

6252 Bower Road
Trumansburg, NY 14886
July 21, 2014

Michael L. Lausell, New District III
Schuyler County Legislature
5120 County Road 4
Burdett, NY 14818

Re: Follow-up re LPG Safety

Dear Mr. Lausell:

Thank you for asking for my opinion of the risks that Schuyler County should consider as it evaluates its response options regarding liquid propane gas (LPG) storage proposals. As a healthcare executive with a particular interest in safety I have worked on and/or been exposed to a wide range of risk evaluations, from natural disasters to nuclear power plants. You asked:

Is the proposal to supply liquid propane gas by rail, store it in solution-mined salt caverns, and deliver it by road an acceptable risk to Schuyler County residents?

Attached is my independent, high-level, quantitative analysis of the three critical safety issues you presented last Monday to the Schuyler County Legislature, based on my training and experience in health safety work. I have made no attempt to judge the merits of complex arguments on geologic strata or surface infrastructure. Such judgments are not necessary for this purpose. I have simply used publicly available data sources and some fairly easy math to answer the safety questions you raised about LPG storage in Schuyler County:

My report is not submitted on behalf of any other entity, such as Cayuga Medical Center, Concerned Citizens of Schuyler County, Crestwood, EarthJustice, Gas Free Seneca, Schuyler Hospital, or you. I am one of your constituents, and reside in New District III in the Town of Hector. I have received no compensation from any source for this work. It is not copyrighted, and you are free to use, or not use it, it as you see fit.

To summarize, my analysis finds that under the proposal in question the likelihood of an LPG disaster of serious or extremely serious consequence within the county in the next twenty-five years is greater than 40%. In my view this is an unacceptable risk.

As in my comments before the Schuyler County Legislature on July 14th, I would respectfully suggest that it is now time for a "safety time-out". Every effort should be made to communicate with the company, its regulators, the community, and local and state leaders about the likelihoods and consequences of this risk, so that a broad consensus can be developed for an alternative that better ensures the health, safety, and welfare of Schuyler County.

Thank you once again for asking for my input. If I can be helpful in any other way, please let me know.

Sincerely,

A handwritten signature in blue ink that reads "Rob Mackenzie MD". The signature is written in a cursive, flowing style.

Rob Mackenzie, MD, FACHE

Independent High-Level Quantitative Risk Analysis
Schuyler County Liquid Propane Gas Storage Proposal

*D. Rob Mackenzie, MD, FACHE
6252 Bower Road
Trumansburg, NY 14886
July 21, 2014*

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Quantitative Risk Analysis:
Schuyler County Liquid Propane Gas Proposal
July 21, 2014
D. Rob Mackenzie, MD

Executive Summary

An independent, high-level quantitative assessment was performed to evaluate the major risks associated with expansion of liquid propane (LPG) and butane storage in dormant Schuyler County solution-mined salt caverns. The risks of events associated with LPG rail transport, truck transport, and salt cavern storage were evaluated using standard methodology, a twenty-five year exposure interval, and publicly available sources.

Rail transport events are scored a very low likelihood at 3%, but risk reduction efforts should be considered because of possibly extreme consequences. Truck transport events are scored a low likelihood at 8-10%, but are an unacceptable risk because of extreme consequences. Salt cavern storage events are scored a medium likelihood at 35%, and are an unacceptable risk because of extremely serious consequences. The very low likelihood of major brine leak with extreme consequences, and the fact that the salt cavern is located in bedded plane geology rather than in a salt dome, add to that risk.

In aggregate, the likelihood for a liquid propane gas disaster of serious or extremely serious consequences within the county in the next twenty-five years is scored at more than 40%. From the perspective of community safety based on this analysis, the Crestwood proposal carries an unacceptable risk of serious or extremely serious consequences. Because risk mitigation efforts in salt cavern storage have thus far proven unsuccessful in significantly reducing the frequency of serious and extremely serious incidents, an alternative plan should be considered.

Introduction

Risk assessment work starts with a prioritization process, based on the likelihood and consequences of identified untoward events. For events of extreme seriousness and high likelihood, the risk is ordinarily deemed unacceptable, and efforts are made chiefly to reduce or eliminate the risk. For events of minor consequence and low likelihood, the risk may be deemed acceptable, and a response plan is developed. A matrix is commonly used to display the combination of consequence and likelihood:¹

MATRIX FOR RISK ASSESSMENTS at NTNU

CONSEQUENCE	Extremely serious	E1	E2	E3	E4	E5
	Serious	D1	D2	D3	D4	D5
	Moderate	C1	C2	C3	C4	C5
	Minor	B1	B2	B3	B4	B5
	Not significant	A1	A2	A3	A4	A5
		Very low	Low	Medium	High	Very high
		LIKELIHOOD				

Principle for acceptance criteria. Explanation of the colours used in the risk matrix.

Colour	Description
Red	Unacceptable risk. Measures must be taken to reduce the risk.
Yellow	Assessment range. Measures must be considered.
Green	Acceptable risk Measures can be considered based on other considerations.

Figure 1 – Sample Risk Matrix

In a high-level quantitative risk analysis (QRA) I have applied this process to evaluate the risk of the Schuyler County liquid propane gas (LPG) storage proposal submitted by Crestwood-Midstream Partners, LP.

Crestwood's predecessor company, Inergy Midstream commissioned its own QRA, reported in 2012.² That analysis evaluated the frequency, severity, and consequences of equipment-related potential gas releases at the facility in great detail, and concluded that the hazards and risk to on-site and nearby individuals were acceptable and "similar to those of LPG storage, transport, and processing facilities worldwide."

However, that QRA did not analyze risks associated with transport to or from the site, even though the transport stage of the energy chain is responsible for a volume of fatalities and injuries several orders of magnitudes higher than the facility stage.³ It did not analyze the potential or consequences of release of salt brine from the facility, even though such release may have major public health consequences and cause irremediable environmental damage (see *Salt Brine*, below).

And that QRA greatly underreported the salt cavern failure rate: It cited a European study which determined the annual probability of major accidents resulting in severe injury from *all types* of underground storage to be one in 100,000. Yet that study included depleted oil and gas wells (which have a much better safety track record), and omitted a number of incidents. The annual probability of such accidents *in salt caverns* is greater than one in 100—a thousand times higher than Inergy's QRA claimed (see *Salt Caverns*, below).

