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UNITED STATES OF AMERICA
NUCLEAR REGULATORY COMMISSION



Before the Atomic Safety and Licensing Board



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| In the Matter of | ) | |
| | ) | |
| Philadelphia Electric Company | ) | Docket Nos. 50-352 |
| | ) | 50-353 |
| (Limerick Generating Station, | ) | |
| Units 1 and 2) | ) | |

# APPLICANT'S PROPOSED FINDINGS OF FACT AND CONCLUSIONS OF LAW IN THE FORM OF A PARTIAL INITIAL DECISION

Philadelphia Electric Company, Applicant in the captioned proceeding, in accordance with 10 C.F.R. §2.754 and the Atomic Safety and Licensing Board's March 23, 1984 order (Tr. 9276-A), hereby submits the attached Proposed Findings of Fact and Conclusions of Law in the form of a partial initial decision with respect to Contentions V-3a and V-3b.

Respectfully submitted,

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April 20, 1984



DS03

## PARTIAL INITIAL DECISION
## (On FOE Contentions V-3a and V-3b)

### Preliminary Statement

1. On September 19, 1981, Friends of the Earth in the Delaware Valley ("FOE") petitioned to intervene in the Limerick Generating Station ("Limerick" or "Station") operating license proceeding. At a prehearing conference held January 6-8, 1982, this Atomic Safety and Licensing Board ("Board") found that FOE had standing to intervene and gave it an opportunity to specify its contention alleging dangers to the Station resulting from nearby oil and gas pipelines.[1/] In our unpublished "Order (Concerning Proposed FOE Contentions on Hazards From Industrial Activities)," dated November 22, 1982, FOE Contentions V-3a and V-3b, as respecified, were admitted.[2/] Contention V-3a states that:

> In developing its analysis of the worst case rupture of the ARCO pipeline, the Applicant provided no basis for excluding consideration of siphoning. Thus, the consequences from the worst case pipeline accident are understated.

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1/ <u>Philadelphia Electric Company</u> (Limerick Generating Station, Units 1 and 2), LBP-82-43A, 15 NRC 1423, 1440, 1513-14 (1982).

2/ The Applicant had moved for summary disposition of these contentions on October 7, 1983. Its motion was supported by the NRC Staff but opposed by FOE. The motion was denied. "Memorandum and Order Denying Applicant's Motion for Summary Disposition of Contentions V-3a and V-3b and V-4" (November 8, 1983).

Contention V-3b states that:

> In discussing deflagration of gas and petroleum due to pipeline rupture, no specific consideration has been given to the effect of radiant heat upon the diesel generators and associated diesel fuel storage facilities.3/

Evidentiary hearings on these matters were held on December 9-14, 1983, January 9-10, January 23-25, and March 8-9 and 20-23, 1984 in Philadelphia, Pennsylvania.

Summary

2. The Board has analyzed FOE Contentions V-3a & V-3b and determined that they have no merit. With respect to the ARCO pipeline, we initially examined the amount of gasoline that would be lost from a postulated breach and the surface area that would be covered by the escaping gasoline and made available for evaporative purposes. We determined that a complete breach of the ARCO pipeline would result in a spilled area available for evaporation the size of the Possum Hollow Run streambed into which the spill would flow, an area very conservatively estimated to be 610 meters long and one meter wide, capable of containing approximately 5,000 gallons of gasoline. We also examined a number of other scenarios postulated by the parties which varied the

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3/ At our request, the parties subsequently filed testimony specifically addressing the structural integrity of safety-related structures to withstand postulated overpressures resulting from the detonation of gasoline or natural gas.

location and size and shape of the assumed break, including the effects of a spray of the escaping gasoline. We concluded that even the worst-sized breach would not result in a spray that would create an evaporative area which would affect the safety of the facility. We also examined the effects of postulated siphoning and continued pumping and found them to be irrelevant to the outcome of the evaluation.

3. We also examined whether the gasoline vapor in Possum Hollow Run could accumulate into a single point source, rise above the banks of the Run, move toward the Station, and detonate. While we concluded that this sequence of events could not occur, we nonetheless analyzed that scenario and concluded that a detonation of the vapor cloud would not harm the Station.

