

DEGADIS

Endpoint Distance Modeling

Prepared By:
TRC Environmental Corporation

SECTION 11
MODELING FOR TFI GUIDANCE
prepared by
TRC Environmental Corporation

This appendix presents the methodology used to develop the distance to the toxic endpoint for anhydrous ammonia and aqueous ammonium (30%) presented in the body of this report. This appendix is organized as follows:

- 11- 1 Model Selection
- 11 - 2 Worst-case Release Scenario - Anhydrous Ammonia
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- 11 - 5 Alternate Release Scenario - Aqueous Ammonia
- 11 - 6 Comparisons to ALOHA and the EPA Guidance
- 11 - 7 Conclusions

11- 1 MODEL SELECTION

TRC Environmental Corporation (TRC) has selected DEGADIS as the model which is appropriate and matches the characteristics of ammonia releases needed to prepare Risk Management Plans for the EPA Risk Management Program. The EPA Risk Management Program requires modeling of both a "worst-case" release scenario and an "alternate" release scenario.

Certainly for the worst-case scenario and possibly for the alternate scenario, the maximum offsite concentrations with anhydrous ammonia are associated with a dense gas plume which slumps to the ground and travels downwind. Accidental releases which result from stack or buoyant jet emissions of ammonia are not likely to result in offsite concentrations as high as those associated with dense gas releases. Therefore, a dense gas model with proven capability to model ammonia releases is needed. The RMP rule assumes, however, that anhydrous ammonia is a neutrally buoyant gas and that aqueous ammonia is a liquid.

One major test of dense gas model performance sponsored by EPA is contained in "Evaluation of Dense Gas Simulation Models," EPA-450/4-90-018, May 1991¹. This model evaluation compared seven dense gas models (DEGADIS, SLAB, AIRTOX, CHARM, FOCUS, SAFEMODE and TRACE) against the measured results of accidental release field trials. For ammonia, the field trial was Desert Tortoise conducted in 1983 at the Liquefied Gaseous Fuels Spill Test Facility in Nevada. Three high volume, high pressure releases of 15 to 60 m³ of liquid ammonia

were suitable for model comparisons. Release times ranged from 1 to 8 minutes. There were two arcs of downwind ammonia concentration measurements at 100 meters and 800 meters.

DEGADIS overpredicted the concentrations at each sampling arc for each test. That is a favorable response since we would like the selected model to be conservative. Additionally, DEGADIS slightly overpredicted concentrations at the second downwind arc where we want it to be more accurate in determining the distance for the accidental release, i.e., its large overpredictions near the source are of less consequence.

The other models which did reasonably well at the second downwind arc are TRACE and FOCUS. The other four models (AIRTOX, CHARM, SAFEMODE and SLAB) either significantly underpredicted the values at the second downwind arc or had erratic performance. AIRTOX, for instance, is very low in Test 1, slightly low in Test 2 and very high in Test 4.

The primary reason to pick DEGADIS over TRACE and FOCUS is that it is a public domain model rather than a proprietary model. DEGADIS is available from EPA to anyone to use and thus available to all TFI members to use at their own facilities. Additionally, DEGADIS is an Appendix B model of the EPA Guideline on Air Quality models. SLAB and HGSYSTEM are also Appendix B models.

Although of less interest to TFI, the performance of DEGADIS for LNG spills (the Burro experiments) and HF spills (The Goldfish experiments) is also sufficiently acceptable to recommend its use. For the Goldfish experiments DEGADIS (D) was the best model although underpredicting, and for the Burro experiments it was the best of the overpredicting models.

A more recent evaluation of dense gas models was performed by Hanna, 1993. This is a comparison of the models' performance for 123 individual tests which are continuous releases. DEGADIS again performed well in this evaluation with relatively low variability and a tendency to overpredict. CHARM and SLAB tended to underpredict and the variability of AIRTOX is self-evident. The variability of FOCUS is substantially higher than DEGADIS. While TRACE was on average closer to the measured concentrations, its variability was higher than DEGADIS. The Hanna evaluation included HGSYSTEM which had nearly equivalent performance to DEGADIS, which is not surprising given their common heritage.

EPA issued in January 1996, a draft report² entitled "Generic Guidance Risk Management Program (RMP) for Ammonia Refrigeration Facilities." This "Guidance" uses a different model,

SACRUNCH, to provide nomographs for calculations of accidental releases. TRC has reviewed this guidance in depth. SACRUNCH is a proprietary model. It is not presently available in any public form. Additionally, the EPA contractor who prepared the Guidance states that the model “is comparable to ... similar models such as DEGADIS when tested against the Desert Tortoise experiments.” In checking with the contractor for proof of this claim, TRC was told that the document referenced is proprietary. This leads TRC to conclude that DEGADIS remains a model of choice.

In summary, the performance of DEGADIS is as good or better than the majority of models available. While not being the only model that could be selected, the ready availability and Guideline status of DEGADIS led to its selection for this application.

11 - 2 WORST-CASE RELEASE SCENARIO - Anhydrous Ammonia

11-2.1. Input Values

The worst-case release scenario is specified by the RMP rule to have the following characteristics:

- Anhydrous ammonia is defined as a buoyant, toxic gas which when stored at ambient temperature or as a liquid under pressure is assumed to be released at a constant rate over ten minutes (refrigerated tanks would be handled differently).
- For this worst-case release analysis, diking of anhydrous ammonia when stored at ambient temperature does not affect the calculation.
- The windspeed is set at 1.5 meters/second (3.4 miles per hour) and F stability (assumes nighttime, light windspeed conditions, no or little cloud cover, i.e., an inversion).
- The temperature for the atmosphere and the ammonia is assumed equal to the highest temperature recorded in the past three years. These analyses were prepared using 43°C (110°F). The temperature has no effect on the amount or duration of the release. The temperature does, however, affect the amount of ammonia which is vapor versus entrained liquid. At 35°C (95°F) the distance to the endpoint decreases by 7%. At 25°C (77°F) the distance to the endpoint decreases by 16%. Similarly, the humidity used in these analyses was assumed to be 50%, but no corrections need be made to other relative humidities (differences in modeled distance to endpoint are less than 2%).
- The “toxic endpoint” is 200 ppm (0.14 mg/l) for all of these analyses. There is a possibility that sometime in the future this “toxic endpoint” might change.

The DEGADIS model has been run in the “isothermal” mode and the thermodynamics have been entered manually for aerosol formation and rainout.

The density of the ammonia plume used in DEGADIS has been calculated assuming that a portion of the anhydrous ammonia is flashed adiabatically at its atmospheric boiling point to vapor and liquid, and that the remainder of the ammonia is carried along in the plume as a liquid aerosol with the flashing vapor. In reality, some of the liquid will not be entrained and form an evaporating pool. It is important to note that a dike may be of assistance in reducing further evaporation from this pool, but the worst-case release scenario specified by EPA does not give credit for this situation for anhydrous ammonia.

The toxic endpoint used is the one specified in the RMP rule Appendix A, i.e., 200 ppm (0.14 mg/liter). It is adopted from the ERPG-2 value of the AIHA which specifies exposures of up to one hour. The RMP rule does not specify an averaging time.

TRC has written a post-processor to DEGADIS which uses the DEGADIS output to extract distances for any averaging time. The distances for the worst-case anhydrous ammonia release are all 10 minute average concentrations.

The DEGADIS model has been run with two different surface roughnesses (z_0) representative of two different types of terrain. These are:

- Rural terrain (surface roughness 3 centimeters): Indicative of areas where “there are no buildings in the immediate area and the terrain is generally flat and unobstructed.” [§68.22(e)]
- Urban terrain (surface roughness 100 centimeters): Indicative of areas where “there are many obstacles in the immediate area; obstacles include buildings or trees.” [§68.22(e)]

It is necessary at each site to select either rural or urban terrain as defined above before using the tables. This is a subjective determination but the purpose is that if the gases from ammonia release would be obstructed, i.e., have to go around buildings, trees or other obstacles before getting to the public, then it will be significantly more dispersed than if it travels over open terrain.

11.2.B. Results

The DEGADIS model results for the worst-case release scenario for anhydrous ammonia are presented in Table 1. This covers a range of anhydrous ammonia storage from 10,000 to 200,000 pounds. This table applies to the maximum capacity of the largest single anhydrous ammonia storage vessel at the site. The distances should be measured from the center of the storage vessel and used as the radius of a circle which defines the area of the worst-case release scenario impact.