Brief summary of LPG storage proposal:

Crestwood, Inc.'s DEC application for a Schuyler County liquid propane and butane gas storage facility reportedly calls for up to 24 inbound rail tank cars, every twelve hours during summer months, to deliver LPG for storage in a US Salt cavern from which salt is no longer being solution-mined. Their plan then calls for up to four outbound tanker trucks per hour during winter months, to deliver LPG to the northeast US.⁴

In this case multiple stakeholders have identified three high-level processes in which a catastrophic event or events might occur. I limited my analysis to these three contingencies. Stated as questions:

- (1) Is LPG transportation by rail an acceptable risk?
- (2) Is LPG transportation by road an acceptable risk?
- (3) Is salt cavern storage of LPG an acceptable risk?

Tools and techniques for risk assessment scoring in the petroleum and natural gas industries include guidelines from the International Organization for Standardization (ISO) and other energy sector sources.^{3 5 6 7}

To assign probabilities on the continuum from “very low” to “very high” likelihood I used an ISO risk matrix with an exposure interval of 25 years, which is standard in the occupational health literature⁸ and appropriate for longer-term community planning.

RISK ANALYSIS**Rail Transportation Risk:**

LPG rail ingress from the south would proceed north from the southern tier corridor at Corning on the Norfolk Southern Railroad on Class II (“regional”) track.⁹ It would cross Watkins Glen State Park gorge on a trestle constructed in the 1930's and terminate at a proposed new rail siding at the Crestwood site.

The most serious risk in LPG rail transportation is derailment with overturned tank cars, when puncture and leakage of fuel is common.¹⁰ In the decade 1995-2004 there were 17 serious incidents of U.S. train derailment, tank fracture, hazardous gas release, or chemical reaction, resulting in 9 dead, 5000 injured, and 10,000 evacuated.³ It has been speculated that if a similar accident were to occur on the trestle over the state park, the relatively heavy propane gas would flow like a liquid down the gorge or the hill in two to four minutes and spread out in the town below, and that ignition from vehicle exhaust, etc., would then almost certainly cause an explosion, propagate a blast wave, and start fires.¹¹

In my literature review and in discussions with fire officials I found this catastrophic scenario credible, but rare. One instance would be the small-town LPG railroad tank-car derailment that occurred in Viareggio, Italy in 2009.¹² In that horrific case there were many flattened buildings and 30 fatalities. Computer modeling after the fact indicated that it likely took the propane gases 100 seconds to reach the furthest-away incinerated house, even with flat local terrain and under calm weather conditions. Because of the fast spread of gas, emergency response in Viareggio was limited to evacuation and after-the-fact injury care. These types of crashes would be scored **extremely serious** on the ISO risk matrix.

From industry-published rates the probability of rail tanker derailment with overturnment within the county over twenty-five years is about 3%,¹³ assuming the planned schedule of two trains daily². This estimate could be further refined by looking at speed, number of cars, class of track, and the integrity of bridges and other rail infrastructure. Without such evidence I have placed this event in cell E1, **very low likelihood**. This cell indicates “assessment range,” so ways to reduce risk further should be still considered **because of the possibly extreme consequences**.

CONSEQUENCE	Extremely serious	TRAIN RISK	E2	E3	E4	E5
	Serious	D1	D2	D3	D4	D5
	Moderate	C1	C2	C3	C4	C5
	Minor	B1	B2	B3	B4	B5
	Not significant	A1	A2	A3	A4	A5
		Very low	Low	Medium	High	Very high
LIKELIHOOD						
Color		Description				
Red		Unacceptable risk. Measures must be taken to reduce risk				
Yellow		Assessment range. Measures must be considered				
Green		Acceptable risk. Measures can be considered based on other considerations				

Figure 2 -- Train Risk

Truck Transportation Risk:

It has been proposed that outbound trucks travel via NYS Routes 14 and 414, with most traffic southward on Route 14 toward the southern tier corridor.² South from the Crestwood plant, Route 14S descends a 3.6% grade for 2 miles, and then proceeds around a left-right “S” curve, as it enters the Village of Watkins Glen.¹⁴ (Because comparison to a recent Ithaca incident has been suggested,¹⁵ Ithaca’s NYS Route 79W descends a 4.6% grade over one half mile into Ithaca.¹⁶)

The most serious risk in LPG truck transportation is tanker-truck crash with tank rupture and explosion.¹⁰ It has been speculated that if such a truck were to lose its brakes on the Route 14S downgrade at the edge of the Village of Watkins Glen, the relatively heavy propane gas would again flow like a liquid into the town and cause a conflagration.¹¹ A similar truck event happened in Ithaca on June 20, 2014 when a car carrier reportedly lost brake power on Route 79W, crashed into a building, killing one person, injuring others, and burned in the heart of downtown. The resulting fire did not involve propane, however, and was promptly extinguished by bystanders.¹⁷

Truck crashes involve a lower volume of LPG spillage than railcars, and are often spectacular but less often catastrophic¹⁸. A truck crash into a building in the center of town such as the one seen recently in Ithaca, however, would still be scored **extremely serious**, when compounded by propane leakage and conflagration with multiple casualties.

Based on online, industry-reported rates of LPG tank-truck rupture from crashes per mile, giving due credit for more recent improvement in road safety, and estimating the road tanker traffic at 80 percent of the levels requested by the company, the twenty-five year probability of an LPG road tanker rupture and explosion within the county is about 5 percent, assuming travel on “average” roads¹⁹.

Some segments of the Schuyler County roads in question, of course, are not “average.” There is good information about the adverse road characteristics that increase or decrease truck crash likelihood.^{20 21} More than half of all fatal truck accidents occur on rural, two-lane roads as compared with urban roads and divided highways. Frequency rises further with both steepness and with curves. The combination of a downhill grade and a curve is particularly deadly when the curve is to the left, as vehicles in the right lane are then more likely to leave the road. Large truck crashes are concentrated on such road segments.

In the case of traffic on Route 14S, the hill is relatively steep, the first curve is to the left, the second curve is to the right. The major intersection three blocks south, at the center of Watkins Glen can be congested, but mainly in summer, when LPG tanker-truck traffic should be lower. Based on the literature on adverse road conditions, the twenty-year probability of tank rupture from a crash is raised from 5 to between 8 and 10 percent. This would be scored **low likelihood** over the twenty-five year time frame. That score would place tanker-truck crashes on the matrix in cell E2, i.e., **an unacceptable risk because of the extremely serious consequences**.