4. With respect to the postulated rupture of the Columbia Gas pipeline, the Board first examined whether an unconfined natural gas vapor cloud could detonate and concluded it could not. Despite this finding, we nonetheless examined whether such a cloud could otherwise approach the Station and what the effects of an assumed detonation might be. We concluded that while a vapor cloud could conceivably approach to within 1,200 feet of the Station under idealized conditions, it would still be insufficient to affect the Station's safety-related features. Even using highly conservative assumptions, the safety-related buildings have sufficiently large structural margins over

the postulated blast overpressures that they would not fail. While certain non-safety-related structures such as the cooling towers could fail, their failure would not impact the safety-related features necessary to the safe shutdown of the facility.

5. We also examined the effects of a postulated deflagration resulting from an accident at each pipeline and concluded that, even using conservative analyses, the safe operation of the Station would not be affected.

6. As discussed below, we therefore conclude that an assumed detonation resulting from a postulated breach of either the ARCO or Columbia Gas pipelines would not affect the Station.

## Introduction

7. The Applicant presented the testimony of LeRoy Christman, Manager, Montello District, ARCO Pipe Line Company, and Jack Brown, Director of Transmission Engineering, Columbia Gas Transmission Corporation, concerning the construction, management and operation of the ARCO and Columbia Gas pipelines, respectively. Both men were highly knowledgeable about the respective pipelines and their testimony greatly assisted the Board. The Applicant then presented the testimony of Walter Payne concerning the location of the ARCO and Columbia Gas pipelines. Mr. Payne is a highly experienced Registered Professional Land Surveyor whose testimony is entitled to great weight. The Applicant also presented the testimony of John Walsh, a science

specialist with Bechtel Group, Inc. Mr. Walsh, a professional meteorologist, has performed numerous accident analyses for over one dozen nuclear power plants. The Board has observed the demeanor of these witnesses on the stand and has relied heavily upon their testimony.

8. The Applicant also presented the testimony of a panel of witnesses relating to the ability of safety-related structures and systems to withstand the postulated overpressure from an assumed Columbia Gas or ARCO pipeline detonation, including the margin inherent in the design of such structures. This panel included Vincent Boyer, mechanical engineer, Senior Vice President Nuclear Power, PECO; H. William Vollmer, Professional Engineer (Civil) and Engineer-in-Charge of PECO's Structural Branch; John Benkert, Professional Engineer (Civil), Bechtel Power Corporation ("Bechtel"); Ranga Palaniswamy, Professional Engineer (Civil), Bechtel; Albert Wong, Registered Engineer (Civil and Structural), Bechtel; John Walsh, previously mentioned; Dr. Gordon Ashley, physicist, Bechtel; and Dr. Kenneth Buchert, structural engineer, consultant and professor. The members of this panel are highly competent in their respective disciplines and their testimony is authoritative and entitled to great weight.

9. The same is true of the Staff's witnesses. The Staff presented the testimony of Dr. Kazimieras Campe, Senior Site Analyst, NRC; Earl Markee, Senior Meteorologist, NRC; and Charles Ferrell, Site Analyst, NRC, all of whom

were able and competent witnesses. With respect to the calculation of overpressures and their effect on safety-related structures, the Staff presented the testimony of Mr. Ferrell, mentioned above; Norman Romney, Professional Engineer (Structural) NRC; and Dr. Pao-Tsin Kuo, Professional Engineer (Civil), NRC. Finally, the Staff presented the testimony of Rex Wescott, a hydraulic engineer, and William Lefave, a mechanical engineer responsible for, inter alia, reviewing the adequacy of the flood protection features provided at Limerick for internal and external events. These witnesses were also able and competent.

10. In contrast is the testimony of Bevier Hasbrouck, sole witness for FOE. Mr. Hasbrouck has a Bachelors degree in physics, but no further qualifications by way of education, training or experience that are applicable to the issues presented by these contentions. Tr. 5770-88, 5846-57. The Board has reviewed his qualifications, responses to questions about those qualifications and his answers to particular questions. On this basis, we have determined that his testimony is not entitled to any weight and, consequently, have discounted it entirely.