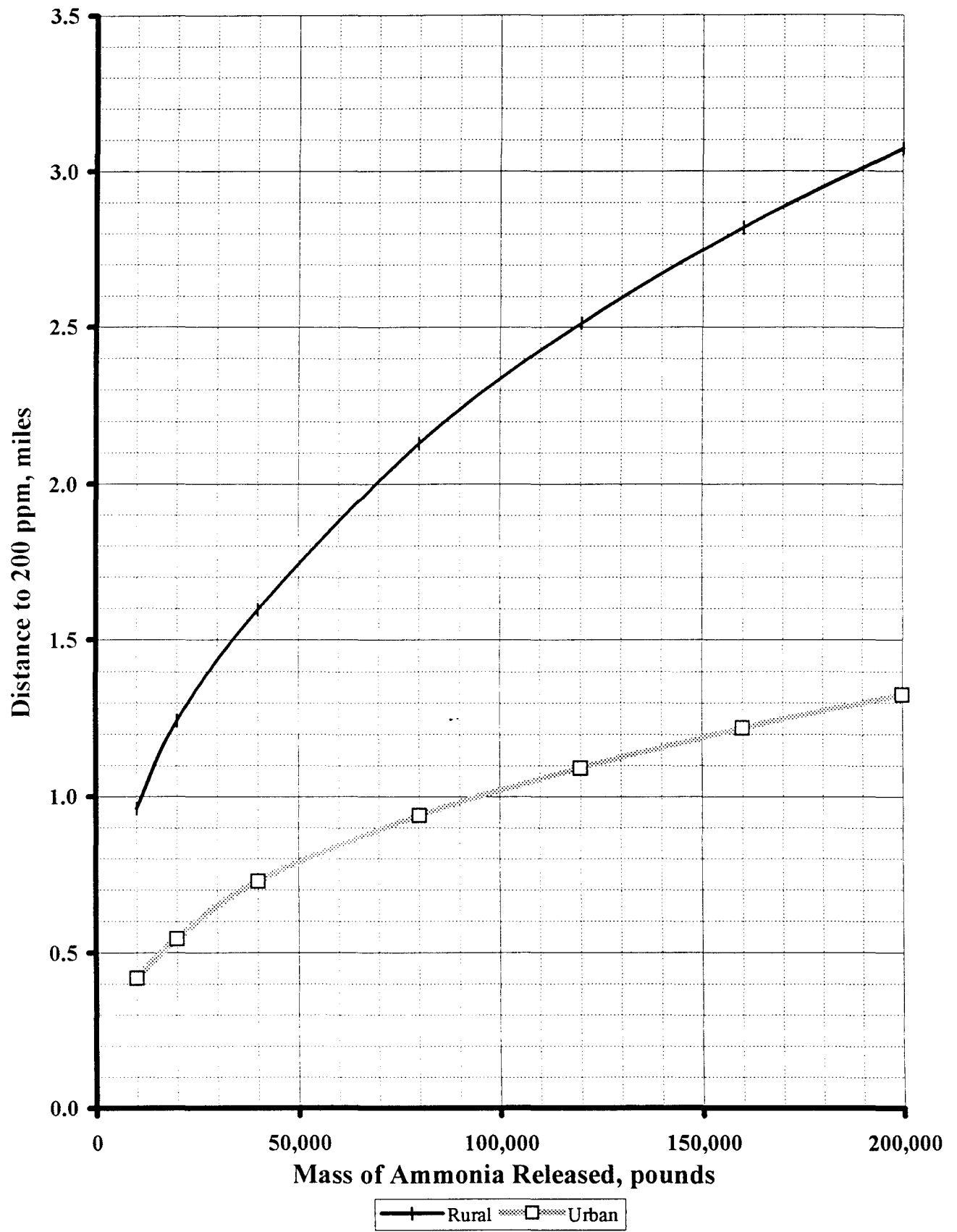
Figure 1 shows the results of Table 1 graphically. The distances for rural terrain are the longest, and the urban terrain yielded the shortest distances. Interpolation to obtain distances from these curves is acceptable.

Table 1

TFI Worst-Case Anhydrous Ammonia Releases: Summary of Results

Amount Released (lb)	Distance to 200 ppm, miles, for Terrain:	
	Rural	Urban
10,000	0.96	0.42
20,000	1.24	0.55
30,000	1.43	0.65
40,000	1.60	0.73
50,000	1.75	0.79
60,000	1.87	0.84
70,000	2.00	0.89
80,000	2.13	0.94
90,000	2.23	0.98
100,000	2.34	1.02
110,000	2.43	1.06
120,000	2.51	1.09
130,000	2.60	1.12
140,000	2.68	1.16
150,000	2.76	1.19
160,000	2.82	1.22
170,000	2.87	1.25
180,000	2.95	1.28
190,000	3.00	1.30
200,000	3.07	1.33

**Figure 1: TFI Worst-Case Anhydrous Ammonia Releases:
Endpoint Distance as Function of Mass Released
(10-Minute Averaging Time)**



11 - 3 ALTERNATE RELEASE SCENARIO - Anhydrous Ammonia

11.3.A. Input Values

The alternate release scenario selected for anhydrous ammonia is a break of a pipe leading from or to the anhydrous ammonia storage tanks. The four pipe diameters used by the Nebraska DEQ¹ were selected and a 4" pipe diameter was added to the evaluations. It is assumed that each pipe releases ammonia for 2 minutes before an automatic or manual shutoff intervenes to stop the flow of ammonia.

The technical assumptions in this case are very conservative, i.e., lead to longer distances than actually expected. These assumptions are:

- 1) That the liquid release rate of anhydrous ammonia is governed by the Bernoulli equation [as is done in the ARCHIE model. See Section 11-6.] It is expected that actual release rates will be substantially less because ammonia vapors will be generated in the pipe, which results in a lower two-phase density and lower flow rate out of the pipe than for the Bernoulli equation.
- 2) As with the worst-case release scenario, it has been assumed that all of the released ammonia becomes a gas or is entrained in the gas. Depending on atmospheric conditions some portion of the ammonia would either spill onto the ground or rainout quickly as liquid droplets. This effect would also reduce actual peak release rates.

The windspeed is set at 3 meters/second. This is meant to represent the annual average windspeed. If the average annual windspeed at the site is higher than 3 meters/second (6.7 miles/hour), the distances would tend to be less than those in the Tables.

The annual predominant stability class is D stability for all sites.

As in the worst-case release example for anhydrous ammonia, the temperature and relative humidity have only slight effect on the distances as calculated. In actuality, such releases would be affected by these variables in terms of both release rate and liquid dropout, e.g., the higher the humidity the more the liquid rainout.

These alternate release scenarios evaluations have again been run as 10 minute averages using the DEGADIS post-processor.

11.3.B. Results

The alternate release scenario results for anhydrous ammonia are shown in Table 2 and depicted graphically in Figure 2. It should be noted that Table 2 indicates nominal diameters of Schedule 80 pipe but the horizontal axis of Figure 2 uses the actual inside pipe diameters as obtained from Perry's Chemical Engineers Handbook. Note also that the endpoint distances of these alternate releases are generally shorter distances than the worst-case releases. If your alternate release scenario yields a longer distance, you should reconsider the alternate release scenario.