CONSEQUENCE	Extremely serious	TRAIN RISK	TRUCK RISK	E3	E4	E5
	Serious	D1	D2	D3	D4	D5
	Moderate	C1	C2	C3	C4	C5
	Minor	B1	B2	B3	B4	B5
	Not significant	A1	A2	A3	A4	A5
		Very low	Low	Medium	High	Very high
LIKELIHOOD						
Color		Description				
Red		Unacceptable risk. Measures must be taken to reduce risk				
Yellow		Assessment range. Measures must be considered				
Green		Acceptable risk. Measures can be considered based on other considerations				

Figure 3 – Train and Truck Risks

Salt cavern risk:

Event rates

As of 2012 there were 414 underground natural gas storage facilities in the US. Most are in depleted oil and gas fields; a few are in aquifers, and 40 are in “salt cavern” facilities.²² Most salt caverns have been developed over several decades from naturally occurring, globular, so-called “salt domes” in the Gulf states. Nine have been added since 2007. A few salt caverns are in “bedded salt” deposits like Schuyler County’s, which itself has been used in the past for LPG and natural gas storage. Safety oversight of underground gas storage is performed by both federal and state agencies.

Despite this supervision, between 1972 and 2012 there have been 18 serious or extremely serious incidents in salt cavern storage facilities.^{3, 7} With the average number of facilities in operation through most of the last two decades close to 30,²² the US incidence is about 60 percent (compared to 40 percent worldwide²³), and the frequency is about 1.4% per year. Causes of failure have included corroded casings, equipment failure, brine erosion leading to breach, leakage into other geologic formations, and human error.^{3, 7}

The erroneous salt cavern failure rate cited in Inergy’s QRA was derived from the European Marcogaz study which looked at all underground storage facilities, most of which do not use riskier salt caverns, but the much safer depleted oil and gas fields. Worldwide, the percentage of incidents *involving casualties* at salt cavern facilities as a percentage of the number of facilities operational in 2005 was 13.6 percent, compared to 0.63% for gas and oil fields, and 2.5% for aquifers.³

Nine of the salt cavern incidents were accompanied by large fires and/or

explosions. Six involved loss of life or serious injury. In eight cases evacuation of between 30 and 2000 residents was required. Extremely serious or catastrophic property loss occurred in thirteen of the 18 cases.^{3, 7} The likelihood of a serious, very serious, or catastrophic incident over twenty-five years is 35 percent.²⁴ This would be initially scored a **medium likelihood**, with the potential for at least **serious** consequences, and possibly **extremely serious** consequences, and thus an **unacceptable risk**.

Salt brine

The possibility of catastrophic salt cavern brine leakage has been a subject of local concern.⁴ Crestwood's plans are for rail-tank LPG to be pumped in to displace the naturally saturated salt brine from the cavern, with the brine stored in large surface ponds open to the atmosphere. The brine would then be pumped back in to the cavern to displace LPG when distribution by truck is called for.²

Crestwood has also identified Schuyler County as a location for northeastern U.S. brine disposal.²⁵ In Crestwood's Bath storage facility, excess pond brine resulting from precipitation is discharged into the Cohocton River and an existing disposal well under a state permit.²⁶ In the case of Schuyler County, Crestwood has identified the U.S. Salt facility as a disposal option.²⁷

Brine leakage has been an uncommon problem in salt cavern failure, although it has extreme consequences because it may be difficult or impossible to remediate. In the oil hydrofracking industry, a one million gallon 2006 brine leak into North Dakota's Charbonneau Creek, a tributary of the Yellowstone River, is widely reported to have been "the worst environmental disaster in state history" with cleanup still in progress.²⁸ The amount of brine spilled in that pipeline event is roughly one percent of the amount proposed for storage in Crestwood's ponds.²⁹

Among the 141 salt brine leaks that occurred in 2012, in the North Dakota oil fields where Crestwood has a significant presence, 91 leaks caused a spillage of 336,000 gallons. The most recent major North Dakota spill occurred from a pipe managed by a Crestwood subsidiary between July 4 and July 10, 2014. One million gallons spilled, threatening the drinking water supply for a reservation for the 6000 members of the Mandan, Hidatsu, and Arikara tribes.³⁰ The scale of environmental damage and public health risk remains uncertain at this point.

The level of concern which brine spillage has generated in Schuyler County is indicated by the number of technical precautions proposed by stakeholders and/or the company.³¹ However, leakage has already been documented to occur at least twice on a small scale at Crestwood's Schuyler site. The company's most recent brine spill in North Dakota, suggests that some level of risk remains.

Seneca Lake is already the saltiest of the Finger Lakes at 150-170 parts per million chloride, (versus 20 to 50 ppm for the other Finger Lakes), probably because its basin intersects the same salt strata from which the caverns are derived³². The brine ponds proposed for the proposed LPG/butane storage project would contain enough salt to raise the Seneca Lake chloride concentration to an average of 220 ppm,³³ close to the 250 ppm level shown to be a hazard to health.³² Further gas storage expansion, alluded to in Crestwood's SEC filing,³⁴ could raise the risk higher still.

Because of incomplete mixing and density gradients, southern lake sources would be at toxic levels with such a spill. Contamination would be greater at drinking water intake sites, and remediation would be difficult or impossible. Brine from an accidental or intentional breach of the pond's dams, if it reached Seneca Lake--less than one-half mile downhill, would contaminate the source of drinking water for about 70,000 people.³² Other long-term water sources would be needed, or else large populations would be obliged to move.

The geologist responsible for Seneca water quality monitoring has cited yet a more serious concern: that increased pressure on the salt formation itself could cause an increased flow of lake basin salt deposits to leach into the lake³⁵. In that event, remediation for large-scale brine contamination would be impossible.

Few salt caverns are adjacent to a large lake. I could find no reported cases of catastrophic brine leakage in fuel storage facilities, but "brine gushers" have occurred in capped brine caverns³. While a brine disaster would be scored a **very low likelihood**, it would certainly have **extreme consequences**, and risk mitigation should (and already has) been considered. When considered together with the other extremely serious incidents, it raises the consequence of salt cavern events into the **extremely serious** range.