Location of Pipelines

11. Mr. Walter Payne testified as to the location of the ARCO and Columbia Gas pipelines on behalf of the Applicant. He tied the location of the ARCO pipeline to a base map utilizing accurately-related monuments of the

Pennsylvania Coordinate System. In this manner, it was determined that the ARCO pipeline, at its point of closest approach, is 1,603 feet, ± one foot, from the Unit 2 reactor enclosure and 1,665 feet from the Unit 2 diesel generator building. Payne, ff. Tr. 5357, at 2-6; Tr. 5380 (Payne). Mr. Payne also determined the location of the Columbia Gas pipelines using a combination of Columbia Gas installed pipeline markers, photogrammetric interpretation, field measurements, and maps furnished by Columbia Gas. He testified that these pipelines are located 3,500 feet, ±51 feet, from the Unit 2 reactor enclosure at their closest approach. The location of the ARCO and Columbia pipelines in relationship to the Station's structures is accurately represented on Applicant's Ex. 7. Payne, ff. Tr. 5357, at 7-10. FOE conceded so much and further stated that even if the represented locations were off by as much as 100 feet it would not be a controlling factor. Tr. 5136, 5361, 5961.

<u>ARCO Pipeline</u>

12. That portion of the ARCO pipeline traversing Chester and Montgomery Counties, Pennsylvania which passes near the Station is known as the Northeast Boot to Fullerton Pipeline. It runs 48.87 miles from Boot Pumping Station to the Fullerton Terminal where the product is discharged and the line terminates. The line, constructed in 1955, is eight inches in diameter. It has a capacity of 31,700 barrels per day (approximately 42,000 gallons per hour) and operates at a maximum pumping pressure of 1,100 psig.

Christman, ff. Tr. 5093, at 2-3; Tr. 5100-01, 5152, 5177 (Christman).

13. The products that may be carried in the ARCO pipeline are set forth in a tariff established by the Pennsylvania Public Utilities Commission ("PUC"). This tariff states that gasoline, kerosene, jet engine fuel, tractor fuel, and light and medium fuel oil may be carried. Christman, ff. Tr. 5093 at 4; Tr. 5119-21 (Christman). The pipeline has never been used to transport aviation fuel, which is simply a higher octane gasoline, and thus lower in volatility and less dangerous, than that used in automobiles. Christman, ff. Tr. 5093, at 4; see Tr. 5879 (Hasbrouck).

14. While ARCO is a common carrier, and thus must carry the products of other shippers, all products shipped on the line are subject to its tariff. Tr. 5106-08 (Christman). This tariff was originally established in 1973 and amended in 1978. No new products have been added since that time. The local ARCO offices would be notified well in advance if the tariff were to be changed. Tr. 5121-22 (Christman). Moreover, such changes would have to be approved by the PUC in any event. Tr. 5210 (Christman).

15. The ARCO tariff does not provide for the transport of propane, butane, or liquified natural gas. The pipeline has never carried those products and could not do so without modifications to the pumping units and terminal facilities. Christman, ff. Tr. 5093, at 4; Tr. 5109, 5218 (Christman).

Large pressure vessels would have to be installed to store these gases, which are not normally liquid at environmental temperatures, and the piping would have to be modified, a process that would likely take years to complete. Tr. 5235-37 (Christman). Moreover, under the terms of an ARCO agreement with PECO, ARCO may not transport propane through this line. Christman, ff. Tr. 5093, at 4. See Agreement attached to the Testimony of Vincent Boyer, ff. Tr. 5412.

16. Boot Pumping Station, located approximately 15.5 miles south of Limerick, is the only pumping station on this line segment. Boot Station is remotely controlled from the Point Breeze Station in Philadelphia, as well as from the ARCO Control Center in Independence, Kansas. Both of the latter stations continuously monitor the line and are equipped to regulate its pumpages, open and close the line and shut down the pumps. Christman, ff. Tr. 5093, at 4-5; Tr. 5147, 5195-99 (Christman).

17. Boot Station is equipped with a sensor which automatically shuts off its pumps if line pressure drops below 365 psi or exceeds 1,100 psi. Christman, ff. Tr. 5093, at 6; Tr. 5152, 5195, 5221 (Christman). In the event of a complete rupture, Boot Station would shut down within minutes. Christman, ff. Tr. 5093 at 6; Tr. 5211-12 (Christman). Even if this sensor failed, the Point Breeze or Independence Stations would provide independent backup shutdown capability. Christman, ff. Tr. 5093, at 6; Tr. 5195-99 (Christman).

18. FOE postulated that a partial breach of the line might cause a leak that would not reduce pressure below 365 psi and would, therefore, allow continued pumping. Tr. 5174-75. To the contrary, the testimony indicated that controllers monitoring the lines at Point Breeze and Independence have the capability to detect variations in operating pressure as small as one psi and that they are authorized to terminate pumping and shut down the line in the event of an unexplained drop in pressure. Christman, ff. Tr. 5093, at 5-7; Tr. 5220 (Christman). It would take an operator approximately 5-10 minutes to shut down the line and check the source of the pressure drop. If it were determined that a problem existed, work crews would be sent out immediately. Christman, ff. Tr. 5093, at 7; Tr. 5201-04 (Christman).