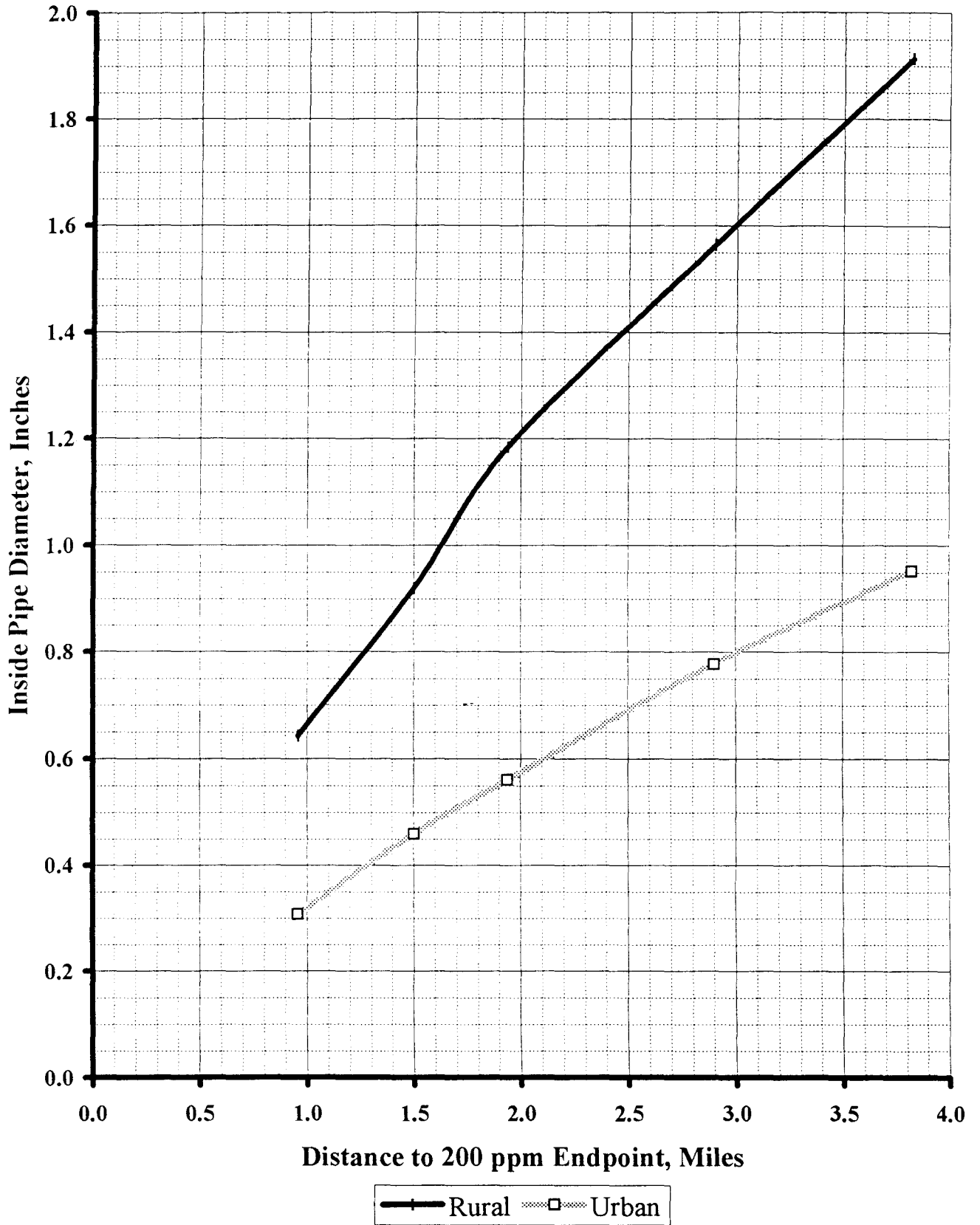
Table 2

TFI Alternate-Case Releases of Anhydrous Ammonia:
 Pipe Leaks at 3 m/s Wind Speed, D Stability: Summary of Results

Nominal Pipe Diameter Inches	Release Rate lb/min	Mass Released Lb*	Distance to Threshold, miles, for Terrain:	
			Rural	Urban
1	1,450	2,901	0.64	0.31
1.5	3,563	7,127	0.92	0.46
2	5,954	11,908	1.18	0.56
3	13,319	26,638	1.56	0.78
4	23,182	46,364	1.91	0.95

* Assumes release is stopped through human intervention after 2 minutes

**Figure 2: TFI Alternate-Case Anhydrous Ammonia Releases:
Endpoint Distance as a Function of Pipe Diameter
(10-Minute Average)**



11 - 4 WORST-CASE RELEASE SCENARIO - Aqueous Ammonia

11.4.A. Input Values

The aqueous ammonia solution chosen for these scenarios contains 30% ammonia by weight. For equivalent amounts of 24% aqueous ammonia solutions, distances can be approximated by reducing the distance by 14%. For equivalent amounts of 20% aqueous ammonia solutions, distances can be approximated by reducing distances by 23%. Alternatively, an estimate of the distance can be made by using the pounds of ammonia column on Table 3, i.e., calculate ammonia released instead of solution released to account for different solution percentages. These results will be overestimates of 6-10%.

The worst-case release scenario assumes that the entire contents of the tank are released and are treated as a liquid from which the ammonia evaporates with time. It is assumed that a pool of 1 centimeter depth is formed, and that the ground surface does not absorb any liquid (impervious surface at ambient temperature). The rate of evaporation and release of ammonia has been calculated in 10 second time steps, which include changes in water content and evaporation, as well as changes in the size of the pool (decreases with time and evaporation).

The worst-case release scenario assumes there is no dike. If a dike is present and the entire spill is contained, the rate of evaporation and release of ammonia is much less, depending on the area of the dike, and thus the distance to the toxic endpoint is much less. Table 3 contains a column of maximum pool area in square feet. If the diked area, in square feet is less than the listed value for the amount of ammonium released (or solution release assuming 30% solution), the distance to the endpoint will be less. An approximation can be made by using the square footage of the diked area to enter the table.

Also shown on Table 3 is the amount of time, in minutes, that it takes to evaporate 90% of the ammonia in the aqua pool. As can be seen, the length of time exceeds 60 minutes. The results, however, have been obtained using an averaging time of 10 minutes as evaluated using DEGADOSE.

When ammonia evaporates from a pool of aqueous ammonia it is actually lighter than air. The DEGADIS model is not designed to handle lighter than air releases. DEGADIS has been run as if the ammonia were neutrally buoyant. The results presented are thus overestimates of the distance to the actual endpoint.

For this evaluation, the temperature of 110°F (43°C) was selected. The rule calls for the use of the highest temperature in the last three years for the site. As temperature increases the evaporation of ammonia also increases. The increased evaporation rate is balanced, however, by a shorter release duration, leading to not much change in the distance to the endpoint. Similarly, relative humidity has little effect on the distance to endpoint.

11.4.B. Results

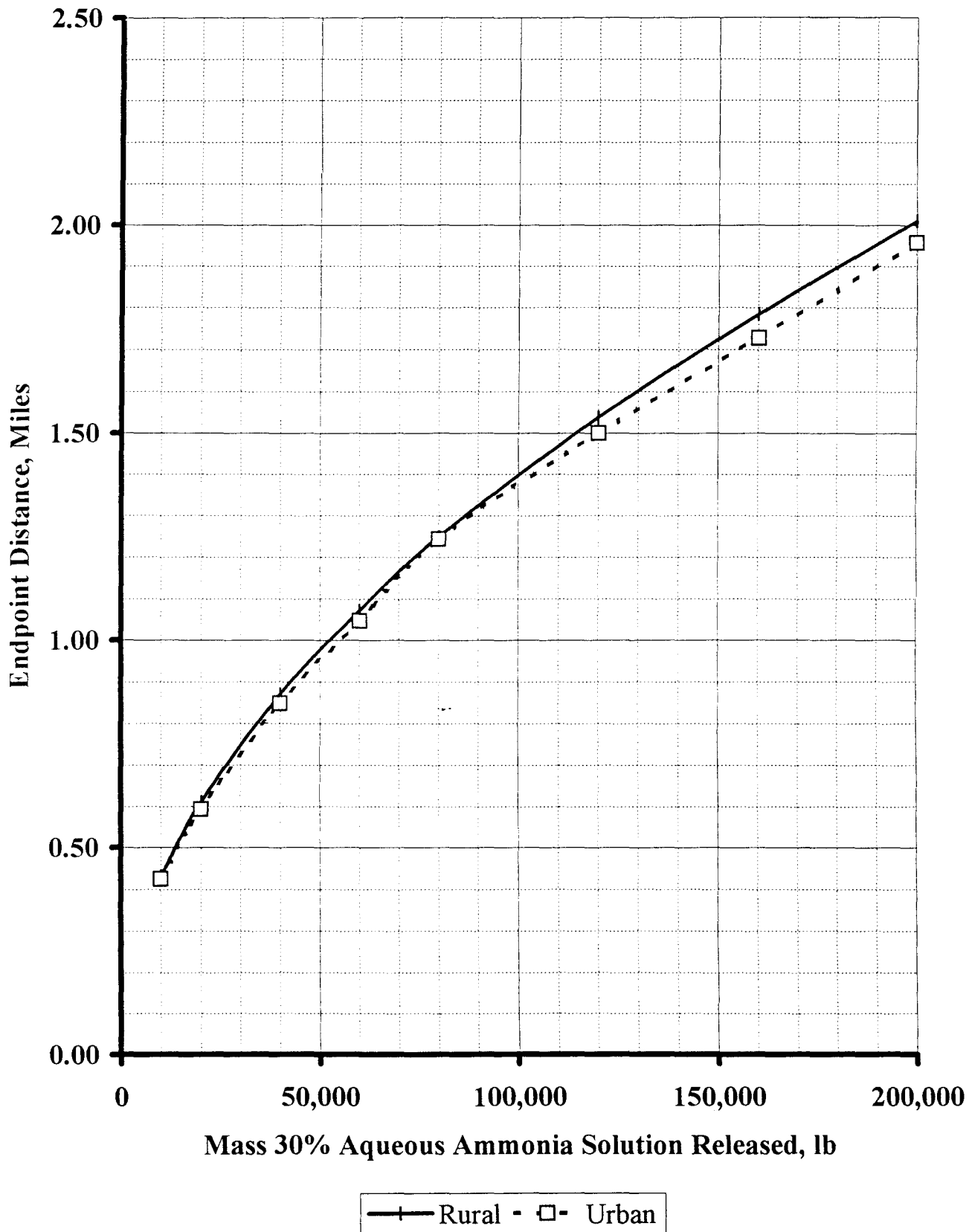
The results of the worst-case release scenario for 30% aqueous ammonia are presented in Table 3. Figure 3 presents the results graphically.