Geology

Much concern has also been raised about the geology of the solution-mined caverns proposed for LPG storage. There has been a great deal of discussion over faults, partial roof collapses, rubble piles, undiscovered uncapped wells, and so on. In its detailed and very considered approval of an application to increase natural gas storage in Schuyler County in March, the Federal Energy Regulatory Commission (FERC) recently acknowledged serious concerns raised by independent geologists as to the stability of the Schuyler County salt caverns, but chose to support the company geologists' reassurances and test results, merely requiring the company to monitor for gas leaks, ground subsidence, and the like.³⁵

Likewise, the New York State Geologist is obliged by statute to rule on the

integrity of caverns used to store hydrocarbons, Earlier this year, an official in that office did vouch for the “long track record” of the LPG caverns in a half-page document.³⁶ I do not have the expertise to evaluate such concerns, reassurances, rulings, or requirements.

However, I would reiterate that it is not necessary to get into such detail for this level of analysis. From the risk assessment perspective it is enough to recall that standard and additional regulatory recommendations, routine mechanical integrity testing, and every other careful industry precaution have failed to prevent the eighteen serious or extremely serious salt cavern incidents. Some have been quite recent, and some have occurred in caverns with long safety track records.³

It should also be noted that both oversight and industry literature report that using the salt cavern subset of bedded salt deposits like Schuyler County’s is riskier than using the salt domes common in the Gulf, perhaps for geologic reasons like those mentioned above, and especially when single well-bore holes are used,³ as planned in this case. The most instructive incident in this connection occurred at the Yaggy salt cavern facility seven miles northwest of Hutchinson, Kansas, a town of 44,000. Gases that escaped from the salt cavern due to human error traveled along sedimentary layers, erupted in the town itself, and resulted in fire, explosion, two deaths, one injury, and more than 250 evacuations. A detailed summary, map, and photos are appended. The unfavorable geology and irregular cavern shapes generally associated with bedded salt deposits³ probably push the likelihood of salt cavern failure somewhat higher in the **medium likelihood** category.

Risk tolerance

This level of consequences per facility over twenty-five years--major fires, explosions, collapses, catastrophic loss of product, evacuations--is an unusual level of risk. Most other regulated industry sub-segments with a persistent serious to extremely serious facility incident rate of over thirty percent would be shut down or else voluntarily discontinued, except in wartime. Even in the petroleum industry, which is widely known to tolerate higher risks than most others, the rate of events per facility involving casualties is more than 20 times higher in salt caverns than in the alternative--depleted oil and gas fields.³

In most other industries, including healthcare, automotive, and nuclear power, to name a few prominent ones, severe regulatory sanctions are imposed for catastrophic failure rates that are many, many times less than in salt cavern facilities. Salt caverns provide less than ten percent of U.S. working gas storage,²² and LPG transport has a relatively better safety profile as noted above. So even though salt caverns have shorter cycle times and may be closer to

market, the depleted oil and gas option alternative is clearly the better safety option from a national perspective.

To be sure, there have been many advances in assessment, extraction, storage, and transportation technology over the years in which salt caverns have been used for LPG and natural gas storage. Yet those advances have not yet led to a significant reduction in the rate of serious and extremely serious incidents.³⁷ This may in part be lag time; the interval from commissioning to events has often been a decade or more. As in oil drilling, however, there may also be an increased tolerance for riskier project selection. Experience from NASA, nuclear power plants, car manufacturing, and healthcare consistently shows that to improve safety the critical requirement is not better technology but cultural change.

The QRA performed in 2012 for Inergy did not analyze previous salt cavern failures, the associated need for short- or long-term evacuation, or any of the hazards associated with road and rail LPG delivery.² As noted above, their conclusion after omitting such considerations, was that Crestwood’s proposal was “no more dangerous than other similar facilities.”² Sadly, of course, Yaggy/Hutchinson (see appended report) is “similar” in many respects. There have been scattered other reports and articles praising the safety of underground storage. The flaws and biases in those analyses from the point of view of Schuyler County are not hard to identify.³⁸

CONSEQUENCE	Extremely serious	TRAIN RISK	TRUCK RISK	SALT CAVERN RISK	E4	E5
	Serious	D1	D2	D3	D4	D5
	Moderate	C1	C2	C3	C4	C5
	Minor	B1	B2	B3	B4	B5
	Not significant	A1	A2	A3	A4	A5
		Very low	Low	Medium	High	Very high
LIKELIHOOD						
Color		Description				
Red		Unacceptable risk. Measures must be taken to reduce risk				
Yellow		Assessment range. Measures must be considered				
Green		Acceptable risk. Measures can be considered based on other considerations				

Figure 4 – Train, Truck, and Salt Cavern Risks

Other risks:

Diesel air pollution, traffic congestion, noise pollution, loss of jobs in tourism and wineries from “industrialization,” and many other risks have been discussed widely in community forums. They are not included in this analysis because they are unlikely to require emergency response, but they may well have health or

other consequences that are more difficult to quantify.

Risk summary and Conclusion:

None of the three possible events—among trucks, trains, caverns—is contingent on any of the other events, so for probability purposes they are considered “independent” risks. Combining the three independent probabilities, **the likelihood for an LPG disaster of serious or extremely serious consequence within the county in the next twenty-five years is more than 40%³⁹**. Most of this risk, of course, comes from the possibility of serious or extremely serious salt cavern events as described above.

CONSEQUENCE	Extremely serious	E1	E2	LPG STORAGE RISK	E4	E5
	Serious	D1	D2	D3	D4	D5
	Moderate	C1	C2	C3	C4	C5
	Minor	B1	B2	B3	B4	B5
	Not significant	A1	A2	A3	A4	A5
		Very low	Low	Medium	High	Very high
LIKELIHOOD						
Color	Description					
Red	Unacceptable risk. Measures must be taken to reduce risk					
Yellow	Assessment range. Measures must be considered					
Green	Acceptable risk. Measures can be considered based on other considerations					

Figure 5 – LPG Storage Proposal Risk

The risk may be higher because of adverse road topography, possibly adverse geology, worsening traffic, or simultaneous train deliveries in and truck deliveries out. It could also drop lower over time, if both technology and safety culture improve.

Worst case scenarios are not hard to imagine. They would involve some combination of loss of life, loss of the lake as a source of drinking water, and/or temporary or permanent evacuation. Each of these scenarios has happened in other salt cavern facilities. Fortunately for the nation, but of no help to Schuyler County, most of the other events occurred in locations more isolated from population centers than ours.