19. In addition to continuously monitoring pipeline flow, the Control Center simultaneously compares the amount of product introduced into the line with the amount delivered at the terminal points and computes an hourly line balance. If there is an imbalance that can not be attributed to normal operating conditions such as temperature changes, the Control Center would isolate the line and determine the cause of the problem. Tr. 5246-48 (Christman). Additionally, the flow rate into tankage is continuously monitored as well. The receiving end operator would notify the remote control stations if there were a

drop in output from the specified level. Christman, ff. Tr. 5093 at 7; Tr. 5246-48 (Christman).

20. FOE then postulated that a communications interruption might prevent a speedy shut down of the system. Tr. 5149-51. The evidence indicated that ARCO uses a microwave radio system and Bell Company lease lines and that this system has never experienced a problem that has affected its ability to operate the pipeline. Tr. 5147-51, 5240-41 (Christman). ARCO's dedicated telephone lines are not located on the right-of-way; therefore, a hypothetical fire or explosion could not affect communications. Tr. 5240-41 (Christman). Even if communications with one station were lost, the ability to communicate with the other stations would still exist. Moreover, if there were any question as to the safety of allowing the continued operation of the line, it would be shut down and isolated per normal procedure. Tr. 5241-42, 5251 (Christman).

21. In addition to the automatic shutoff capability at Boot Station and the remotely-controlled shutoff capabilities from Point Breeze and Independence, there are 10 hand operated valves which may be used to shut down the line. The nearest valve below Limerick is 3,000 feet south of the Station; the nearest valve to the north is 7.9 miles away. Christman, ff. Tr. 5093, at 7. Work crews could close the valves nearest a leak within one hour during working hours and within two hours at other times.

Christman, ff. Tr. 5093, at 7. Conservatively, no credit was taken in the analyses for the use of these valves.

The Applicant's Assumptions and Methodology

22. In calculating the effects of a postulated ARCO pipeline breach on the Station, the Applicant's witness, Mr. Walsh, assumed that the Boot Station automatically stopped pumping; that the rupture occurred while automotive gasoline, the product that is most volatile and has the highest energy content, was being carried; that the rupture occurred where the pipeline crosses Possum Hollow Run, the point at which it would have the greatest effect on the Station; and that the entire contents of the pipeline (4962 gallons) between the two nearest adjacent high points of land flowed into Possum Hollow Run and formed a pool three centimeters deep and 610 meters long by one meter wide. Walsh, ff. Tr. 5411, at 4-5; Tr. 5480, 5561-67 (Walsh).

23. While not critical to its analysis, the Applicant also assumed that no siphoning occurred from beyond the nearest adjacent high points. For siphoning to occur, air at atmospheric pressure would have to enter the line at a point higher than the postulated break and beyond one of the adjacent high points. Thus, two separate openings of the pipe would have to occur. In the absence of a second such break, air would enter the line and travel above the surface of the draining fluid until it reached the adjacent high points where it would prevent further drainage. Walsh, ff. Tr. 5411, at 5-6; Tr. 5562 (Walsh).

24. Once distributed in Possum Hollow Run streambed with a conservatively assumed width of one meter and a length of 610 meters, the Applicant assumed that the gasoline evaporated, forming a vapor gradient at decreasing concentrations above the stream and confined horizontally within the valley walls. Walsh, ff. Tr. 5411, at 6-7. There is no justification for the vapor rising above the banks of the stream. Tr. 5546, 5579 (Walsh); see 5893-96 (Hasbrouck). The explosive limits of gasoline are between 1.3% and 6% by volume of vapor and air. Everything over 6% is above explosive limits and too rich to detonate or deflagrate; everything below 1.3% is too lean to detonate or deflagrate. Walsh, ff. Tr. 5411, at 7; Tr. 5448, 5550-51 (Walsh).