Table 3

TFI Worst-Case 30% Aqueous Ammonia Releases:
Summary of Results

Solution Released Lb	Ammonia Released Lb	Maximum Pool Area ft ²	99% Evap. Duration Min.	Distance to 200 ppm, miles, for Terrain:	
				Rural	Urban
10,000	3,000	5,492	74.5	0.43	0.42
20,000	6,000	10,984	74.5	0.61	0.60
30,000	9,000	16,476	74.5	0.75	0.72
40,000	12,000	21,968	74.5	0.87	0.86
50,000	15,000	27,460	74.5	0.97	0.95
60,000	18,000	32,952	74.5	1.07	1.05
80,000	24,000	43,936	74.5	1.25	1.25
100,000	30,000	54,920	74.5	1.40	1.38
120,000	36,000	65,904	74.5	1.54	1.56
160,000	48,000	87,872	74.5	1.78	1.75
200,000	60,000	109,840	74.5	2.01	1.98

**Figure 3: TFI Worst-Case Releases of 30% Aqueous Ammonia:
Distance to 200-ppm Endpoint (10-Minute Average)
as a Function of Mass Released**



11 - 5 ALTERNATE RELEASE SCENARIO - Aqueous Ammonia

11.5.A. Input Values

The Alternate Release Scenario chosen for 30% Aqueous Ammonia was the release of up to 10,000 pounds of solution. The exact timing of the release is not crucial since the evaporation rate determines the distance.

The primary difference between this alternate release and the worst-case release for aqueous ammonia is both the windspeed and stability class. If the average windspeed at the site is higher or lower than 3 meters per second (6.7 miles per hour), it does not affect the distance to the endpoint by much. While the higher windspeed would increase dispersion resulting in a shorter distance, the higher windspeed would also result in greater initial evaporation rates, and the two factors tend to balance each other. The same balancing occurs if different temperatures and relative humidities are used.

This evaluation was also performed with DEGADIS assuming neutral buoyancy. Since the ammonia released is actually lighter than air, the results presented overstate the distance to the endpoint. As before, the results are presented as 10 minute average values.

The RMP rule requires that the alternate release scenario distance to the toxic endpoint exceed the boundaries of the site property, i.e., have any offsite impact. If the distance in the results does not include an offsite impact the pounds released must be increased until it does.

11.5.B. Results

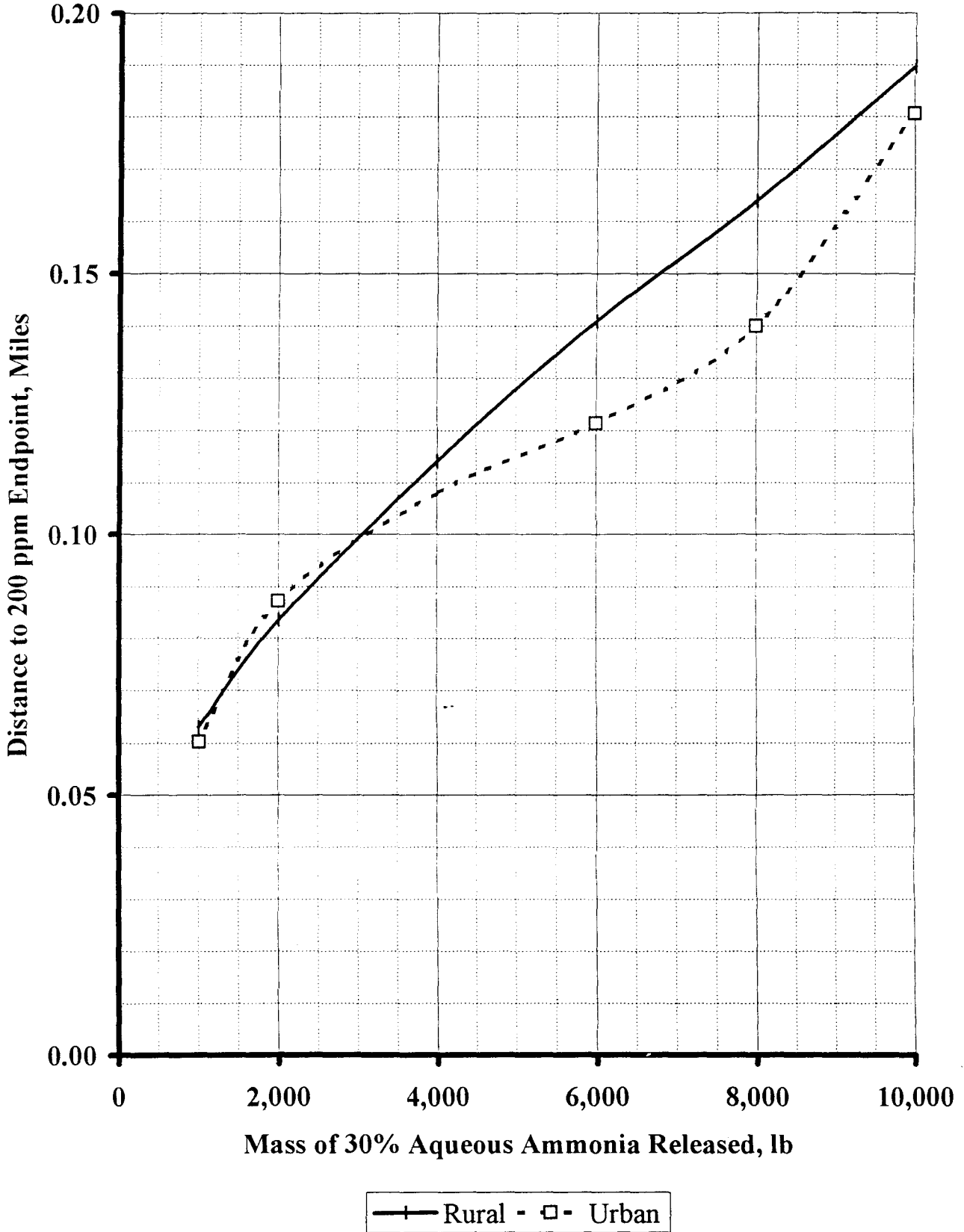
The alternate release scenario results for 30% aqueous ammonia are shown in Table 4 presented graphically in Figure 4.

