From: "ZINKE, GEORGE A" <GZINKE@entergy.com>
To: "Christian J Araguas (cja2@nrc.gov)" <cja2@nrc.gov>, "'Mark Blumberg'" <wmb1@nrc.gov>, "'Bret Tegler'" <bat1@nrc.gov>, "'kazimieras campe '" <dcampe@verizon.net>, "'Lynn Mrowca'" <lxm4@nrc.gov>, "'Margie Kotzalas'" <mxk5@nrc.gov>
Date: Wed, Mar 1, 2006 1:09 PM
Subject: GGNS ESP BARGE HAZARD SUPPLEMENTAL INFORMATION

Attached is supplemental information relating to 2/24 conference call.

Christian: (1) let me know if a conference call is needed, (2) if the info is satisfactory for formal submittal

Mail Envelope Properties (4405E339.77B : 24 : 42875)

Subject: GGNS ESP BARGE HAZARD SUPPLEMENTAL INFORMATION
Creation Date: Wed, Mar 1, 2006 1:08 PM
From: "ZINKE, GEORGE A" <GZINKE@entergy.com>

Created By: GZINKE@entergy.com

Recipients
nrc.gov
owf4_po.OWFN_DO
CJA2 (Christian Araguas)

nrc.gov
OWGWPO01.HQGWDO01
WMB1 (Mark Blumberg)

nrc.gov
TWGWPO02.HQGWDO01
BAT1 (Bret Tegeler)

nrc.gov
TWGWPO01.HQGWDO01
LXM4 (Lynn Mrowca)

nrc.gov
OWGWPO02.HQGWDO01
MXK5 (Margie Kotzalas)

verizon.net
dcampe ('kazimieras campe ')

Post Office	**Route**
owf4_po.OWFN_DO	nrc.gov
OWGWPO01.HQGWDO01	nrc.gov
TWGWPO02.HQGWDO01	nrc.gov
TWGWPO01.HQGWDO01	nrc.gov
OWGWPO02.HQGWDO01	nrc.gov
	verizon.net

Files	**Size**	**Date & Time**
MESSAGE	190	Wednesday, March 1, 2006 1:08 PM
TEXT.htm	1336	
Clarification Responses_Final Draft_2-28.doc	121856	
Mime.822	1	

Options

Expiration Date:	None
Priority:	Standard
Reply Requested:	No
Return Notification:	None
Concealed Subject:	No
Security:	Standard

DRAFT WORK PRODUCT - 2/28/2006

Supplemental Information: Grand Gulf Early Site Permit, SSAR Section 2.2, Nearby Industrial, Military and Transportation Facilities and Routes

A conference call was held on February 24, 2006 with the NRC Staff regarding the System Energy Resources, Inc. (SERI) Response to the NRC Request for Additional Information, provided via SERI letter dated February 22, 2006 (Reference 1). The following discussion provides SERI's response to the NRC clarification questions raised in the conference call.

(Note: Unless otherwise note, page references to sections, tables, and pages in the following response to the NRC's questions pertain to numbered sections, tables, and pages in the "RAI Response," that is, Attachment 1 of Reference 1.)

<u>NRC Staff Clarification Questions</u>

1. <u>Page 8, item b:</u> **While it is reasonable to rule out simultaneous explosions for multiple damaged barges, there is no apparent basis for ruling out the effects of multiple spills cumulatively developing a single vapor cloud. The key factor with respect to vapor cloud formation is that it typically can take a substantial amount of time to develop in comparison to the timing between specific hull damage and spill of multiple barges. Hence, in the vapor cloud explosion risk assessment multiple barge damage/spill effects need to be accounted for, either mechanistically or on a probabilistic basis.**

   <u>RESPONSE</u>

   Based on the above question and discussion with the NRC Staff on February 24, 2006, it is understood that the principal focus of this concern is related to an incident that damages one or more barges, resulting in a spill of contents, plume formation and drift, followed by delayed ignition. The topic of vapor cloud release and subsequent delayed ignition is discussed in most detail in Section G of the Response (analysis of plume length and potential overpressure). The probabilistic review of this subject is discussed in Section H in general, and specifically in H.4 "Plume Assessment, Plume Drift." The following response provides supplemental information on this subject.

   Some of the key factors involved in plume length determination (i.e., what distance from the spill gas plume concentrations are above the "lower explosive limit") include the amount of material available to spill and that which does spill, the time required to release the contents, the surface onto which the spill occurs (e.g., water or solid surface), and the nature of the area surrounding the damaged vessel. (Meteorological conditions are also important. This factor is discussed in more detail in response to Question 10.)

   <u>Total Mass Available.</u>

DRAFT WORK PRODUCT - 2/28/2006

As recognized in the RAI Response (p. 7), tows typically involve multiple barges. However, a reasonable bound for the total available spill quantity for this analysis was based on the largest single barge indicated in shipping history data past the ESP site in 2003 and 2004.

- Use of this recent data has the benefit of reflecting the current fleet of barges.
- In addition, as noted in the RAI Response, the largest single barge capacity is consistently larger than the average TOTAL shipment of a given commodity in a single trip past the ESP site per the U.S. Army Corps of Engineers data (p. 8).
- Considering total spill amounts in the range of 4,000 to approximately 6,000 tons, this analysis is thus dealing with marine incidents that are well beyond those reported in the review of USCG data recorded over the past 4 years.

While it is recognized that multiple barges could be involved, there are a number of factors that support the position that the total maximum amount of a single barge capacity remains a reasonable bound for the purposes of the analysis.

a. Barge design. While designs vary greatly, it is understood that river barges typically would provide six to eight separate and insoluble subcompartments. Thus, collision or other spill mechanisms would, by design, be limited to only a portion of the barges full cargo.
b. The Oil Pollution Act of 1990 (OPA-90) mandated double hulls on all newly constructed oil tankers and specified a precise retirement data for all single hulled tankers based on their age and weight at the time of the enactment of OPA-90 (Reference 2). Based on discussions with a large domestic barge operator, it is understood that a significant number of barges currently in operation are double hulled. The retirement date per OPA-90 for single hull barges is 2015 (Reference 3). Double-hull barges provide substantial added safety which minimizes spill frequency and volume.
c. The low frequency of very large spill volumes, suggested by the use of later, improved barge designs, is borne out by the analysis of the USCG spill incident data. The frequency of such large volumes is very low, per the data in Table H-1 and will become lower as the single hulled barges are retired from service.