25. The Applicant then determined the amount of gasoline vapor that would be within explosive limits. Conservatively assuming that the entire butane component and one centimeter of the remaining components evaporated during the first hour 1,920 gallons of gasoline would vaporize. Walsh, ff. Tr. 5411, at 7; Tr. 5547, 5740 (Walsh); see Tr. 6178 (Campe). It was also conservatively assumed that the distribution of vapor concentration was linear rather than exponential to increase the amount of vapor within flammable limits. On this basis, it was calculated that 4.7% of the 1,920 gallons vaporized, or 90.25 gallons, would be within explosive limits. Walsh, ff. Tr. 5411, at 7; Tr. 5550-51, 5736-37 (Walsh); see Tr. 7495 (Markee).

26. The TNT-equivalent of the vapor was then determined in an extremely conservative manner to calculate the peak overpressure at the Station. The Applicant assumed that 100% of the gasoline vapor within flammable limits detonated. Reg. Guide 1.91 (Rev. 1) (Staff Ex. 7), however, states that only 1% of the hydrocarbon vapor might actually detonate. Since hydrocarbon vapors have 10 times the explosive capability of TNT, the amount of vapor within explosive limits is obtained, using Reg. Guide 1.91 methodology, by multiplying 1% times 10 to obtain a TNT-equivalent. Walsh, ff. Tr. 5411, at 7; Tr. 5430-31, 5554 (Walsh). Reg. Guide 1.91 then uses a multiplier of 2.4 to further conservatively account for the explosive content of the vapor, thus providing, in essence, that 24% of the vapor could detonate. The Applicant's calculations assuming that 100% of the mixture would detonate are therefore conservative by over a factor of four. Tr. 5430-31, 5550-51, 5554 (Walsh); Tr. 6152-55 (Ferrell, Campe).

27. Although the evidence indicated that unconfined gasoline vapors cannot explode, detonation was assumed to occur at a point along Possum Hollow Run, alternatively, at 800 feet from the closest safety-related structure, where the slope is more gradual and provides the greatest access to safety-related structures, and at 550 feet, the closest approach of Possum Hollow Run to the Station. The resulting peak reflected overpressure on the Unit 2 reactor enclosure was determined to be 1.9 pounds per square inch ("psi") at

800 feet and 3.0 psi at 550 feet. Walsh, ff. Tr. 5411, at 7-8; Tr. 5575-78, 5583-88 (Walsh).

Conservatisms

28. The Applicant utilized a number of significant conservatisms in its analysis other than those mentioned above. One such assumption related to the pooling capacity of Possum Hollow Run. The Applicant assumed that the pooling capacity of the streambed is one meter wide. The evidence, however, indicated that the streambed's pooling capacity is actually only one foot wide. Consequently, the Applicant's estimate of the amount of gasoline the streambed can hold is conservative by a factor of three. Tr. 5481, 5598-5600 (Walsh). Moreover, inasmuch as Possum Hollow Run is quite steep and there exists no mechanical means of blocking the flow of gasoline out the mouth of the stream, any amount in excess of the 5,000 gallons that would be pooled using a streambed pooling width of one meter would flow out of the stream and into the Schuylkill River. Tr. 5481-82, 5501-02, 5567-69, 5598-99, (Walsh); see Tr. 5885, 5888 (Hasbrouck).

29. The Applicant also assumed that all available gasoline vapor remained in the stream bed and exploded at a single point. Actually, the vapor that did not flow out of the valley would be distributed in a line along the stream. Walsh, ff. Tr. 5411, at 5; 5545-46, 5719-20 (Walsh); see Tr. 5890, 6000 (Hasbrouck). Consequently, it would explode as a line source rather than a point source, lessening the

resulting overpressure by as much as a factor of 10. Tr. 5601-03 (Walsh). The stream banks of Possum Hollow Run, which rise approximately 67 feet to grade level, would also provide some shielding of the Station that was not accounted for. Walsh, ff. Tr. 5411, at 8; Tr. 5578-79, 5585 (Walsh, Boyer); see Tr. 5888, 5894-98 (Hasbrouck). Finally, as discussed below in greater detail, the Applicant also utilized a conservative evaporation rate.

Alternative Scenarios

30. The Applicant also examined several other scenarios involving different assumptions and greater postulated releases from the ARCO pipeline. In the first of these, the Applicant assumed that 21,000 gallons of gasoline escaped from the pipeline creating a circular sprayed area 183 feet in diameter on the adjacent hillside, four times the 610 square meters originally assumed. Actually, if 21,000 gallons of gasoline were deposited on the hillside it would form rivulets and run downhill and out Possum Hollow Run. Nonetheless, assuming that four times the amount of vapor originally postulated resulted from the greater sprayed area, the resulting overpressures would be 3.5 psi at 800 feet and approximately 6 psi at 550 feet using the same conservative methodology. Tr. 5702-07, 5723 (Walsh).