By its very nature, there are large uncertainties in any risk assessment estimate. For the sake of argument, though, even if each of the three probabilities has been overestimated by 75 percent, the likelihood for serious or extremely serious consequences over twenty-five years is still more than 25 percent.⁴⁰

From the perspective of health safety, based on this independent analysis, I conclude that the Crestwood proposal carries an unacceptable risk of extremely serious consequences.

Plans should always be made for acceptable risks. And some unacceptable risks can be made acceptable through mitigation. Other municipalities have reduce rail accidents, for example, by enacting ordinances to regulate train speed within their borders.

It is not yet clear, however, that any regulatory or mitigation effort to date has been effective in reducing serious and extremely serious salt cavern incidents frequency to a significantly lower level. Strong consideration should therefore be given to an alternative course of action.



Rob Mackenzie, MD, FACHE

¹ Matrix risk analysis is used world-wide. This typical example is from innsida.ntnu.no, a Norwegian university.

² Quantitative Risk Analysis for the Finger Lakes LPG Storage Facility, prepared for Inergy Midstream by Quest Consultants, Inc., Norman OK 12-02-6822 February 16, 2012

³ Health and Safety Executive of the United Kingdom, *An appraisal of underground gas storage technologies and incidents, for the development of risk assessment methodology*, at:
<http://www.hse.gov.uk/research/rrpdf/rr605.pdf>

⁴ www.gasfree.seneca.com

⁵ ISO 17776:2000(en) Petroleum and natural gas industries--guidelines on tools and techniques for hazard identification and risk assessment at:
<https://www.iso.org/obp/ui/#iso:std:iso:17776:ed-1:v1:en>
(emphasis on off-shore, but much still applicable)

⁶ *Guidelines for Chemical Transportation Safety, Security, and Risk Management*, Center for Chemical Process Safety, John Wiley & Sons, 2008.

⁷ Hopper, John M., *Gas Storage and Single Point Risk*, in Natural Gas, at www.documbase.com/Gas-Storage-And-Single-Point-Failure-Risk.pdf

⁸ Mullai, Arben, *Risk Management System—Risk Assessment Frameworks and Techniques*, DaGoB publication series 5:2006.

⁹ www.nys.dot.gov.

¹⁰ Lee's Loss Prevention in the Process Industries : Hazard Identification, Assessment, and Control, Elsevier Butterworth-Heinemann, 2005.

¹¹ Michael Lausell, county legislator, at a meeting of the Schuyler County Legislature held on 7/14/14.

¹² Brambilla, Sara, Roberto Totaro, and Davide Manca, *Simulation of the LPG release, dispersion, and explosion in the Viareggio railway accident*, at www.aidic.it/CISAP4/webpapers/36Brambilla.pdf.

¹³ The Canvey report from 1978 cited in Lee's Loss Prevention, 2005, appendix 7/9 gives the frequency of rail tank car derailment as 1×10^{-6} / km (= 1.6×10^{-6} /mi), and the probability of overturning (when rupture is most likely to occur) as 0.2.

This frequency is lower than US data from the 1970s, but the US data has dropped and is now similar, at 2×10^{-6} /mi. I used the lower Canvey data, and ignored return-trips with empty tankers, the risk of which would be of lower consequence. GoogleMaps shows the rail distance from the south county border to the Crestwood site to be about 12 mi. Calculation: 1.6×10^{-6} derailments/km x 0.2 overturnments/derailment x 12 mi/trip x 2 trips/day x 180 days/yr x 25 years = 0.0345 = 3%.

¹⁴ Distance and grade were calculated on mapmyrun.com, based on the segment of Route 14S starting at Lucky Lane in the Town of Reading and ending at 1st Street in the Village of Watkins Glen.

¹⁵ Dennis Fagan, Chair, Schuyler County Legislature, at its meeting on 7/14/14.

¹⁶ From mapmyrun based on the segment of Route 79W starting at Mitchell Street in the City of Ithaca and ending at Seneca Way.

¹⁷ www.ithacajournal .com

¹⁸ A web search on *propane truck accidents* yielded dozens of examples.

¹⁹ The Canvey Report from 1978 cited in Lee, Appendix 7/9 gives the frequency of road tanker accident involving spillage as 1.6×10^{-8} /km traveled = 1.0×10^{-8} /mi traveled. According to the text, fire and/or explosion are very likely when spillage occurs.

A more recent general analysis, *An Analysis of Fatal Large Truck Crashes*, published in 2003 (DOT: HS 809 569) gives a much higher frequency of 2.5×10^{-8} /mile traveled.

The petrochemical industry, claims its drivers are more careful than general truck drivers, and since the 1970s, the frequency of large fatal truck accidents per million vehicle miles had dropped by half (although the overall frequency of such accidents has remained constant because the number of miles travels has doubled.) For these reasons I used the lower Canvey number. I discounted return trips with “empty” tank cars containing residual propane by 50% because the risk of explosion is still serious but of lower consequence.

GoogleMaps shows the road distance from the Crestwood site to the county border to be about 12 mi.

Calculation: 1.0×10^{-8} accidents with spillage/km(Canvey) x 12 mi/trip x 96 trips/day (4 per hour from 4am to 8 pm) x 180 days/yr x 25 years = 0.05184 = 5%.

²⁰ Miaou, Shah-Pin, *The Relationship Between Truck Accidents and Geometric Design of Road Sections*, July 1993, Oak Ridge National Laboratory is perhaps the most widely cited reference.

²¹ *An Analysis of Fatal Large Truck Crashes*, DOT HS 809 569, June 2003.

²² www.eai.gov

²³ The lower world-wide incidence is thought by some to reflect under-reporting in Europe and the former Soviet Union.

²⁴ Calculation: 1.4% incidence per year x 25 yrs = 35%

²⁵ Bill Moler, *Gas Storage*, in Pipeline and Gas Technology, June 2010.

²⁶ ECL Article 23 Title 13 Underground Storage Modification Permit. DEC contact person listed as John K. Dahl, NYS DEC – Division of Mineral Resources, Bureau of Oil and Gas Regulation.

²⁷ <http://energyindepth.org/marcellus/we-asked-for-it-we-got-it-were-still-going-to-protest>

²⁸ <http://newsok.com/cleanup-of-2006-nd-saltwater-spill-still-ongoing/article/feed/566967>

²⁹ One million gallons of fracking brine (a less saturated solution) was spilled into Charbonneau Creek; the Crestwood ponds are scheduled to hold up to 92 million gallons of more saturated brine.