<u>Spill Area Geometry.</u>

The analysis, using the ALOHA code, assumes the spilled material forms a puddle or very shallow pool which then evaporates. The code, based on quantity spilled and other input, predicts the pool diameter. The predicted plume length (distance to LEL) from the code is measured from the center of the pool. Due to the relative large quantities involved, the predicted pool diameter is quite large, with plume lengths up to 1.1 miles for the gasoline spill (from 5 sq. meter opening; Table G-1). The code calculates plume length based on this geometry. However, this hypothetical geometry produces conservative results for the following reasons.

a. The spill would not be into a still pool, but is into the river which has a substantial current. (Data in the ER in the ESP application {Table 2.3-1} shows river current

DRAFT WORK PRODUCT - 2/28/2006

averaged about 5 ft/sec over the course of a year in the area of the ESP site.) Some portion of the spilled material will not remain in the area of the damaged vessel(s) but will be transported downriver. While this would increase pool surface area in a southerly direction, only that amount of evaporated material captured by winds blowing toward the ESP site would contribute material to a plume. The length to LEL would, therefore, be shorter than predicted. (It is recognized that for some LNG components, which would tend to evaporate more quickly, the action of the river to move material downriver would be less significant. However, the river current would remain a conservative element to some degree.)

b. As noted by the NRC, a key consideration is the amount of time required to release vessel contents. The longer release times (as would be required for a 5000 ton or greater cargo) would translate to more material moved down river and not available for direct transport (in vapor form) from the pool toward the ESP site.
c. As noted in Tables G-1 and G-2, predicted pool diameters vary from approximately 200 yards (ethylene) to 1.1 miles (gasoline). The river channel width in the area of the ESP site, bank to bank, varies with season but is estimated to be 600 to 1000 yards. If one uses a rough value of 1000 yards, then the maximum breadth of the hypothetical pool would be constrained to 1000 yds. Therefore, for a number of materials (gasoline, pentane, benzene, toluene, and naphtha) would be smaller than the predicted size. This translates to less surface area, less evaporation, less contribution to plume material, and shorter plume lengths (to LEL).
d. The ALOHA model predicts the plume length from the center of the pool, based on the pool being centered on the spill location. The river-constrained pool would have its nearest edge 1.1 miles from the ESP site boundary, at the location assumed for the accident. Therefore, the actual pool would form in an area that expands away from the ESP site. This reservoir of evaporating material feeding the plume will actually move the "origin" of the plume farther from the ESP site than the current analysis credits.

In summary on the above discussion, while multiple barges could be involved, design features of barge compartmentalization decreases the likelihood that the entire volume of one or more damaged barges would be available to feed the spill and resultant plume. Further, the increased use on the river (by public law) of double-hull barge designs reduces the likelihood that overall material containment would be seriously jeopardized. The analysis makes conservative assumptions regarding spill pool geometry. Given the spill is in the Mississippi River, there are features of the river that would tend to reduce available pool surface area that could feed a plume directed toward the ESP site. Therefore, the use of the largest single barge capacity with a static pool for the plume drift evaluation is considered to represent a very conservative amount of material available for plume formation.

To provide additional assurance as to the impact of higher spill values, a sensitivity

DRAFT WORK PRODUCT - 2/28/2006

analysis with twice the tonnage and double the release area was performed to gain insights into impact on plume lengths and overall probability of occurrence. For multiple barge involvement, one should also address the issue of scenario. As discussed above, given barge design (with compartments) and the increased use of double hull barges, it is questionable if barges in the same tow could receive damage from a common source sufficient to provide the spill release that is being considered here. This appears even less likely considering the features of the river near the ESP site with no bridges or other navigational hazards (as discussed in response to Question 2 below). It is more likely that the necessary momentum to potentially inflict significant damage on two barges would involve two separate tows colliding. Therefore, the topic of collision risk is discussed below.

A sensitivity analysis (double the tonnage and double the release area) was conducted for gasoline and naphtha due to their relatively long plume lengths and their higher overall estimated risk for reaching the ESP site. (See Response, Table H-8). The results of the sensitivity study are provided below.

Gasoline (n-heptane)

LEL (ppm) = 10,000

Pool diameter = 1.1 mi

Barge Capacity (tons)	Hole Size (m^2)	Stability Class	Windspeed (m/sec)	Ground Roughness	Distance to LEL (mi)	Concentration at 1.1 mile from pool center (ppm)	Overpressure at 1.1 mile from pool center (psig)
5,654	5	D	1.55	Open	1.3 miles	12,000	0.517
11,308	10	D	1.55	Open	1.7 miles	22,600	0.953
11,308	10	D	1.55	Urban/Forrest	1.2 miles	9,170	0.551

Naphtha (n-Hexane)

LEL (ppm) = 10,500

Barge Capacity (tons)	Hole Size (m^2)	Stability Class	Windspeed (m/sec)	Ground Roughness	Distance to LEL (mi)	Concentration at 1.1 mile from pool center (ppm)	Overpressure at 1.1 mile from pool center (psig)
5654 (note 1)	5	D	1.55	Open	1.9 miles	29,000	0.953
11,308	10	D	1.55	Open	2.6 miles	50,300	0.953
11,308	10	D	1.55	Urban/Forest	1.9 miles	19,700	0.924

As seen above, doubling the barge size (i.e., the amount spilled) and the hole size results in a longer gasoline plume. ALOHA allows two basic ground roughness (terrain) scenarios, either "open country" or "urban/forest" to characterize surface roughness. This is discussed in more detail below (Question 10). Selecting the urban/forest roughness, serves to more accurately characterize the forested areas between the assumed spill site and the ESP site and reduces the plume length to approximately that of the currently analyzed single barge accident. However, to provide a consistent basis of comparison, the risk impact is evaluated with and

DRAFT WORK PRODUCT - 2/28/2006

without credit for increased surface roughness due to forested area around the ESP site.

In regards to the impact on overall risk for gasoline, it is noted that doubling the mass and release size increases the plume length from 1.3 to 1.7 miles. This would increase the "at-risk" path length from $2*(1.3^2-1.1^2)^{0.5}$ = 1.39 miles to $2*(1.7^2-1.1^2)^{0.5}$ = 2.59 miles. Since the length is a term in the risk calculation, this would tend to increase risk by a factor of 2.59/1.39 = 1.9. However, this event would require the additional low probability of a second concurrent spill. If the spill results from a vessel colliding with a second vessel, the probability that the second vessel is also carrying a plume-generating cargo, can be approximated by the ratio of such vessels to all Mississippi River traffic, or less than 0.1. The product of increased risk from longer plumes times the low probability of a dual spill collision = 1.9*0.1 = 0.2 shows that the relative risk from such an event is small compared to the risk of a single vessel event, even though the plume may be longer (assuming no credit for ground roughness).