31. In the bounding scenario, 42,000 gallons of gasoline were assumed to be released covering an evaporative area eight times that originally calculated to be available, resulting in a circular sprayed area 260 feet in diameter.

Assuming that eight times the amount of vapor originally determined were likewise concomitantly available, an explosion at 800 feet would result in an overpressure of 5.5 psig; at 550 feet it would be approximately 9.7 psig. Tr. 5708-10 (Walsh). In actuality, the evidence indicated that it would take many times the 42,000 gallons per hour flowing through the pipeline to wet down a circular area 260 feet in diameter. Tr. 5710-13 (Walsh).

32. The Applicant also investigated the spray pattern that would result from various sized breaks. It determined that a one-inch hole with a discharge coefficient of 0.5 would release approximately 550-580 gallons per minute ("gpm"), tripping the pumps and attracting the operators' attention. A two-inch hole would release 2,300 gpm under normal operating pressures and would result in an almost instantaneous depressurization of the line since its capacity is only 924 gpm. As line pressure dropped, the head available to form spray would be reduced and the liquid would be released as a fountain. The best evidence indicated that the maximum spray that could result from an optimized breach of the pipeline would not extend more than 10 feet into the air. There was simply no evidence that an area 185 feet in diameter or larger could be sprayed. Tr. 5709-13 (Walsh); Tr. 5684-85, 5714-18 (Boyer); Tr. 6175 (Ferrell); see Tr. 5213 (Christman).

33. The Applicant also examined scenarios in which pumping continued after the line was breached and gasoline

was assumed to flow into the break from the direction of Fullerton. It determined that the length of time the pumps operated or that drainage continued would not materially change its analysis since any amount of gasoline in excess of 5,000 gallons is beyond the stream's holding capacity and would flow out of Possum Hollow Run. Tr. 5597-98, 5687-90 (Walsh).

Staff's Analysis

34. The Staff also examined a breach of the ARCO pipeline. It posited a breach at a point due east of the turbine building on the hill overlooking Possum Hollow Run,the pipeline's point of closest approach to the Unit 2 containment. Tr. 7237-38 (Ferrell). The Staff assumed that the line did not shut down and that pumping continued at a full capacity rate of 42,000 gallons per hour. Ferrell et al., ff. Tr. 7136, at 1-3; Tr. 6139-40, 7248-49 (Ferrell). Based on its review of Possum Hollow Run, the Staff, too, concluded that the length of time the pumps continued operating was irrelevant since the streambed has a limited holding capacity and the excess will flow out into the Schuylkill River. Ferrell et al., ff. Tr. 7136, at 3; Tr. 6140, 7249, 7482, 7524-25 (Ferrell). It likewise considered siphoning and concluded that its analysis of continuous pumping presented a worst case scenario which could not be exceeded by that event. Tr. 7155, 7234-35, 7430-32 (Campe, Ferrell).

35. The Staff further assumed that the breach sprayed an area of the hillside three meters wide and 158 meters long (5,099 square feet), covering a surface area of Possum Hollow Run three meters wide and 610 meters long (19,701 square feet) for a total area of 24,800 square feet. Ferrell et al., ff. Tr. 7136, at 2; Tr. 6170-73, 7287-88 (Ferrell). The three meter width was described as a conservative upper bound estimate of gasoline flow down the hill. In reality, the escaping gasoline would form rivulets covering an area a few feet wide at most. Tr. 7290-91, 7293-99, 7425, 7484-87 (Campe, Ferrell). Similarly, the three meter width water surface area of Possum Hollow Run is conservative by a factor of two. Tr. 7156-57 (Ferrell).

36. Intervenor postulated that the gasoline would spray the surrounding vegetation thus increasing the area available for evaporation. Tr. 7424-48. It presented no evidence supporting this theory however. To the contrary, the Staff testified that while the wetting of vegetation would slightly increase the area available for evaporation, vegetation on the ground would blanket the gasoline and reduce its exposure to the wind, which is the driving force behind evaporation. Based on its analysis, the Staff concluded that these forces would work in opposite directions and that any additional evaporation would be insignificant. Tr. 7294-99, 7424-25 (Campe, Ferrell).