Table 4

TFI Alternate Case 30% Aqueous Ammonia Releases
(3 m/s D Stability): Summary of Results

Solution Released Lb	Ammonia Released Lb	Maximum Pool Area ft ²	99% Evap. Duration Min.	Distance to 200 ppm, miles, for Terrain:	
				Rural	Urban
1,000	300	549	43.2	0.06	0.06
2,000	600	1,098	43.2	0.08	0.09
3,000	1,000	1,648	43.2	0.10	0.10
4,000	1,200	2,197	43.2	0.11	0.11
5,000	1,500	2,746	43.2	0.13	0.12
6,000	1,800	3,295	43.2	0.14	0.12
7,000	2,100	3,844	43.2	0.15	0.13
8,000	2,400	4,394	43.2	0.16	0.14
9,000	2,700	4,943	43.2	0.18	0.16
10,000	3,000	5,492	43.2	0.19	0.18

**Figure 4: TFI Alternate-Case Aqueous Ammonia Releases:
Endpoint Distance to 200 ppm as Function of Mass Released**



11 - 6 COMPARISON TO OTHER MODELS

TFI members should understand the comparability of these modeling results presented in this report and modeling results from other commonly available sources. The Local Emergency Planning Committee, the fire department or equivalent may use or have access to the model ALOHA (which is part of the more comprehensive CAMEO system available from the National Safety Council). Additionally, the US EPA has published a guidance document for the RMP rule entitled "RMP Offsite Consequence Analysis Guidance" and a "Model RMP for Ammonia Refrigeration."

ALOHA

ALOHA uses a release rate and a release duration, as well as meteorological parameters as its only input values along with the name of the chemical. For the worst-case release scenario for anhydrous ammonia, Table 5 compares the ALOHA and DEGADIS results.

TABLE 5

TFI Worst-Case Anhydrous Ammonia
ALOHA Comparison

Amount Released, lb	Distance to 200 ppm, miles			
	RURAL		URBAN	
	ALOHA	DEGADIS	ALOHA	DEGADIS
90,000	4.23	2.23	3.36	0.98
170,000	5.59	2.87	4.47	1.25

The ALOHA model does not actually calculate a value for the urban terrain category, i.e., it does not accept surface roughness values greater than 20 centimeters. (If one enters a surface roughness greater than 20 centimeters, ALOHA defaults to 20 centimeters.) Thus, for urban terrain the ALOHA results are more than 3 times longer distance than the DEGADIS results.

For rural terrain they are about twice the DEGADIS distances.

The alternate release scenario for anhydrous ammonia was also run in ALOHA. The ALOHA results and the DEGADIS results are similar ($\pm 8\%$). Results for the 3 inch pipe case are shown in Table 6.

TABLE 6

TFI Alternate Case Anhydrous Ammonia
ALOHA Comparison

Amount Released, lb	Distance to 200 ppm, miles			
	RURAL		URBAN	
	ALOHA	DEGADIS	ALOHA	DEGADIS
26,638*	2.05	1.56	1.74	0.78

* 3" pipe break, 2 minute release

ALOHA does not contain aqueous ammonia in its chemical lists. Additionally, it did not allow a pool diameter of greater than 90 meters (the pool diameter for the initial pool of the 200,000 lbs spill was 114 meters). Thus, in order to evaluate the worst-case release scenario for 200,000 lbs of aqueous ammonia, 60,000 lbs of anhydrous ammonia was used along with a 90 meter diameter pool. The result was about 2.5 miles or nearly double the results of DEGADIS. ALOHA does not provide for urban terrain.

In summary, ALOHA overestimates worst-case release scenario results by about a factor of two compared to DEGADIS in distance for rural terrain. For anhydrous ammonia in urban terrain, the ALOHA results are three times the DEGADIS results. For the alternate release scenarios the ratios between ALOHA and DEGADIS distances are similar.

The official guidance from US EPA on developing worst-case and alternate release scenario distances is contained in the "RMP Offsite Consequence Analysis Guidance." It was prepared using ALOHA for ammonia (categorized in the guidance as a neutrally buoyant gas).

The RMP rule states that use of the Guidance to develop worst-case and alternate release scenario distances is considered compliance with the rule. Any site may use the Guidance results and is not required to use the DEGADIS results in this document.

US EPA has also issued the “Model RMP and Plan for Ammonia Refrigeration” intended for use by the many ammonia refrigeration facilities in the country. It was prepared by an EPA contractor using SACRUNCH, a proprietary model.

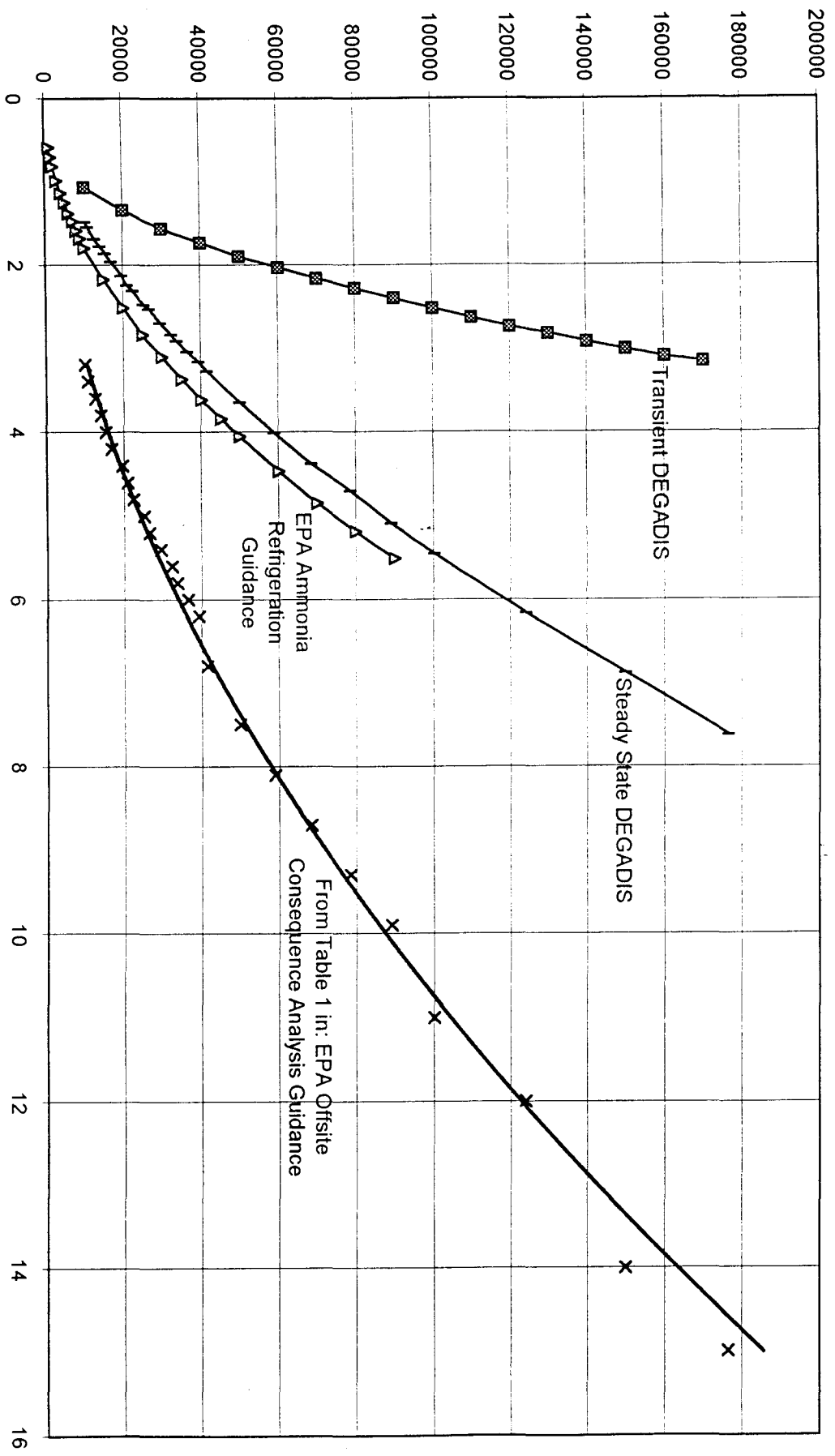
Figure 5 shows a comparison of the two EPA sponsored results versus the results of DEGADIS in two modes, transient and steady - state. Figure 5 is for the worst-case release scenario in rural conditions. The case was chosen because it shows the greatest differences in model performance. The release is the total pounds released in 10 minutes as required by the rule.