In regards to the impact on overall risk for naphtha, it is noted that doubling the mass and release size increases the plume length from 1.9 to 2.6 miles (without considering surface roughness). This would increase the "at-risk" path length from $2*(1.9^2-1.1^2)^{0.5}$ = 3.1 miles to $2*(2.6^2-1.1^2)^{0.5}$ = 4.7 miles. This would tend to increase risk by a factor of 4.7/3.1 = 1.5. For this case, the product of increased risk from longer plumes times the low probability of a dual spill collision = 1.5*0.1 = 0.15 shows that the relative risk from such an event is small compared to the risk of a single vessel event, even though the plume may be longer (assuming no credit for ground roughness).

The other possibility is that an accident of some sort impacts two barges that are being towed in tandem. It is difficult to imagine a mechanism for such an event on the Mississippi River near the ESP site, particularly for these relatively safe vessels in the absence of allision targets. The event would need to not only involve multiple barges, but it must also involve rare and significant major damage to each. So long as the conditional probability of a second barge being opened and drained is less than 1/1.9 = 0.5, and that appears intuitively obvious, the risk of multiple barge accidents is less than that from a single barge, even though the plume may be longer (assuming no credit for ground roughness).

It should also be noted that, in the RAI Response analysis, the ALOHA code analyses were made assuming "open country" for ground roughness. This is conservative since once the plume makes land fall on the riverbank, vegetation and trees would tend to offer increased surface roughness, generating mechanical turbulence and favoring greater dispersion and shorter plume lengths. This is confirmed by sensitivity runs assuming the urban/forest setting for ground roughness. Note that even with double the amount spilled and release area, the

DRAFT WORK PRODUCT - 2/28/2006

plume lengths are essentially the same as the RAI Response values if surface roughness is considered

Variations on meteorological conditions are discussed in response to Question 11.

2. **<u>Page 14, Summary of Confined Space and Local VCE Analyses:</u> What is the basis for the view that the referenced "short stretch of river" is considered to be a "safe" section? How is the attribute "safe" used in the risk assessment?**

<u>RESPONSE</u>
As noted on page 14, reference is made to Section H regarding "features of the river." See discussion at pages 16 and 23 (along with aerial photograph, Figure H-1) and Item 4 on page 25.

In general, the RAI Response is specifically addressing the several mile stretch of the Mississippi River, adjacent to the ESP site. The view offered in the RAI Response that this portion of the river is relatively safe is founded on the features described in Item 4 (page 25). Further, as noted in Item 4, the USCG marine incident database was reviewed to determine if incidents were reported for this area. The review, looking at an approximate 4-mile run from north latitude 31°59' to 32°03,' identified no spill events.

This attribute (a relatively safe portion of the river) was used very conservatively in the risk assessment because it is recognized that it is a difficult feature to quantify. No numeric credit at all is given in the detonation section. A factor of 0.5 is used in the plume section (Item 4, page 34), since while the detonation analysis (Section F) makes no assumption about the time to spill the contents, the analysis of plume drift (Section G) assumes a fast rate of spillage and, therefore, a more dramatic accident. The main purpose of noting and crediting this factor is to recognize the intuitive fact that accidents should be more likely where there are bridges or active ports rather than on a stretch of river that is relatively straight with few potential hazards to navigation (as discussed on pages 16, 23, and 25).

An additional factor in overall safety of navigation relates to tow operational practices and features that tend to support and enhance safety, as discussed with the NRC Staff in the conference call of February 24, 2006. To gain further insight into this, a representative of a major domestic river-barge operator was contacted. It is understood that in addition to following the required "rules of the road" per USCG requirements for inland waterways, tow captains radio their position at designated points along the river course, and they communicate with other approaching tows in their vicinity to provide assurance that each captain understands the intent of the other when vessels are passing on the river. GPS is being introduced in the fleets to assist in more precise location information. Radar is standard equipment, and typically tow captains would slow or stop in severely limited visibility situations, thus further improving navigational safety under such conditions. Such practices and

DRAFT WORK PRODUCT - 2/28/2006

equipment would be considered applicable to the river transportation near the ESP site.

3. Page 16: **The observation of zero events corresponds to what time interval?**

RESPONSE
The subject review of USCG incident database (see page 25, Item 4) applied to records for the last 4 years (from December 2001 through 2005).

4. Page 22, 2.1 Spill Frequency Assessment: **What is the basis for excluding spills involving commodities such as chlorine, coconut oil, diesel, lubricating oil ,etc? It is reasonable to expect a spill being the result of some sort of loss of tankage integrity (e.g., puncture, rupture). Hence, there is no apparent functional relationship between the type of commodity and the initiation of a spill in the event of a barge mishap. Exclusion of spills on the basis of commodity type can lead to a significant underestimating of the spill frequency.**

RESPONSE
There are two ways to have approached the spill frequency. One is on a spill per vessel basis. Then it would make sense to include all spill types, generate a per vessel frequency, and then multiply by the number of vessels. This is not what was done in the analysis of Reference 1. Rather, a spill of combustible contents per river mile frequency was calculated. The advantage of this approach is that it is not necessary to know the number of vessels involved. If, in the approach of Reference 1, a total spill per river-mile frequency was calculated by including chlorine, coconut oil, diesel, lubricating oil, etc., the results would then have to be multiplied by the portion of spills that involved the commodities of interest (e.g., gasoline, benzene, etc.), and the exact same final result would have been obtained. That is, the spill frequency may go up by a factor of X, but the portion involving materials of concern with would be 1/X, and these numbers would be multiplied together.

The question might then be asked why incident data for distilled fuel oil (DFO) was included in the analysis of spill frequency. DFO was included initially because it considered to be a possible plume or detonation source. Once DFO was out of the plume and detonation calculations, consideration was given to removal of DFO spill incident data from the spill database. However, the additional DFO spills (128 out of 255) are effectively cancelled out when multiplied by the fraction of vessels containing gasoline, benzene, etc. Since the DFO spills amounted to 128/256 (0.50 of the total) and the percentage of DFO is 0.40 of the total quantities shipped, it is conservative to keep the DFO data.

As an example, consider the spill frequency versus tonnage relationship developed

DRAFT WORK PRODUCT - 2/28/2006

in the RAI Response text (Section H). If the total number of spills in each bin is ten times greater, then the curve fit will be an order of magnitude greater ($f = 10*10^{(-0.4871*LOG(tonnage)-2.7457)}$). But then, when determining the fraction of spills that are one of the critical commodities, a multiplication factor of 1/10 would be applied, providing the same equation, $f = 10^{(-0.4871*LOG(tonnage)-2.7457)}$ again.