37. The Staff then determined the total evaporation rate, taking into account, inter alia, the air velocity and

heat transfer coefficient past the liquid, the solar load, and properties of the gasoline itself, including viscosity and vapor pressure. Tr. 6162-63, 6175-79 (Ferrell). These parameters are known values for which there is a high degree of reliability. Tr. 7440 (Campe). Although gasoline is blended differently in warmer weather than colder weather to maintain a constant vapor pressure, the Staff did not account for seasonal blending, which would reduce the evaporation rate during the summer, thus making their calculations conservative. Tr. 6184 (Campe); <u>see</u> Tr. 5596 (Walsh); <u>see</u> Tr. 5879-80 (Hasbrouck).

38. In calculating the evaporation rate, the Staff assumed a very conservative diffusion coefficient of 0.2 centimeters squared per second ("$cm^2$/sec"). In actuality, the diffusivity of most hydrocarbons, including gasoline, is less than 0.1 $cm^2$/sec. For example, the diffusivity of n-octane, the principal ingredient in gasoline, is .06 $cm^2$/sec. Ferrell <u>et</u> <u>al</u>., ff. Tr. 7136, at 4; Tr. 7157-58, 7440-41, 7455-56 (Campe).

39. Based on their calculations, the Staff determined that the upper bound range of evaporation rates under any conditions would be between 0.27 and 0.57 grams per meter squared per second ("$gm^2$/sec") depending on the wind speed. Ferrell <u>et</u> <u>al</u>., ff. Tr. 7136, at 3; Tr. 7443-44 (Campe). An evaporation rate of 0.27 $gm^2$/sec is approximately one-seventh that of the one centimeter per hour rate utilized by the Applicant. Tr. 7326-31 (Campe).

40. The Staff then used the methodology set forth in Reg. Guide 1.91 to estimate the vapor's explosive content. Ferrell _et al_., ff. Tr. 7136, at 5; Tr. 7153, 7445 (Campe). Its testimony indicated that the appropriate conversion factor actually varies from hydrocarbon to hydrocarbon and that 2.4 bounds all hydrocarbons. Tr. 7445-50 (Campe). Assuming that the entire amount of vapor was within flammable limits, the Staff determined that 1856 pounds of TNT-equivalent vapor would be present in Possum Hollow Run. Ferrell _et al_., ff. Tr. 7136, at 5; Tr. 7263, 7554 (Ferrell, Campe). Actually, only about 25% of this amount would realistically be within flammable ranges, thus making this calculation conservative by a factor of four. Tr. 7158 (Ferrell); Tr. 7165 (Markee). Based on an evaporation rate of 0.27 $gm^2$/sec, the overpressure at 960 feet would be 1.1 psi; 1.3 psi at 800 feet; and 2.1 psi at 550 feet. Ferrell _et al_., ff. Tr. 7136, at 6; Tr. 7344-46 (Campe).

41. The Staff also examined additional scenarios in which it was postulated that the evaporative area was increased. In the bounding scenario, the three meter wide sprayed hillside area was increased to 30 meters. Tr. 7300. While the TNT-equivalency would not necessarily concomitantly increase, this figure was nonetheless tripled. Tr. 7301 (Campe). The evidence indicated that the 10-fold increase in evaporative area would increase the overpressure on the Station by about 0.5 psi. Tr. 7303-04 (Campe). A 100-fold

increase in evaporation area would increase the overpressure at 960 feet to about 5.5 psi. Tr. 7305-06 (Campe).

42. FOE postulated that wind blowing up the valley would inhibit the flow of vapor down Possum Hollow Run and increased the amount available for detonation. Tr. 7352-54. The uncontroverted testimony indicated that while a mild breeze would tend to inhibit the downward flow of vapor, it would also create additional mixing that would further dilute the vapor plume. Even if a portion of the vapor were thus raised above Possum Hollow Run, greater overpressures would not result since the vapor would be dispersed in all directions and a lesser amount would approach the Station than the 100% originally assumed. Tr. 7353-54, 7356-59, 7489-90 (Markee).

43. Finally, FOE suggested that the cooling tower draft could draw either gasoline or natural gas vapor toward the Station. Hasbrouck II, ff. Tr. 5750, at 3; 7352-53. It had not, however, calculated the velocity at the bottom of the cooling towers or the zone of influence. Tr. 5971-72 (Hasbrouck). To the contrary, the evidence established that the intake velocity at the base of the cooling towers is only three meters per second. This figure drops to less than one meter per second a few diameters from the towers. Tr. 7353, 7488-89 (Markee). Thus, the cooling towers will clearly not pull vapor toward the Station.