³⁰ <http://abcnews.go.com/US/wireStory/saltwater-pipeline-leaks-indian-reservation-24488733>

³¹ Brine pond storage proposed precautions include double pond liner, leak detection system, interceptor trenches, groundwater monitoring, liner performance monitoring, liner replacement procedure, overflow prevention brine redirect plan to U.S. Salt facility, brine spill control plan, and emergency response plan, according to reference 27.

³² Limnology and Water Quality— *Seneca Lake at*:
<http://www.gflrpc.org/Publications/SenecaLakeWMP/chap6a.pdf>

³³ Calculation: Storage lagoon of 9.2×10^7 gal = 3.48×10^{11} ml. Saturated brine in cold water contains 35.7 gm NaCl/100 ml yielding a total of 1.24×10^{13} gm NaCl and 7.5×10^{12} gm Cl. Dividing by Seneca lake volume of 15.9×10^{12} liter yields 0.47 gm/l = 47 mg/100ml = 47 ppm.

³⁴ Peter Mantius, www.DCBureau.org

³⁵ Concern reported in 147 Federal Energy Regulatory Commission ¶ 61,120: Arlington Storage Company, LLC, May 15, 2014.

³⁶ Andrew Kozlowski, Acting Associate State Geologist, to Peter Briggs, Director, NYSDEC, March 15, 2014.

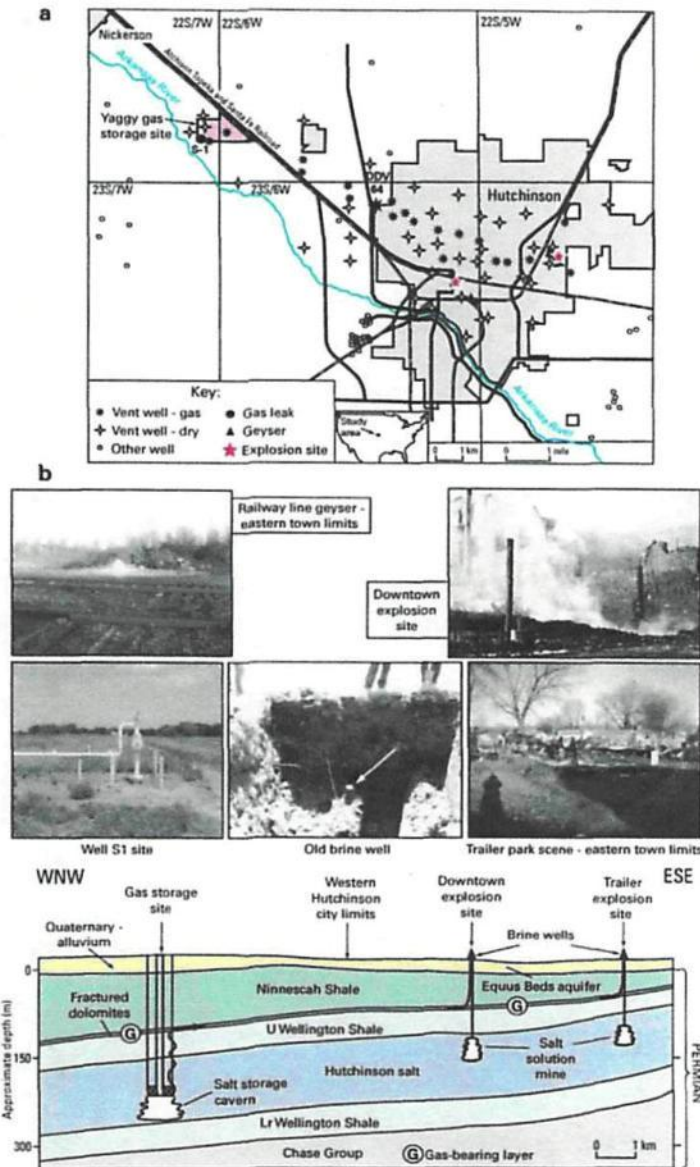
³⁷ Industry sources cite a reduction in incident frequency in the 1990's, but this reversed with a spate of incidents in the early 2000's.

³⁸ Such flaws include:

- failure to separate out salt caverns from other forms of underground storage
- among salt caverns, failure to separate out bedded salt geology from salt domes
- claims that salt cavern storage is safer than above-ground storage, which may be true but is beside the point
- claims that the total number of casualties in underground storage incidents is lower than the corresponding number for other parts of the petrochemical distribution chain, without calculating incidence or frequency rates per facility, per mile, etc.
- claims that human error and technology failures because they are potentially correctible, should be discounted from the risk analysis
- failure to include transportation risks and other risks in analysis
- desire to promote other types of underground storage
- petrochemical industry funding

³⁹ Calculation: $1 - ((1 - 0.03) * (1 - 0.09) * (1 - 0.35)) = 42.6\%$

⁴⁰ Calculation: $1 - ((1 - 0.017) * (1 - 0.05) * (1 - 0.2)) = 25.4\%$



After Hutchinson Fire Department, Kansas Geological Survey, CUDD Drilling and Shannon Pope of RPC Inc. BQSCNERC. All rights reserved

Figure 35. Details of the Hutchinson incident. (a) location map illustrating the site of the storage facility circa 11 km (7 miles) NW of the town of Hutchinson (b) WNW-ESE cross section showing the stratigraphy and structure of the area and the route taken by the gas from the storage cavern to the town (after Kansas Geological Survey). Images shown courtesy of Chief Forbes, Hutchinson Fire Department; Kansas Geological Survey; Kansas Department of Health and Environment, CUDD Drilling and Shannon Pope of RPC Inc.

An appraisal of underground gas storage technologies and incidents, for the development of risk assessment methodology, Health and Safety Executive, United Kingdom, 2/2008, pp 161-164:

Hutchinson – aka Yaggy, Kansas (USA)

The town of Hutchinson, with a population of around 44,000, lies around 11 km (7 miles) SE of the Yaggy Storage Field (Figs. 25&35), and provides the location for perhaps the most publicised and notorious UGS incident. The area is underlain by the Hutchinson Salt Member, which has been mined and extracted at Hutchinson since the 1880s and in which caverns had been created for storage purposes. At the time of the incident, the Yaggy storage facility played a key role in the supply of gas in central Kansas and was thus of national importance. It was one of 30 “hubs” in the USA national gas distribution system and one of 27 such cavern storage fields in the USA. The incident has been extensively reviewed elsewhere and so will only be outlined here, with emphasis on the history of the facility to illustrate the background to the disaster.