Of course, the new spills may not increase each bin total by an identical ratio. If the new spills tended to be of a smaller size, they would tilt the curve fit such that it would have a more negative slope. Evaluation of diesel spills (all spills in the MisleVslPoll database identified as diesel, some 2102 spills), show this is the case. A plot of curve fits to diesel spills and to the commodities previously identified is shown below. Since the diesel curve fit is steeper, it would be non-conservative to include diesel spills.

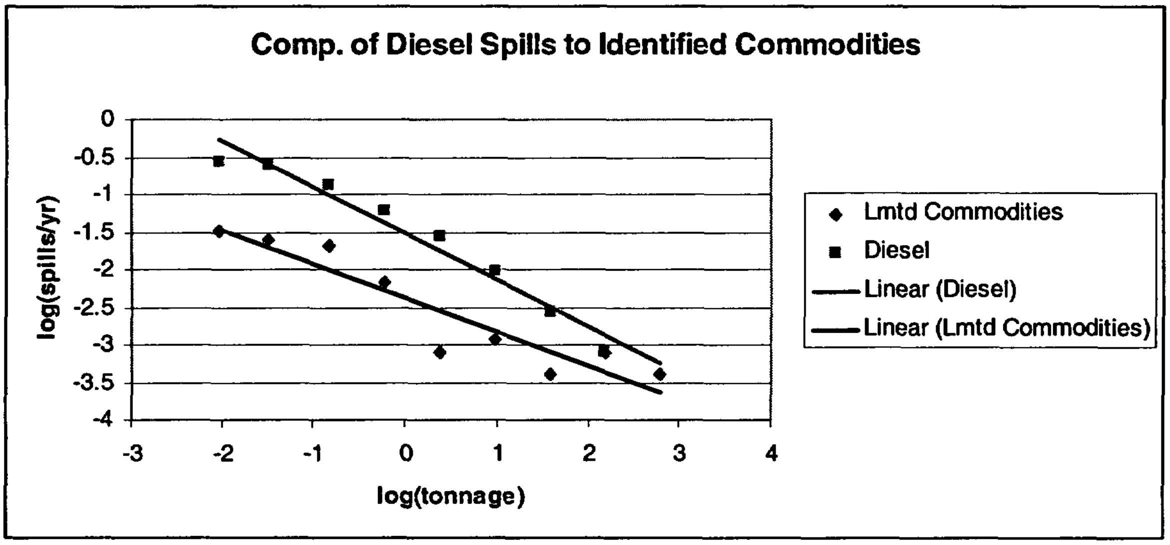

Figure: Comparison of Spill Frequency of Identified Commodities of Concern on the Mississippi River to Diesel Spills on all U.S. Navigable Waters. Note: since the diesel spills are not confined to the Mississippi River, the scale is changed to Spills/yr rather than Spills/river-mile-yr as in the submittal. The only comparison to be made here is in the relative slopes. The steeper diesel slope implies that if diesel spills were included in the spill vs. frequency calculation, and then that result were to be multiplied by a percent gasoline, etc., the net result would be non-conservative for large spills.

5. **The consideration of type of navigational waters can have a bearing on the barge mishap (e.g., collision, grounding) initiation frequency. However,**

DRAFT WORK PRODUCT - 2/28/2006

exclusion of spills not occurring on the Mississippi is not appropriate, since the type of navigational waters has no apparent connection to the likelihood of spill initiation.

RESPONSE

In general, the overall goal in studying marine incidents was to establish the relationship between spill frequency and spill quantity in order to gain risk insights into the occurrence frequency for the significantly large spill that is considered in the analysis of transportation risk near the ESP site on the Mississippi River. Data gathering was, therefore, focused on a research of the USCG incident database to obtain data that was most reflective of the transportation of (hazardous) materials by barge on a major river route.

While larger, deep draft ships are recognized to share a number of similar qualities that may lead to spills, fires, or explosions, these vessels typically see potentially much more hazardous weather and navigational challenges while at sea and along coastlines. Ships typically would carry considerably larger cargoes, travel at greater average speeds, and represent, therefore, substantially more momentum that could play a role in collisions with other ships or objects (such as submerged rocks or other obstacles). The narrowed focus for incident data gathering on the major river routes of the Mississippi and Ohio Rivers is considered appropriate and justified in that incidents on these rivers would be most indicative and characteristic of river conveyance by barge. Such data, restricted to river transportation events, should reflect those barge designs, operator performance, operating practices, and aspects of river navigation that would be unique and most associated with river transportation. Further, a review of US Corps of Engineer shipping data (Waterborne Commerce Statistics Center) indicated that in 2004, the combined cargo (all commodities) shipped on the Mississippi and Ohio Rivers represented almost 60% of the total domestic waterborne traffic. This is considered an adequate portion of total traffic upon which to base an assessment of river spill frequencies.

The type of spills of concern here requires very large flow rates, for example, ripping a 5 m^2 hole. It is apparent that such a large spill would require both a large accident and a large vessel. Including ocean-going vessels would include tankers running aground, and so on, greatly and unfairly increasing the incidence of large spills. Furthermore, in this analysis, the spill frequency is divided by the mileage of the Mississippi River (in a conservative fashion, since we also include events on other rivers). If we were to consider all navigational waters, we would also have to include some measure of their length, which becomes complicated for ocean-going trips. Finally, the Mississippi is a soft-bottom river with well established safety practices, no tidal concerns, no rough seas, no rocky shores, etc., and it is reasonable to credit these features.

6. Page 25: **It is appropriate to exclude spills from fixed storage facilities, since**

DRAFT WORK PRODUCT - 2/28/2006

the mechanisms for spill initiation can be significantly different from those associated with barge mishaps. However, with respect to shipping accidents, as noted previously, spill frequency does not have any apparent dependency on the type of navigable water, so the entire database of 47 spills should be considered.

RESPONSE

In general, the database of 47 spills is considered inappropriate for incorporation in the collection of river/barge spill events, for reasons stated above. These 47 spills (of over 100,000 gallons) came from a database that included both facilities and vessels. In reviewing available data, it was determined that much less than 47 spills (greater than 100,000 gallons) were associated with vessels. In any case, to properly treat data associated with large spill events recorded in U.S. waters, some sort of conversion to a per mile basis would be needed, such as dividing by the total length of navigational waters. Given that one would presume that the total length of miles navigated would be relatively much greater than the length of miles associated with the Mississippi and Ohio rivers, identification of a few large spills in U.S. waters would not have a significant effect on the spill rate per river mile.