First, consider the DEGADIS results. When DEGADIS is used in the steady state mode, it assumes that the release continues indefinitely at the prescribed release rate. When DEGADIS is used in the transient mode, it assumes that the release stops at the end of 10 minutes and a puff of ammonia moves downwind. Figure 6 shows the puff at a series of time steps as it moves downwind. The concentrations in the puff at each time step are represented by a different set of symbols. Figure 6 is for a 100,000 pound release over 10 minutes in the transient mode where the distance to 200 ppm was predicted as 4041 meters (2.5 miles). The model calculates that it takes 2.5 hours for the puff to travel the 2.5 miles, i.e., an effective speed of 1 mile per hour.

The reason that the transient mode calculates much shorter distances than the steady-state mode is that the puff spreads out in the downwind direction, which does not occur in the steady-state mode.

The EPA Ammonia Refrigeration Guidance selected the steady-state mode in SACRUNCH for its final results. These results agree fairly well with the DEGADIS steady-state mode results. The EPA Guidance, however, gives substantially greater distances. The EPA Guidance is designed to be conservative, i.e., overestimate the distances.

Figure 5 - "Distance to Endpoint" for worst-case anhydrous ammonia releases in rural terrain settings.



Steady State DEGADIS 2.1

1.479423285	10000
1.539090037	10780
1.680934548	12600
1.771770239	14000
1.860709548	15400
1.957001328	16800
2.125778198	19600
2.237175226	21000
2.308130026	22400
2.476233244	25200
2.525372982	26600
2.694547892	29400
2.834932089	32200
2.908764839	33600
3.040369272	36400
3.155944347	39200
3.271858215	41440
3.645863771	49840
4.003080368	58800
4.373847008	68320
4.695893288	78400
5.082471371	89040
5.449575901	100100
6.155717373	123900
6.875126839	149800
7.620993614	176400

From Table 1 in: EPA Offsite Consequence Analysis Guidance

3.20000048	10000
3.40000095	10780
3.59999905	12600
3.79999952	14000
4	15400
4.199999809	16800
4.40000095	19600
4.59999905	21000
4.800000191	22400
5	25200
5.199999809	26600
5.40000095	29400
5.59999905	32200
5.800000191	33600
6	36400
6.199999809	39200
6.800000191	41440
7.5	49840
8.100000381	58800
8.699999809	68320
9.300000191	78400
9.899999619	89040
11	100100
12	123900
14	149800
15	176400

EPA Ammonia Refrigeration Guidance

0.587121189	1000
0.700757563	1500
0.814393938	2000
0.984848499	3000
1.136363626	4000
1.25	5000
1.38257575	6000
1.477272749	7000
1.590909123	8000
1.685606003	9000
1.799242377	10000
2.178030252	15000
2.518939495	20000
2.840909004	25000
3.106060505	30000
3.371212006	35000
3.61742425	40000
3.844696999	45000
4.053030491	50000
4.469696999	60000
4.848484993	70000
5.189393997	80000
5.511363506	90000

Transient DEGADIS 2.1

1.059999943	10000
1.340000033	20000
1.559999943	30000
1.730000019	40000
1.899999976	50000
2.029999971	60000
2.160000086	70000
2.279999971	80000
2.400000095	90000
2.519999981	100000
2.630000114	110000
2.740000001	120000
2.819999933	130000
2.920000076	140000
3.009999999	150000
3.099999905	160000
3.160000086	170000

0.959999979	10000
1.24000001	20000
1.429999948	30000
1.600000024	40000
1.75	50000
1.870000005	60000
2	70000
2.130000114	80000
2.230000019	90000
2.339999914	100000
2.430000067	110000
2.509999999	120000
2.599999905	130000
2.680000067	140000
2.759999999	150000
2.819999933	160000
2.869999886	170000

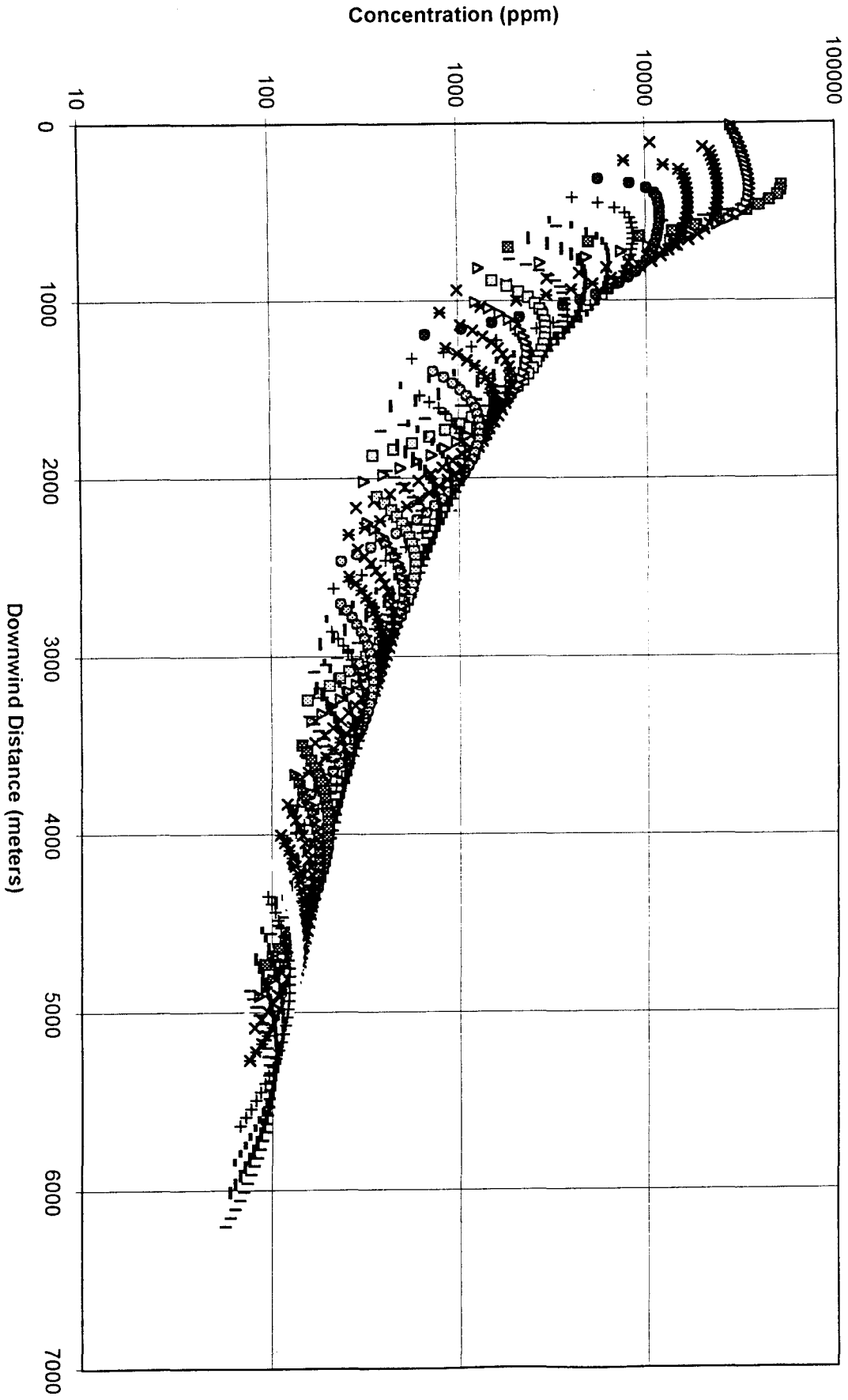


Figure 6 TFI Worst Case release: Anhydrous Ammonia (100,000 ils in 10 minutes)

467	31910	353	51750	17.1	28300	112	10610	211
496	25730	381	51270	41	29200	137	20140	238
525	20070	408	49250	65.3	30000	163	21750	264
554	12230	436	44640	89.8	30730	188	22240	291
583	3366	465	39440	115	31380	214	22660	318
		493	33990	140	32010	240	23030	345
		522	28600	165	32570	267	23330	372
		551	23440	191	33100	293	23590	400
		580	18440	217	33580	320	23810	428
		609	13780	243	33990	348	23960	456
		639	9250	269	34350	375	24050	484
		669	4958	296	34830	403	24060	513
		699	1862	323	35050	431	23970	542
				350	35280	459	23800	571
				378	35190	487	23500	600
				406	35070	516	23100	630
				434	34790	545	22530	660
				462	34170	574	21680	690
				490	32800	603	20430	720
				519	30530	633	18780	750
				548	27460	663	16810	781
				577	23950	693	14630	812
				606	20330	723	12380	843
				636	16800	753	10180	874
				666	13440	784	8090	905
				696	10280	815	6158	937
				726	7382	846	4430	969
				756	4827	877	2970	1001
				787	2746	908	1812	1033
				818	1291	940	986.0001	1065