The Yaggy field was originally developed in the early 1980s to hold propane. The storage caverns were formed by salt dissolution using brine wells, drilled to depths between 152 m and 274 m in the lower parts of the Lower Permian Hutchinson Salt Member of the Wellington Formation (Fig. 35). The top of each cavern was located about 12 m below the top of the salt layer to ensure an adequate caprock that would not fracture or leak and the wells were lined with steel casing into the salt. The Wellington Shale Formation is overlain by the Ninnescah Shale, both of which dip to the west and northwest and form the bedrock to 15 m or more of the sands and gravels of the Equus Beds. These unconsolidated deposits underlie (Fig. 35) and provide the municipal water supply for the city of Hutchinson, and the city of Wichita to the east.

Decreasing financial viability eventually led to the closure of the propane storage operations in the late 1980s. The wells were cased into the salt and later plugged by partially filling them with concrete. In the early 1990's, Kansas Gas Service, a subsidiary of ONEOK of Tulsa (Oklahoma), acquired the facility and converted it to natural gas storage. The existing caverns were re-commissioned, which required drilling out the old plugged wells, whilst further wells were drilled to solution mine additional caverns.

Mention is made of the Yaggy Storage Field consisting of 98 caverns in the Hutchinson Salt Member at depths greater than 150 m. It appears that at the time of the 2001 incident, the facility had about 70 wells, of which 62 were active gas storage caverns, at depths greater than 152 m. More than 20 new wells had been drilled and were being used to create new caverns for expansion of the facility (Allison, 2001a). The wells, with 90-120 m spacing, are located on a grid. A group of wells are connected at the surface via pipes and manifolds, allowing gas to be injected or withdrawn into all the caverns in the group simultaneously. The capacity of the Yaggy field was circa 90.6 Mcm (c. 3.2 Bcf) of natural gas at around 600 psi.

The incident at Hutchinson occurred on the morning of January 17th, 2001, when monitoring equipment registered a pressure drop in well S-1, which connected to a cavern being filled. The cavern could hold 1.7 Mcm of gas at an operating pressure of about 4.65 MPa (675 psi). This could, however, range from 3.8 to 4.7 MPa (550 to 684 psi). Later that morning a gas explosion occurred in downtown Hutchinson, around 11 km (7 miles) away and was followed by a series of gas and brine geysers, up to 9 m high, erupting about 3.2 km (2 miles = c. 9 miles from the storage site) to the east along the outskirts of Hutchinson (Fig. 35). The following day (18th January), a gas explosion at the Big Chief Mobile Home Park killed 2 and injured another (Fig. 35). The city promptly ordered the evacuation of hundreds of premises: many not returning to

their homes and businesses until the end of March 2001.

An investigation into the incident led by the Kansas Geological Survey (e.g. Allison, 2001a&b), found the leak was the result of a large curved slice in the casing of the S-1 well at a depth of 181.4 m, just below the top of the salt and 56 m above the top of the salt cavern. The damage to the casing resulted from the re-drilling of the old cemented well when re-opening the former propane salt cavern storage facility. Furthermore, ONEOK computer operators in Tulsa had overloaded the storage field caverns with natural gas, causing the initial leak. For at least 3 days the casing leak allowed natural gas at high pressure to escape and migrate upwards through the well cement and fractures in rocks above the salt. On reaching a permeable zone formed by a thin bed of micro-fractured dolomite near the contact between the Wellington Formation and the overlying Ninnescah Shale at around 128 m, the gas was trapped by overlying gypsum beds, preventing further vertical movement. The dolomite was fractured in the crest of a low- amplitude, asymmetric, northwesterly plunging anticlinal structure and the pressure of the escaping gas induced parting along the pre-existing fracture system. The gas migrated laterally southeastwards up-dip along the crest of the anticline towards Hutchinson, where it ultimately encountered old abandoned and forgotten brinewells that provided pathways to the surface (Allison, 2001a; Nissen et al., 2003 & 2004).

Geological investigations of the area suggest that the fractures in the dolomites were related to deep seated fractures that caused faulting in the overlying strata. These fractures then appear to have permitted undersaturated water to penetrate down and dissolve the Hutchinson salt, causing variations in thickness of the halite beds. Faulting in strata overlying the halite beds is greatest where dissolution has taken place and the edge of this dissolution zone trends NW close to the crest of the anticlinal structure. The dissolution of the halite appears to have locally enhanced structural relief, which led to further stresses, fracturing and preferred zones of weakness in the overburden, providing pathways for gas migration along the trend of the anticline (Watney et al., 2003a; Nissen et al., 2004b). Shut in tests on vent and relief wells following the incident revealed that with reduced gas pressures, fracture apertures were reduced and closed as pore pressures declined.

Basic volumetrics of the fracture cluster were calculated (Watney et al., 2003b):

- Length – 14 km (8 miles)
- Width – 300 m (1000 ft)
- Height – 0.9 m (3 ft)
- Porosity – 2%
- Fracture volume – 78,000 m³ (2.8 Mcf)
- Estimated volume of gas released – 4.04 Mscm (143 Mscf) = 99,109 m³ (3.5 Mcf) at 4.14 MPa (600 psi), 12°C (54°F)

Other storage facilities exist around Hutchinson and provide some useful information on storage pressure gradients. In late 1996 to 1997, Western Resources Inc. who operated a hydrocarbon storage well facility to the west of Hutchinson, submitted requests to the Kansas Department of Health and Environment (KDHE) to increase the maximum storage pressure gradient at their facility. KDHE regulate gas storage operations and operated a ‘rule of thumb’ that the maximum storage pressure gradient at such facilities in the Hutchinson area was limited to 0.75 psi/foot of depth. This was in order to prevent fracturing of the salt deposit. Following tests on rock cores, Western Resources Inc. requested increasing the pressure from 0.75 psi/foot of depth to a pressure gradient of 0.88 psi/foot of depth, which was actually close to the average fracture pressure gradient of 0.89 psi/foot of depth. One rock sample actually had a fracture pressure

gradient of 0.72 psi.foot of depth (KDHE, 1997).