7. **Page 31: (a). Limiting spill data to the Mississippi and Ohio rivers is inappropriate. The geographic location of the spill does not have any effect on the likelihood of it leading to a vapor cloud explosion. By restricting the estimate to just the one BLEVE event may seriously underestimate the probability of explosion per spill**

RESPONSE

The key is that this is a rate of explosions (involving the entire contents) per spill. If other explosion locations are to be included, the number of spills must be proportionally increased. The data is that 255 spills are in the database, and none are associated with an explosion. We consider it conservative to assume the one BLEVE event is associated with a spill in order to generate a non-zero rate. In point of fact, the value we generate is 1 per 128 spills, or roughly 0.008 explosions/spill. That appears to be a fairly conservative rate. As a check, consider that the US department of Transportation Facts 2001 (Reference X) reports that only 0.001 of traffic accidents result in a fire, much less, an explosion.

Further investigation involved the use of the 1980 to 1991 database vcas.txt (Reference X). This database was used because it identifies explosions of the cargo within its descriptor fields. Searching the 68,595 events revealed 74 cargo explosions and 17,529 collisions. However, many of these are duplicate records, so eliminating the duplications reduced the total number of cargo explosions to 52. The primary nature of the explosions were:

allisions: 1 (caused by personnel fatigue)

DRAFT WORK PRODUCT - 2/28/2006

capsizing: 1 (caused by improper loading)
collision: 3 (operator error; failure to account for current; unsafe speed)
fire: 1 (unknown cause)
Floundering: 1 (Inadequate fire fighting equipment)
Explosion was primary cause: 45

The detailed causes of the 45 explosions as primary cause were:
Lightning: 2
Faulty design: 1
Improper storage/loading: 3
Improper safety procedures: 3
Improper maintenance: 1
Improper Safety Precautions: 4
Inadequate supervision: 1
Smoking: 2
Service condition exceeded: 1
Failed material/mechanical: 1
Failed material/structural/fatigue: 1
Failed material/other: 2
Improper welding: 1
Inadequate fire fighting equipment: 1
Static Electricity: 2
Improper securing: 1
Unknown: 18 (secondary causes: static electricity 6; smoking 1; improper maintenance 1; safety procedures 1; faulty lights 1; and no secondary cause 8)

A conservative grouping would combine the allision, capsizing, collisions, failed material, and unknown without secondary cause explosions and associate them all with a spill event. This amounts to 17 explosions possibly related to spills in the period from 1980 to 1991 (11 years) for all US waters. The total number of spills from vessel in all US waters in a 4-year period from the MisleVslPoll file is on the order of 5681 events. Extrapolating to 11 years gives about 15,600 spills. This gives a conditional probability of 17/15600 = 0.001 explosions/spill. This is an order of magnitude smaller than the value used in the analysis of Reference 1.

8. <u>Page 31: (b).</u> **The factor of ten reduction appears to be arbitrary. One could just as easily select a factor of two or a factor of a hundred.**

<u>**RESPONSE**</u>
This factor pertains, in general, to establishing a value for the probability that if the cargo contents are spilled, they are all involved in a detonation (page 29). The subject reduction factor (of ten) specifically applies to the concept that if a detonation were to occur, that the full content of material would be effectively

DRAFT WORK PRODUCT - 2/28/2006

involved.

As is often common in this type of risk assessment, this is an element that is clearly important in a common sense fashion, but difficult to quantify. The subject factor of 10 reflects the fact that the overall approach in estimating the explosion size is highly conservative. The maximization of energy from the detonation of a certain quantity of flammable fuel would involve both perfect mixing of all the fuel with oxidant (air) prior to combustion or dispersion, followed by an ignition source. While a larger factor could have been chosen, a factor of ten is considered a minimum reduction reflecting the extremely low likelihood that all the cargo would be involved in a subsequent explosion.

For example, significant traffic accidents involving automobiles are quite common. A typical auto's gasoline tank contains approximately 20 gallons of fuel. Calculations show that this amount of gasoline (at a 10% yield factor) is roughly equivalent to 130 pounds of TNT. However, even with the high frequency of significant automobile accidents, the events in which the crash leads to a detonation that approaches something close to over 100 pounds of TNT is quite rare. In similar fashion, it is reasonable and conservative that appropriate dispersion of such a significant amount of fuel, perfect mixing, and presence of a timely ignition source would happen no more frequently than one out of ten. (See also discussion on page 30 for additional points as to why a decrease of an order of magnitude is considered conservative.)

9. **Page 16: "The potential for deflagrations in a plume resulting from a barge accident was evaluated using the ALOHA (Areal Locations of Hazardous Atmospheres) computer program..." The staff would like further clarification as to the use of the ALOHA code specifically relating to:**

   Page 16: (a). The ALOHA code models pure chemicals that are not mixed such as chlorine, anhydrous ammonia and propylene. Common mixtures or solutions such as most petroleum products including gasoline and aqueous ammonia are not contained in ALOHA.

   RESPONSE
   For the ALOHA simulation runs, certain hazardous commodities that are mixtures were modeled as single components. This is a necessity due to the nature of the software, but it is also a reasonable simplification. Critical parameters evaluated in ALOHA are heat of combustion, molecular weight, and lower explosion limit (LEL). By identifying single components that closely match the mixture in these properties, an appropriate surrogate can be identified. Four commodities, which are mixtures, are evaluated using single component surrogates – gasoline (modeled as n-heptane), naphtha (modeled as n-hexane), ammonia (modeled as anhydrous ammonia, rather than aqueous ammonia), and acetylene (modeled as pure acetylene rather than 98% acetylene in acetone).

DRAFT WORK PRODUCT - 2/28/2006

Gasoline

Gasoline has an average molecular weight of 95 to 98 (Ref. 7), a heat of combustion of 110,000 Btu/gal (40,900 kJ/kg) (Ref. 8, Fig 9.4), and an LEL of 1.4 % (Ref. 9). Further, major components of gasoline include normal alkanes (e.g., n-heptane), branched alkanes (e.g., iso-octane), aromatics (e.g. toluene), and a lesser quantity of cyclic alkanes and olefins. Normal heptane and iso-octane are commonly used separately or blended to simulate gasoline in laboratory conditions.