7665	315	5577	422	4120	533	3107	648	2396
12460	342	8164	450	5637	562	4054	678	3018
14940	370	10020	479	6881	592	4883	708	3583
15750	397	11000	507	7712	621	5511	738	4043
16080	425	11430	536	8172	651	5923	769	4379
16300	453	11610	565	8394	681	6159	799	4598
16470	482	11720	594	8492	711	6275	830	4722
16590	510	11770	624	8525	741	6316	861	4776
16650	539	11780	654	8519	772	6311	893	4782
16660	568	11750	684	8472	802	6272	924	4756
16620	597	11670	714	8395	833	6206	956	4702
16520	627	11540	744	8282	864	6109	988	4627
16340	657	11370	775	8132	896	5987	1020	4525
16090	687	11130	805	7936	927	5830	1052	4400
15750	717	10840	836	7696	959	5639	1085	4248
15320	747	10470	868	7405	991	5411	1117	4070
14770	778	10020	899	7056	1023	5143	1150	3863
14040	808	9462	930	6643	1055	4832	1183	3626
13110	840	8796	962	6163	1088	4482	1217	3364
11990	871	8035	994	5630	1121	4097	1250	3081
10720	902	7192	1026	5049	1154	3684	1284	2778
9344	934	6291	1059	4434	1187	3252	1317	2465
7938	965	5371	1091	3810	1220	2814	1351	2148
6546	997	4462	1124	3197	1253	2383	1385	1836
5226	1030	3599	1157	2609	1287	1972	1420	1538
4018	1062	2805	1190	2069	1321	1588	1454	1258
2949	1095	2105	1223	1590	1355	1244	1489	1005
2042	1127	1507	1257	1174	1389	945.3	1524	782
1322	1160	1032	1290	834.1	1423	695.4	1559	591.3
795.3	1193	661.8	1324	566.1	1458	493.1	1594	433.3

765	1885	886	1512	1010	1232	1137	1020	1267
796	2313	918	1816	1042	1455	1170	1188	1300
827	2710	949	2102	1075	1667	1203	1348	1334
858	3048	981	2353	1108	1856	1237	1493	1368
889	3312	1013	2559	1140	2016	1270	1618	1403
921	3498	1046	2713	1173	2141	1304	1720	1437
953	3616	1078	2819	1207	2232	1338	1797	1472
985	3678	1111	2881	1240	2290	1372	1849	1506
1017	3697	1144	2907	1273	2319	1406	1878	1541
1049	3683	1177	2903	1307	2323	1440	1886	1576
1081	3643	1210	2875	1341	2306	1475	1876	1611
1114	3582	1243	2829	1375	2271	1510	1850	1647
1147	3501	1277	2764	1409	2219	1545	1810	1682
1180	3401	1311	2682	1444	2155	1580	1758	1718
1213	3280	1344	2586	1478	2077	1615	1694	1754
1247	3138	1379	2473	1513	1985	1650	1621	1790
1280	2976	1413	2346	1548	1884	1686	1539	1826
1314	2795	1447	2203	1583	1772	1722	1448	1863
1348	2595	1482	2049	1618	1649	1758	1351	1899
1382	2380	1517	1883	1654	1519	1794	1248	1936
1416	2154	1552	1710	1690	1385	1830	1141	1973
1451	1920	1587	1532	1725	1247	1866	1031	2010
1485	1685	1622	1353	1761	1107	1903	920.9	2047
1520	1454	1657	1176	1797	969.9	1940	811.9	2084
1555	1230	1693	1005	1834	836.7	1976	706.4	2122
1590	1021	1729	844.1	1870	710.1	2013	606.2	2159
1626	829.1	1765	696.1	1906	593.6	2051	512.3	2197
1661	658.4	1801	562.8	1943	487.5	2088	426.1	2235
1697	509.1	1837	444.8	1980	392.8	2125	349	2273
1733	384.2	1874	344.4	2017	310.1	2163	280.6	2311

855.2	1399	725.1	1534	621	1672	536.5	1812	467.3
983.6	1433	825.3	1569	700.5	1707	600.4	1848	519.1
1107	1468	921.6	1604	777	1743	661.9	1885	569
1220	1503	1011	1640	848	1779	719.2	1921	615.5
1319	1538	1090	1675	911.6	1815	770.8	1958	657.7
1401	1573	1156	1711	966	1852	815.1	1995	694.4
1465	1608	1209	1747	1010	1888	851.6	2032	725
1510	1643	1248	1783	1043	1925	879.3	2069	748.7
1537	1679	1273	1819	1065	1962	898.3	2107	765.3
1547	1715	1284	1855	1075	1998	908.4	2144	774.6
1542	1750	1282	1892	1075	2036	910	2182	777
1523	1786	1268	1928	1066	2073	903.6	2220	772.5
1492	1823	1244	1965	1048	2110	889.7	2258	761.9
1451	1859	1211	2002	1022	2148	869	2296	745.4
1401	1896	1170	2039	988.7	2185	842.5	2334	723.7
1341	1932	1123	2077	949.5	2223	810.4	2372	697.6
1274	1969	1068	2114	905.1	2261	774	2411	667.4
1200	2006	1009	2152	856.2	2299	733.1	2450	633.7
1122	2043	944.5	2189	803.4	2338	690.1	2488	597
1039	2080	877.1	2227	748	2376	643.7	2527	559
953.2	2118	806.8	2265	689.9	2415	596.1	2567	518.6
865.4	2155	734.9	2303	632	2454	547.2	2606	477.8
776.9	2193	663	2342	571.6	2492	497.9	2645	436.9
689.5	2231	591.5	2380	513.1	2531	449.2	2685	395.8
604	2269	522.2	2419	455.7	2571	400.8	2725	355.4
522.9	2307	455.9	2457	400.5	2610	354.8	2764	316.3
446.3	2346	392.7	2496	348	2649	310.9	2804	278.9
376	2384	334.5	2535	299.1	2689	269.1	2844	243.7
312.1	2423	280.9	2574	254	2728	230.8	2885	210.8
254.8	2461	232.6	2614	213.1	2768	195.7	2925	180.5

1954	409.8	2099	361.7	2246	321	2395	286.4	2547
1991	452.3	2137	396.9	2284	350.3	2434	311	2586
2028	493.2	2174	430.6	2322	378.5	2473	334.7	2625
2065	531.5	2212	462.3	2361	405	2512	356.8	2665
2103	566.2	2250	491.3	2399	429	2551	377	2705
2140	596.7	2288	516.7	2438	450.3	2590	394.9	2744
2178	622.3	2326	538.1	2477	468.3	2629	410.2	2784
2216	642.3	2365	555.1	2516	482.7	2669	422.5	2824
2254	656.7	2403	567.5	2555	493.4	2709	431.7	2864
2292	665.2	2442	575.1	2594	500.1	2748	437.8	2905
2330	667.8	2481	577.8	2633	502.9	2788	440.4	2945
2368	664.9	2520	575.9	2673	501.7	2828	439.8	2986
2407	656.7	2559	569.6	2713	496.6	2868	436	3026
2446	643.6	2598	559.1	2752	487.9	2909	429.1	3067
2485	625.9	2637	544.7	2792	476.1	2949	419.5	3108
2524	604.4	2677	526.9	2832	461.4	2990	406.8	3149
2563	579.4	2717	506.1	2872	444.1	3030	392.1	3191
2602	551.5	2756	482.8	2913	424.5	3071	375.5	3232
2641	521.1	2796	457.4	2953	402.8	3112	357.2	3273
2681	488.5	2836	430.4	2994	379.6	3153	337.7	3315
2721	454.9	2877	401.7	3035	355.4	3195	317	3357
2760	420.9	2917	372.6	3075	330.4	3236	296.1	3399
2800	385.7	2957	342.8	3116	305.5	3278	274.7	3440
2840	351	2998	313.5	3158	279.5	3319	252.1	3483
2881	316.9	3039	284.1	3199	254.6	3361	230.4	3525
2921	283.7	3080	255.6	3240	230	3403	209.3	3567
2961	251.8	3121	228.3	3282	206.2	3445	188.6	3610
3002	221.6	3162	202.1	3323	183.4	3487	168.7	3652
3043	193	3203	177.4	3365	161.9	3529	149.7	3695
3084	166.7	3244	154.4					

