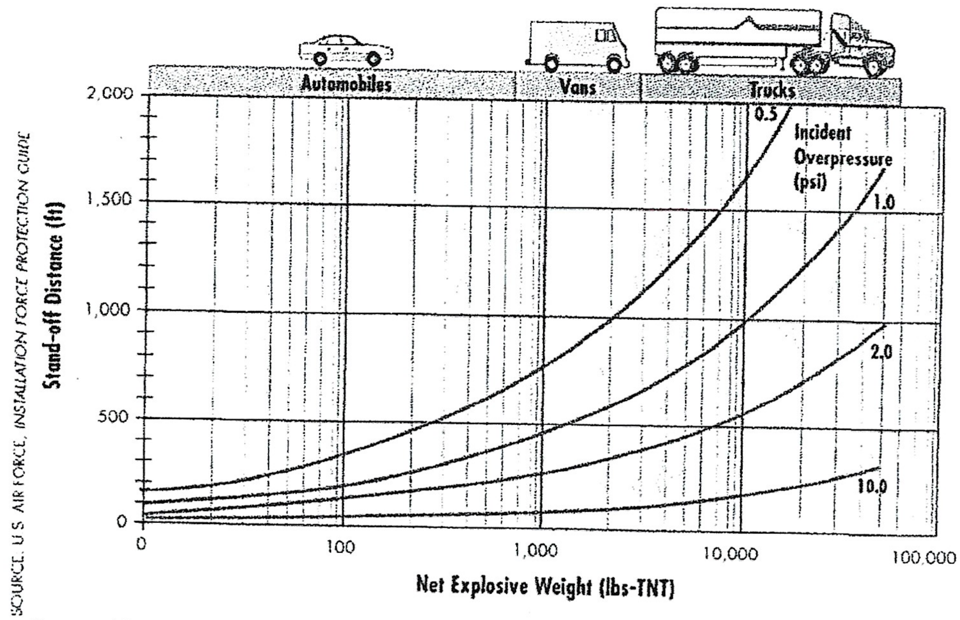

Figure 4-10 Incident overpressure measured in pounds per square inch, as a function of stand-off distance and net explosive weight (pounds-TNT)

A widely known publication applicable to the RMR situation is Report of Investigations 8485 *Structure Response and Damage Produced by Airblast from Surface Mining,* by David E. Sisking, Virgil J. Stachura, Mark S. Stagg and John W. Kopp of the Bureau of Mines of the U. S. Department of the Interior in 1980. The results of the research described in RI 8485 and results from a number of similar studies were summarized by Siskind in *Vibrations from Blasting* published by the International Society of Explosives Engineers in 2000. The Perkins and Jackson equation from the 1964 Handbook is cited in RI 8485 and in David Siskind's book *Vibrations from Blasting.*

To evaluate the most probable effects from the only records of air overpressure available to me from the monitor located at the RMR facility, I traveled to the RMR facility on April 11, 2017 to determine the location of the shredder on the property. Mr. Chris Bedell had provided an ASCII text file with numeric data recorded when a propane tank exploded on March 6, 2017 and a graphical record of the air overpressure data obtained at a monitor on that date. He also provided similar records from several other events that occurred in March 2017 but the air overpressures from those events were not nearly as high as the 138.1 dB recorded on March 6; that decibel reading is equivalent to a pressure of 0.023 pounds per square inch (psi). The monitor device is located on the roof of the old scale building; I determined the location of that building also. The old scale building is approximately 300 feet from the shredder, according to repeated determinations by MRM personnel. Then, I drove from the old scale building to Mellwood Avenue to what I estimated was the location of the nearest structure in that area to the gas detonation point. That distance was almost exactly 0.5 miles. I verified that estimate by measuring the distance from the entrance to the RMR yard at the old scale house to Mellwood Avenue on a quadrangle map published by the U. S. Geological Survey.

The air overpressure recorded at the monitor on the old scale building on March 6, 2017 was 138.1dB, or about 0.023 psi. Using the distance from the shredder (the point of energy release) to the monitor, 300 feet, and the distance from the shredder to Mellwood Avenue, approximately 2,800 feet, the predicted air overpressure at Mellwood Avenue would have been 0.00105 psi, or about 111.3 dB.

For context, comprehensive studies by the United States Air Force and other federal agencies on the effects of sonic booms (another form of air overpressure) show that components of residential structures most vulnerable to air overpressure effects are windows, especially windows poorly mounted in their frames. For those components, the air overpressure required for the initiation of damage is about 0.15 psi, or about 154 dB, according to FEMA (Table 4.3, chapter 4, FEMA 426). The overpressure predicted at Mellwood Avenue, 0.00105 psi, would be about 0.7 percent (or 1/142rd) of the FEMA assumed damage threshold of 0.15 psi. The most common damage caused in residential structures is breakage of windows, and a very conservative value of the air overpressure required to damage even very poorly supported windows is 140 dB, or 0.029 psi. Even for that very conservative and safe threshold for damage, the predicted pressure of 0.00105 psi would be only 3.6 percent of the damage threshold.

Structures closer than the residences along Mellwood Avenue include the Spring River complex at 2205 River Road. If the monitor is 300 feet from the shredder and the Spring River complex is 700 feet from the shredder (a conservative estimate), then the March 6 event would have produced an air overpressure of about 0.0071 psi or about 128 dB at the complex. The level of air overpressure used by federal authorities as the threshold for damage to poorly mounted windows is 0.15 psi (Table 4.3 FEMA 426), or at least 21 times the predicted pressure of 0.0071 psi. The windows in a new condominium complex would be well-mounted, and for glass breakage in such windows, an air overpressure on the order of 0.2 psi, or about 31 times the 0.0071 psi predicted pressure would be required. O.2 psi is equivalent to about 157 dB.

Of course, human beings are sensitive noise receptors and their reactions to a sudden noise may vary from curiosity to irritation. The level of irritation tends to drop as the frequency of the explosions decreases (longer times between events). In terms of injury to hearing, however, the safe impulsive noise exposure criteria of the US Army require no ear protection for peak noise levels below 140 dB regardless of the number of events per day (RI 8485 p. 62). The air overpressure spike from a propane tank exploding in the RMR shredder lasts for one second or less and is less intense and much shorter in duration, for residences on Mellwood Avenue, than a peal of thunder from a nearby lightning strike.

Summary

- Using an assumption of no confinement and the air overpressure of 138.1 decibels or 0.023 psi recorded at the monitor on the old scale building at the RMR facility, an air overpressure of about 111.3 decibels or 0.00105 psi was predicted from that event at the nearest location on Mellwood Avenue.
- The predicted overpressure amounts to only about 0.7 percent of the

pressure required to damage windows poorly mounted in their frames in a residential structure, according to FEMA guidance documents.

- At the River Spring complex, air overpressure from the March 6, 2017 event was estimated to be about 0.0071 psi or 128 dB, only about 3.6 percent of the overpressure of 0.2 psi, or 157 dB, usually associated with damage to well-mounted windows.

If you have any questions about the opinions I have given in this report, please call me at your earliest convenience.

Yours truly,

D. J. Hagerty, PE
Registered KY 8264

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LICENSED
PROFESSIONAL ENGINEER