Normal heptane has a molecular weight of 100, a heat of combustion of 118,000 Btu/gal (43,800 kJ/kg) (Ref. 10), and an LEL of 1.05 % (Ref. 11). This is a better match than iso-octane (MW=114, HC=119,000 Btu/gal, LEL=1.1%, Ref. 10 and 12), n-hexane (MW=86, HC=115,000, LEL=1.2%, Ref. 10 and 13), or toluene (MW=92, HC=133,000, LEL=1.3%, Ref. 10 and 14).

Additionally, other components of gasoline are evaluated as their pure components – benzene and toluene, pentane (as a representative acyclic hydrocarbon)and n-hexane (as a surrogate for naphtha) are all evaluated.

Naphtha

Naphtha is approximately equal parts pentane, hexane, 2-methylpentane, and heptane (Ref. 15). Averaging the molecular weight of these normal and branched alkanes provides an average molecular weight of (73+86+86+100)/4=86.25. The heat of combustion of naphtha varies depending on the composition, but is on the order of 128,000 Btu/gal (Ref. 4), and the LEL is about 2.5 % (Ref. 15).

As noted above, n-hexane properties (MW=86, HC=115,000, LEL=1.2%, Ref. 10 and 13) are a reasonably good match, with the lower LEL being conservative. 2-Methylpentane will behave very similar to hexane, both being normal six carbon alkanes, and between the two components are approximately 50% of the constituents of naphtha. Of the remaining components, heptane (MW=100, HC=118,000 Btu/gal, LEL=1.05 % Ref. 4 and 5) is evaluated as a surrogate for gasoline and pentane (MW=72, HC=4,260 kJ/kg=101,000 Btu/gal, LEL=2.5 % Ref. 16 and 17) is evaluated for acyclic hydrocarbons.

Ammonia

Anhydrous ammonia is a chemical feedstock and is used as a fertilizer. It is a gas at ambient conditions (BP= -28°F, Ref. 18), so is shipped under pressure (the vapor pressure is 93 psi at 60°F; and nearly 200 psi at 100°F). Ammonia is also commonly shipped in an aqueous solution (up to about 30% NH_3) at ambient conditions. The available shipping data does not distinguish between the two commodities.

ALOHA models an ammonia spill as a pure component, i.e. anhydrous ammonia. As a result, the ammonia is assumed to escape as two-phase flow, thus maximizing the quantity of ammonia in the air. Anhydrous ammonia liquids that reach the surface of the MS River will no longer be anhydrous, will be dissolved into the water and will behave thereafter as aqueous ammonia.

Aqueous ammonia can give off ammonia vapors, particularly when the ammonia is

DRAFT WORK PRODUCT - 2/28/2006

near the solubility limit of the solution. However, dilute solutions will tend to allow only a small quantity of ammonia to evolve (similar to the vapor pressure of water) due to molecular interactions between the water and ammonia molecules (hydrogen bonding due to van der Waals forces). Therefore, anhydrous ammonia liquids which are dissolved and diluted in the huge quantity of river water, or aqueous ammonia solutions spilled in the river are both physically unable to evolve a significant quantity of ammonia and will not be able to support a vapor phase concentration above 16% -- the LEL for ammonia (Ref. 19).

Since ALOHA models the ammonia as an anhydrous liquid that flashes on release and does not interact with the water surface, it provides an extremely conservative model for flammable plume and VCE evaluation.

Acetylene

Similar to aqueous ammonia, acetylene is commonly shipped in solution in acetone. Through similar arguments to those presented for ammonia, assuming pure acetylene, flashing as it exits the vessel, is quite conservative. In this case, however, the acetone solvent will pool and be dissolved into the river, largely releasing the acetylene, and the evaluation of a pure acetylene product is appropriate and not overly conservative.

10. **Page 16: (b). The ALOHA code does not model hilly terrain such as that of the bluff located at the ESP site.**

RESPONSE

The statement that the ALOHA code does not model hilly terrain is correct. The dispersion models used in ALOHA are inherently flat-earth models, and perform best over regions of transport where there is minimal variation in terrain. As noted in the DOE guidance report, ALOHA has a recognized limitation in not modeling steering effects from terrain, such as a canyon that would tend to limit plume width (Table 1, Reference 6). However, the code does recognize the impact of variances in surface roughness. The RAI Response analysis (Reference 1) selected the "open field or open terrain" input option which conservatively assumes the minimum ground roughness. This translates to minimum mechanical turbulence which would increase downwind dispersion. In fact, in the case at the ESP site, vegetation and tree growth on the site could be considered to resemble the other input option, that is "urban / forest" which models the contributions of greater turbulence. Sensitivity analyses were conducted (Question 11 response) using the urban/forest option, resulting in suggested shorter plume lengths, as would be expected, based on an increased turbulence. ALOHA does not currently support other variations, such as elevation differences. While arguments could be made for shorter plumes (due to surface roughness), conclusive statements can not be offered regarding terrain differences. The overall conservative nature of assumptions in treating meteorological conditions is discussed below. In addition, as shown below, the sensitivity study shows that, even for longer plumes (resulting from much more stable conditions), the RAI Response conclusions regarding low risk to the site are

DRAFT WORK PRODUCT - 2/28/2006

supported.

11. <u>Page 16: (c).</u> **Page 16 states: "For each commodity of interest, the vapor dispersion was determined based on a wind speed of 1.55 m/sec, a stability class of D, and a 90 degree Fahrenheit ambient air temperature. Were there any sensitivity studies performed to make the determination that these values are limiting for determining a conservative dispersion.**

<u>**RESPONSE**</u>

Per Section G of the RAI Response:

> For each commodity of interest, the vapor dispersion was determined based on a wind speed of 1.55 m/sec, a stability class of D, and a 90°F ambient air temperature. The combination of a high Stability Class, which would be expected during nighttime hours, with a high ambient temperature, which would be expected during daytime hours, is a deliberate conservatism. These meteorological conditions were chosen to maximize the vaporization rate of the commodity of interest while limiting the downwind dispersion.

This basic approach used in selecting meteorological conditions combined certain parameters not normally likely (collectively and simultaneous), thus providing an overall degree of conservatism but at the same time, not representing the most severe conditions. This provided reasonable bounds for meteorological conditions that were not overly penalizing. For example, the wind speed selected (1.55 m/sec) is slightly lower than the average 33 ft windspeed of 1.87 m/sec at the site for the years 1996 – 2003 (see SSAR Table 2.3-1). Stability Class D was selected since normally this is the most common stability classification due to the large number of combinations of cloud cover and windspeed that can result in Stability Class D. In addition, the increased dispersion due mechanical turbulence induced by ground roughness was conservatively neglected by choosing the rural terrain option of ALOHA. Additional factors contributing to the overall conservative nature of the analysis include the following.