256.6	2701	230.9	2856	208.6	3014	189.1	3174	172
277.4	2740	248.7	2897	223.8	3055	202.2	3215	183.3
297.3	2780	265.6	2937	238.3	3096	214.6	3257	194
316.1	2820	281.5	2978	251.9	3137	226.3	3298	204.1
333.2	2860	296.1	3018	264.4	3178	237	3340	213.3
348.5	2901	309	3059	275.5	3219	246.6	3382	221.5
361.4	2941	320.1	3100	285	3261	254.8	3424	228.6
371.9	2982	329.1	3141	292.8	3302	261.5	3466	234.4
379.8	3022	335.9	3182	298.8	3344	266.7	3508	238.9
385	3063	340.5	3224	302.8	3386	270.2	3550	242
387.4	3104	342.7	3265	304.9	3428	272.1	3593	243.7
387.1	3145	342.6	3307	305.1	3470	272.2	3635	243.9
384	3186	340.2	3348	303.2	3512	270.9	3678	242.7
378.4	3228	335.6	3390	299.5	3554	267.7	3721	240.1
370.4	3269	328.9	3432	293.9	3597	262.9	3764	236.1
360.3	3311	320.4	3474	286.5	3639	256.8	3807	230.9
348.1	3352	310.1	3516	277.6	3682	249.2	3850	224.6
334.1	3394	298.2	3559	267.4	3725	240.6	3893	217.3
318.6	3436	285.1	3601	256.2	3768	231	3936	208.9
301.9	3478	270.8	3644	243.9	3811	220.4	3980	199.9
284.3	3521	255.7	3686	230.9	3854	209.2	4024	190.1
266	3563	239.9	3729	217.2	3897	197.4	4067	179.9
247.1	3605	223.8	3772	203.2	3941	185.2	4111	169.3
228.3	3648	207.4	3815	189	3984	172.8	4155	158.4
209.4	3691	191	3858	174.8	4028	160.3	4199	147.4
191.7	3734	174.8	3902	160.9	4072	147.9	4244	136.5
172.8	3777	159.4	3945	147.1	4116	135.7	4288	125.6
155.4	3820	144.3	3989	133.6	4160	124.1	4332	115
138.9	3863	128.9	4032	120.1	4204	112.1	4377	104.8

3336	156.9	3499	143.5	3665	131.6	3832	121	4002
3377	166.6	3542	152	3708	139	3876	127.5	4045
3419	176	3584	160.1	3751	146.1	3919	133.7	4089
3461	184.7	3627	167.6	3794	152.7	3962	139.5	4133
3504	192.7	3669	174.5	3837	158.7	4006	144.8	4177
3546	199.8	3712	180.7	3880	164.1	4050	149.5	4221
3588	206	3755	186	3923	168.7	4094	153.6	4266
3631	211	3798	190.4	3967	172.6	4138	157	4310
3674	214.9	3841	193.9	4010	175.6	4182	159.6	4355
3716	217.7	3884	196.3	4054	177.7	4226	161.5	4399
3759	219.1	3928	197.7	4098	178.9	4270	162.6	4444
3802	219.4	3971	198	4142	179.2	4314	162.9	4489
3845	218.5	4015	197.2	4186	178.6	4359	162.4	4534
3889	216.3	4059	195.4	4230	177.1	4404	161.1	4579
3932	213	4102	192.6	4275	174.8	4448	159.1	4624
3976	208.6	4146	189	4319	171.6	4493	156.3	4669
4019	203.1	4190	184.5	4363	167.7	4538	152.9	4715
4063	196.9	4235	179.1	4408	163.1	4583	148.9	4760
4107	189.9	4279	173	4453	157.8	4628	144.4	4806
4151	182.1	4323	166.1	4498	151.8	4674	139.2	4852
4195	173.7	4368	158.7	4543	145.3	4719	133.5	4897
4239	164.7	4413	150.8	4588	138.4	4765	127.5	4943
4283	155.4	4457	142.6	4633	131.2	4810	121.1	4989
4328	145.8	4502	134.2	4678	123.9	4856	114.6	5036
4372	136.1	4547	125.6	4724	116.3	4902	107.9	5082
4417	126.5	4592	117.1	4769	108.6	4948	101.2	5128
4462	116.8	4638	108.5	4815	101	4994	94.41	5175
4507	107.4	4683	100.1	4861	93.53	5040	87.73	5221
4552	98.24	4728	91.8	4907	86.15	5087	81.06	5268

111.5	4173	103	4346	95.32	4520	88.4	4696	82.13
117.2	4217	108.1	4390	99.82	4565	92.4	4742	85.7
122.7	4261	112.9	4435	104.1	4610	96.17	4787	89.05
127.7	4306	117.3	4480	108	4656	99.67	4833	92.17
132.4	4350	121.4	4525	111.6	4701	102.9	4879	95.01
136.5	4395	125	4570	114.9	4746	105.7	4925	97.55
140.1	4439	128.2	4615	117.6	4792	108.2	4971	99.75
143.1	4484	130.9	4660	120	4838	110.3	5017	101.6
145.4	4529	132.9	4706	121.8	4884	111.9	5063	103.1
147.1	4574	134.4	4751	123.2	4930	113.1	5110	104.2
148.1	4619	135.3	4797	124	4976	113.9	5156	104.9
148.4	4665	135.6	4842	124.2	5022	114.2	5203	105.1
148.1	4710	135.3	4888	124	5068	114	5249	105
147.1	4756	134.4	4934	123.2	5114	113.3	5296	104.4
145.4	4801	132.9	4980	121.9	5161	112.2	5343	103.4
143	4847	130.8	5026	120.1	5207	110.6	5390	102
140.1	4893	128.2	5073	117.8	5254	108.6	5437	100.3
136.5	4939	125.1	5119	115.1	5301	106.2	5484	98.17
132.4	4985	121.5	5165	111.9	5348	103.5	5532	95.73
127.8	5031	117.5	5212	108.4	5395	100.4	5579	92.98
122.9	5077	113.2	5259	104.6	5442	96.98	5626	89.96
117.6	5124	108.5	5306	100.5	5489	93.33	5674	86.62
112.1	5170	103.6	5352	96.11	5536	89.44	5722	83.14
106.3	5217	98.47	5399	91.56	5584	85.35	5770	79.51
100.3	5263	93.2	5447	86.85	5631	81.08	5818	75.74
94.31	5310	87.82	5494	82.04	5679	76.74	5866	71.87
88.24	5357	82.39	5541	77.18	5727	72.36	5914	67.94
82.19	5404	76.96	5588	72.29	5774	67.97	5962	63.97
76.18	5451	71.6	5636	67.44	5822	63.58	6010	60.04

4874	76.48	0	200
4920	79.68	6500	200
4966	82.69		
5012	85.49		
5059	88.04		
5105	90.32		
5151	92.29		
5198	93.95		
5245	95.26		
5291	96.23		
5338	96.83		
5385	97.07		
5432	96.94		
5480	96.44		
5527	95.58		
5574	94.36		
5622	92.79		
5669	90.92		
5717	88.72		
5765	86.23		
5813	83.5		
5861	80.6		
5909	77.5		
5957	74.25		
6005	70.88		
6054	67.4		
6102	63.85		
6151	60.27		
6200	56.71		

11 - 7 CONCLUSIONS

TRC has prepared the worst-case and alternate release scenario model results using DEGADIS. The transient mode of DEGADIS was used to simulate the short duration of the releases, and this results in substantially shorter distances than the other available model results. ALOHA provides distances two or more times those provided by DEGADIS for both worst-case and alternate release scenarios.

REFERENCES

- 1 "Evaluation of Dense Gas Simulation Models," EPA-450/4-90-018, May 1991, prepared by TRC Environmental Corporation under EPA Contract 68-02-4399.
- 2 Generic Guidance Risk Management Program (RMP) for Ammonia Refrigeration Facilities, Draft for EPA, January 1996, prepared by Science Application International Corporation.