The original downtown explosion site was related to a mineral water well in a basement that had provided mineralized waters for a hotel spa. The second explosion occurred at the site of an old abandoned brinewell. Images of a blazing well in the ruins of a building are available on the Kansas Geological Survey website (<http://www.kgs.ku.edu/Hydro/Hutch/CUDD/2nd/set01.html>). The same was found to be true for the numerous gas and brine geysers to the east of the city and the explosion at the Big Chief trailer park. When drilled, most old brine wells were only cased down through the shallow Quaternary “Equus beds” aquifer. The deeper parts of the wells were open-hole and thus provided ready pathways for the gas to escape to the surface. As many as 160 old brinewells are thought to exist in the Hutchinson area, either buried purposely or by subsequent development. It is unlikely that the well casings of these wells, if they exist, are sufficiently gas tight to prevent gas escapes and would present problems if future leaks were to occur.

Following the operations to trace and deal with the January leak incident, a second event occurred around six months later on the afternoon of Sunday, July 7, when one of the vent wells (Deep Drilled Vent well 64) suddenly started venting gas at high pressure (Allison, 2001c). The following day, the flare was reported at about 4 m in height and a pressure of 2.3 MPa (330 psi). Mechanical modifications to the surface pipework were made with the result that the flare reached an estimated 9 m - 30 to 12 m in height by Monday evening. Pressures had dropped to only 0.04 MPa (6 psi) by the following Wednesday; when the well was temporarily shut in. However, the pressures then increased quickly again.

Three possible causes for the flare-up were identified (Allison, 2001c):

- formation or near-well-bore damage – this is caused by the flow of water and gas through the near-well-bore environment. The permeability of the rock near to the well is reduced by the plugging the rock with fine materials, chemical alteration, or by changes in relative permeability as the volume of gas drops relative to the volume of water. Such “damage” routinely occur in oil and gasfield wells and is readily corrected.
- segmented pockets or fractures of gas remained - when the gas first entered Hutchinson it was under sufficiently high pressure that it may have forced open previously closed fractures in the rock layers or pushed its way into areas of ‘tight rocks’, i.e. less permeable rocks. As pressures dropped, it is possible that some fractures would have closed up again, isolating small amounts of gas in separate pockets, which over time, could have worked their way back into the main accumulation and into the vent well.
- another source of gas besides the Yaggy field exists – a scenario thought to be unlikely as well DDV 64 sits in the midst of a swarm of vent wells and it is hard to project a new source of gas that would affect only this one well.

The causes of the resurgence of gas were still being investigated in late 2001/early 2002. However, the results of this investigation, although it is likely that they have been published, have not been found during this study.

The incident in 2001 was not the first time that there had been problems with a cavern and well at the Hutchinson storage facility. On September 14, 1998, a shale shelf collapsed inside the field’s K-6 cavern, trapping a gamma-ray neutron instrument that had been used for monitoring purposes. Downhole video surveys revealed the casing on the verge of collapse at about 183 m, with the camera unable to go below 205 m, due to the blockage. In October 1998, a plan was established to remove gas from the cavern over the winter. In the spring of 1999, the radioactive tool was

buried under 1.2 m of concrete and the cavern's main pipe was relined with bonding cement to block any possible leaks. The cavern is still monitored for radiation leaks.

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PROFESSIONAL EXPERIENCE

- 2003 to 2013 President and Chief Executive Officer, Cayuga Medical Center, Ithaca, NY
Led this 204-bed, \$130M revenue, benchmark independent community medical center in Ithaca, New York. Led statewide CEO taskforces to improve safety performance, leading to 2010 recognition by Consumer Reports as New York State's safest hospital.
- 2002 Oct-Dec Chief Operating Officer, Cayuga Medical Center, Ithaca, NY
Responsible for hospital operations during three-month transition period prior to becoming President / CEO.
- 1993 to 2002 Vice President for Medical Affairs, Cayuga Medical Center, Ithaca, NY
Responsible for quality assurance, utilization management, credentials, regulatory compliance, strategic planning, and physician liaison functions.
- 1991 to 2002 President, Finger Lakes Management Associates, Inc. (MD Org.), Ithaca, NY
Founding member of 150-member, for-profit association of independent physicians to address health care quality, medical business, hospital relations, and third-party reimbursement issues.
- 1995 to 2002 Medical Director, Cayuga Area Plan, Inc. (MD-Hospital Org.), Ithaca, NY
Founding leader of physician-hospital organization to address health care quality, do joint strategic planning, and unify payer negotiations.
- 1984 to 2002 General and Vascular Surgeon, Surgical Associates of Ithaca, P.C., Ithaca, NY
Senior partner until 2002 retirement in an esteemed four-member general, vascular, and thoracic surgery private practice.

EDUCATION

- BA** Harvard College, Cambridge, Massachusetts, 1975
- MD** Albany Medical College, Albany, New York, 1979
- Internship / Residency** University of Toronto general surgery internship, residency, Toronto, Ontario 1979-1984

LICENSURE AND BOARD CERTIFICATION

Diplomate, National Board of Medical Examiners
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Diplomate, Royal College of Surgeons of Canada
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Medical License: New York 1984

ACADEMIC AFFILIATIONS

Instructor in surgery, Weill Medical College of Cornell University, 1993-2002

PROFESSIONAL ASSOCIATIONS

Albany Medical Center Class of 1979, President
Alpha Omega Alpha Medical Honor Society
American College of Healthcare Executives
American College of Physician Executives 1993-2007
American College of Surgeons, Fellow
American Red Cross, Tompkins County, Board of Directors 1997-2000
Cayuga Medical Center Medical Staff President, 1993
Cornell University College of Veterinary Medicine Advisory Council 2006-2012
Governance Institute, Editorial Board 2003-6
Health Planning Council, Tompkins County, Advisory Board 2003-2012
Iroquois Healthcare Association, Board of Directors, Vice Chair 2011
Legacy Foundation of Tompkins County, Board of Directors 2006-2010
Lifetime Healthcare Companies, Board of Directors 2004-2011
Medical Society of the State of New York
Medical Society of the County of Tompkins, Board of Directors 1997-2012
Paleontological Research Institution, Board of Directors, President 2010-11
Royal College of Surgeons (Canada), Fellow
Tompkins Health Network, Board of Directors
VHA Empire-Metro, Board of Directors Chair 2006-9
VHA CEO Safety Network Chair 2008-9

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