- Ambient air temperature was assumed to be 90°F (which would only occur during daytime hours while the selected stability class "D" would only occur during nighttime or early morning hours).
- River temperature was set at the relatively high value of 83°F, surrounding the ruptured tank. [Note: This reflected the average mean temperature for July for 1988-92 for the lower Mississippi River at New Orleans.]
- Constant windspeed and direction was assumed throughout the release duration.

The ALOHA guidance report (Reference 6) recommends using the dominant characteristic of the terrain that surrounds the postulated release and receptor distances of interest. Following this guidance, urban or forest terrain would be

DRAFT WORK PRODUCT - 2/28/2006

selected whenever more than 50% of the surrounding terrain is urban or forest. To quantify the effect of these conservatism's, several sensitivity cases were performed from gasoline and naphtha base cases. These cases are documented below.

Gasoline (n-heptane)
LEL (ppm) = 10,000
Pool diameter = 1.1 mi

Barge Capacity (tons)	Hole Size (m^2)	Stability Class	Windspeed (m/sec)	Ground Roughness	Distance to LEL (mi)	Concentration at 1.1 mile from pool center (ppm)	Overpressure at 1.1 mile from pool center (psig)
5,654 (Base Case)	5	D	1.55	Open	1.3 miles	12,000	0.517
Case 1	5	D	1.55	Urban / Forest	1.0 miles	502	0.312
Case 2	5	F	1	Open	1.7 miles	1,340	0.243
Case 3	5	F	1	Urban / Forest	1.3 miles	more than 1 hour downwind	0.177

Naphtha (n-Hexane)
LEL (ppm) = 10,500

Barge Capacity (tons)	Hole Size (m^2)	Stability Class	Windspeed (m/sec)	Ground Roughness	Distance to LEL (mi)	Concentration at 1.1 mile from pool center (ppm)	Overpressure at 1.1 mile from pool center (psig)
5654 (Base Case)	5	D	1.55	Open	1.9 miles	29,000	0.953
Case 1 (note 1)	5	D	1.55	Urban / Forest	1.5 miles	1,040	0.3
Case 2 (note 2)	5	F	1	Open	2.9 miles	23,800	0.757
Case 3 (note 2)	5	F	1	Urban / Forest	2.1 miles	7070 (Note 3)	0.489

Note 1: Pool diameter (yards) = 1502 Distance from pool center to site = 1.53
Note 2: Pool diameter (yards) = 1587 Distance from pool center to site = 1.55
Note 3: Max Concentration:(in the first hour)
Pool diameter for 11,308 ton barge = 1.1 mi

"Base case" is used above to reflect the RAI Response analysis assumptions. As seen above, taking credit for the forest between the release point and the ESP site reduces the plume length (Case 1). The sensitivity study using more stable weather conditions (Stability Class F and 1 m/sec windspeed) resulted in an increase in the plume length (Case 2); however, when credit is taken for the surface roughness between the release and the site (Case 3), the plume length is the same as the gasoline base case and for naphtha slightly longer than the base case.

The ALOHA code calculated plume length from the center of the hypothetical spill (or pool) to the point where downwind concentrations fall below the LEL. The RAI Response analysis, using ALOHA, was based on the very conservative assumption

DRAFT WORK PRODUCT - 2/28/2006

that the spill was on the river edge (eastern bank) closest to the ESP site. For example, in the gasoline spill case, the ALOHA code predicted spill pool diameter of 1.1 miles. Thus, the theoretical edge of the pool would be 0.55 miles inland toward the site (a physical impossibility) since the pool is constrained by the riverbank. In reality, the pool formed from a spill at this location would disperse downstream and away from the riverbank. If river currents are neglected, and considering the average width of the river is approximately 800 yards (0.45 miles) along the length of the site boundary, the gasoline pool formed would have a center point about 0.22 miles from the river bank (mid-channel) giving a distance from the pool center point to the ESP site of (1.1 + 0.22) = 1.32 miles. Except for LNG, acetylene and ammonia, the formed pools (from the ALOHA output) span the width of the river at the site. (It is recognized that the river width varies and can be greater than 1000 yards. However, the overall point is that, based on ALOHA's method, the starting point of the predicted plume would be offset some distance to the west, away from the ESP site, contributing added conservatism to the results.)

The risk implication of assuming Class F stability was also evaluated. Gasoline and naphtha were selected for this sensitivity analysis due to the longer plume lengths and risk values predicted in the RAI Response (Reference 1).

Overall, as shown in the results provided below, Class F in concert with lower wind speeds predicts a longer plume for gasoline. However, the impact of the longer plume on overall risk is offset by the lower likelihood of the necessary meteorological conditions. Crediting the rough terrain and the reduced "met probability" provides a net risk benefit for gasoline plumes.

Gasoline

Mass	Frequency	Stability Class	Plume Length	At-risk Length	Conditional Probability	Meteorological Condition Probability	Total Risk
5654	5.94E-06	D	1.3 mi	1.39	0.07	0.06	3.45E-08
5654	5.94E-06	F	1.3 mi	1.39	0.07	0.0425	2.45E-08

* hole size assumed to be 5 m^2

The results for Naphtha assuming Class F stability are different, because the plume length is longer even crediting the urban/forest terrain. The impact of the longer plume causes a small increase in risk for naphtha plumes; however, the increase is insufficient to affect the conclusions of low total risk.

Naphtha

DRAFT WORK PRODUCT - 2/28/2006

Mass	Frequency	Stability Class	Plume Length	At-risk Length	Conditional Probability	Meteorological Condition Probability	Total Risk
5654	1.82E-06	D	1.9 mi	3.10	0.07	0.06	2.368E-08
5654	5.94E-06	F	2.1 mi	3.58	0.07	0.058	2.658E-08

* hole size assumed to be 5 m^2

Based on these sensitivity studies, the meteorological conditions used in the base case analysis provide a reasonably conservative basis for plume assessment.

12. Pg 13, table F-1, Note 3 states that LNG, when unconfined is highly unlikely to experience a VCE. **[This is a true statement, but should not be used as a basis to not analyze the case. There is a reference an 2002 VCE event that appears to involve an unconfined VCE].**

RESPONSE

In order for an LNG detonation (and associated overpressure) to occur from an unconfined vapor cloud, it is necessary that the vapor cloud be within the narrow range of flammability limits, and a sufficient quantity of energy must be imparted to initiate the detonation. This energy may come from either the original initiating (ignition) source or from a concentration of the energy expressed by the combustion through obstacles and/or confinement. If the energy comes from obstacles/confinement, it creates an acceleration of the flame and transitions from a deflagration (sub-sonic combustion) to a detonation (supersonic combustion).

In review of the ignition energy required to initiate a LNG detonation, the Sandia National Labs guidance document on LNG (Ref. 4) references the 1978 USCG China Lake Tests wherein an explosive charge of 37 kg of explosive was required to initiate detonation – smaller charges and spark ignitions would not initiate detonation (Ref. 4, page 127). For methane-propane mixtures, a 1 kg explosive charge was required. In the 1979 Vander Molen and Nicholls tests, the addition of ethane to a methane-air mixture reduced this to a few grams of condensed explosive (Ref. 4, page 127). This is still a greater energy level than will be available from a spark ignition that might be found around an barge accident or at the plant site. An unconfined LNG vapor cloud explosion resulting from an initiating ignition source is not a credible accident scenario.

Nor is a deflagration to detonation transition (DDT) a credible accident scenario to result in an unconfined VCE. While the Sandia study does note that one researcher states DDT "is likely with confinement and the presence of obstacles" (Ref. 4, page 127), it proceeds to document this researcher's and others' work examining DDT and flame acceleration. The maximum reported achieved flame acceleration, with confinement and obstacles, was 130 m/s (Ref. 4, page 128), a Flame Mach number of $M_f = 0.4$. The Sandia study also documents the 1999 work of Tang to update the Baker-Strehlow blast overpressure curves (Ref. 4, page 156). From this curve and for a $M_f = 0.4$, a maximum positive overpressure ratio of 0.2 (from atmospheric conditions, 14.7 psi x 0.2 = 3 psid) can occur near the cloud. Near the ESP site, a

DRAFT WORK PRODUCT - 2/28/2006

value of

$R/(E/P_0)^{1/3}$=

where R = 1.1 miles = 1,800 m

E = 5,000 tons TNT (4680 kJ/kg) = 21.23×10^{12} J

P_0 = 1 atm = 101,325 Pa

$R/(E/P_0)^{1/3}$= 3.0

provides an overpressure ratio of 0.03 (from atmospheric conditions, 14.7 psi x 0.03 = 0.44 psid). Due to the slow deflagration that occurs even with maximum laboratory induced flame acceleration, it is not credible that an overpressure in excess of 1 psi will occur at the site.

It is noted that the terrain between the river and the ESP site does not present confinement other than the barge itself that is evaluated for a confined VCE. Nor does it present obstacles other than trees. The wooded nature of the terrain between the river and the ESP site could encourage flame acceleration, but not beyond that obtained under laboratory conditions, evaluated above.

Reference was made by the NRC in the February 24 telecon to the VCE that occurred in Brenham, Texas in 1992 (Ref. 5) (no reference to a 2002 event is made). The scenario resulting in the Brenham explosion was a leak of an ethane-propane-butane gas mixture from a salt dome storage facility – not an LNG leak with a large methane content (The methane content can range from 75% for pipeline quality, up to 95%, as discussed in Attachment 2 of the RAI Response, Reference 1). The heavier than air propane and butane clung to the ground and collected in low-lying areas where they eventually were ignited from a spark ignition source (an automobile). The lighter, more readily detonable, ethane, which had formed a layer on top of the heavier gases, was then detonated by the energy release from the heavier gas combustion, causing subsequent detonations in confined gas collections and in the remaining pockets of heavier gases. The quantity released is estimated at 3,000 to 10,000 barrels (300 to 1,000 tons) and resulted in damage to residential structures up to approximately 2 miles away from the release point.

This is a quite different scenario than any that would result from a postulated LNG spill on the river near the ESP site. The material involved is not LNG, but rather a mixture of volatile hydrocarbon gases, some of which are less prevalent components in LNG. The release destroyed structures in which it gathered and was confined (as the confined VCE in the barge was evaluated). The vapor cloud detonated due to a separation that essentially created a blasting cap (the heavier components) which initiated a detonation in the ethane. LNG is not known to undergo such a separation due to the relatively small quantities of the heavier gases.

DRAFT WORK PRODUCT - 2/28/2006

REFERENCES:

1. "Response for Request for Additional Information Regarding the Grand Gulf Early Site Permit Final Safety Evaluation Report," Entergy letter to the NRC, CNRO-2006-00011, dated February 22, 2006
2. "Statement of Ms. Cynthia L. Brown, President, American Shipbuilding Association," before the House Committee on Transportation and Infrastructure Subcommittee on Coast Guard and Maritime Transportation, June 29, 1999.
3. "Tank Barge Market Report," Marcon International, Inc., December 2005.
4. SAND2004-6258, Guidance on Risk Analysis and Safety Implications of a Large Liquefied Natural Gas (LNG) Spill Over Water, December 2004.
5. NTSB Report No. PB93-916502, Pipeline Accident Report, Highly Volatile Liquids Release from Underground Storage Cavern and Explosion MAPCO Natural Gas Liquids, Inc., Brenham, Texas, April 7, 1992.
6. DOE-EH-4.2.1.3-ALOHA Code Guidance, "ALOHA Computer Code Application Guidance for Documented Safety Analysis", June 2004.
7. Motor Gasolines Technical Review Manual, Chevron, http://www.chevron.com/products/prodserv/fuels/bulletin/motorgas/downloads/Motor_Fuels_Tch_Rvw_complete.pdf (Referenced February 27, 2006).
8. Perry, R. H., Green D., "Perry's Chemical Engineers Handbook," 6th Edition.
9. Gasoline, Exxon MSDS 030000-00380-9130-00F005173.
10. Relative Energy Data, Chart published by Stone and Webster, 1974.
11. Heptane, Mallinckrodt Baker MSDS No. H0584.
12. 2,2,4-Trimethylpentane, Mallinckrodt Baker MSDS No. T6526.
13. Hexane, Mallinckrodt Baker MSDS No. H2381.
14. Toluene, Amoco MSDS No. 11699000 ANSI/English.
15. Petroleum Ether, 50-110C, Mallinckrodt Baker MSDS No. P1700.
16. Pentane, Mallinckrodt Baker MSDS No. P0737.
17. Risk Management Program Guidance for Offsite Consequence Analysis, EPA 550-B-99-009, April 1999.
18. Anhydrous Ammonia, Northeastern Ammonia Co. MSDS No. 6810-00F032029.
19. Ammonia Solution Strong, Mallinckrodt Baker MSDS No. A5472.