Conservatisms

44. The Staff's analysis contained several additional significant conservatisms not mentioned above. For example, although this was not shown to be possible, the Staff assumed that the flow of vapor stopped at the Station and rose over the banks of Possum Hollow Run. Also, the Staff did not credit the ameliorative effects of the intervening terrain between Possum Hollow Run and the Station, but merely assumed that the explosion occurred on a level plain at an elevation equal to that of the diesel generator building or Unit 2 containment building. Tr. 7158-59, 7255 (Ferrell, Campe). Finally, the Staff used a point source instead of a line source in its calculations. As has been seen, vapor would actually be distributed throughout Possum Hollow Run. Ferrell et al., ff. Tr. 7136, at 6; Tr. 6187, 7159, 7263 (Ferrell).

FOE Analysis

45. In its analysis, FOE postulated that 42,000 gallons of gasoline sprayed from the ARCO pipeline covering an area with a radius of 185 feet. It assumed that 21,000 gallons of this amount stayed liquid and flowed into Possum Hollow Creek. The remaining 21,000 gallons was assumed to evaporate. Half of this amount was assumed to go into vapor mixtures too rich or to lean to explode and the remaining 10,500 gallons was assumed to constitute an explosive mixture. Hasbrouck I, ff. Tr. 5750, at 1-3; Tr. 5861-62, 5881, 6042-43 (Hasbrouck).

46. FOE's witness, Mr. Hasbrouck, agreed that the explosive range of gasoline vapor is 1.3% to 6% by volume. He felt, however, that since FOE's hillside spraying scenario offered a greater area for gas/air intermixing, more than the 4.7% calculated by the Applicant would be available for detonation. Ultimately, Mr. Hasbrouck could not state how much of this mixture would be within explosive limits, but guessed that it might be as much as 50%. Hasbrouck I, ff. Tr. 5750, at 2; Tr. 6043-45 (Hasbrouck). No basis was cited for this figure. Tr. 6042-45 (Hasbrouck).

47. In selecting the area it postulated would be sprayed, FOE assumed a generalized split in the pipeline. It did not utilize specific numerical dimensions nor did it calculate the amount of product that would be lost. FOE's loss assumption was based solely on a comment in a pipeline accident report (Hearne, Texas) that the spilled product covered a "large area." The publication did not define that term and FOE did not know what constituted a "large area." Tr. 5869-73, 6021-23 (Hasbrouck). FOE admitted that the size of the sprayed area could not be determined from pictures since the extent of the explosion area vis-a-vis the burned area was not indicated. Tr. 6021-22, 6099-6101, 6115 (Hasbrouck); <u>see</u> 7282-85 (Campe). Ultimately, FOE conceded that its assumption that an area with a radius of 185 feet would be sprayed had no scientific basis. Tr. 5995, 6002-04 (Hasbrouck). FOE also conceded that the spray

discussed in a report describing a Los Angeles pipeline accident, which it cited in support of its argument, covered an area at least four or five times smaller than the area it postulated. Tr. 6094-98, 6113-15 (Hasbrouck).

48. FOE further speculated that the main danger to the Station would come from the 21,000 gallons of gasoline it posited would be sprayed on the hillside. Tr. 5997, 5999 (Hasbrouck). It agreed that Possum Hollow Run streambed could not accommodate more than 5,000 gallons of gasoline and that the excess would flow into the Schuylkill River. FOE's witness admitted that the gasoline in the stream would not create much vapor, that 94% of it would be nonexplosive, that the fumes would not rise above the stream's banks, and that the steep walls of the Run would shield the Station. Tr. 5893-98, 6103-07 (Hasbrouck).

49. Nonetheless, Mr. Hasbrouck estimated that the overpressure resulting from an explosion of the fumes it postulated would be generated by hillside spraying would be 28 psi. Tr. 6103-07 (Hasbrouck). No basis was provided for this figure. Moreover, this overpressure depended on a point source explosion and did not account for the shielding effects of Possum Hollow Run. Finally, it used a TNT-equivalency factor four times that provided for in Reg. Guide 1.91. Admittedly, the calculated overpressures were based on the worst-case scenario that could be postulated and ignored the evidence. Tr. 5889-90, 6107-10 (Hasbrouck).

## Deflagration Analysis

50. The Applicant and Staff also analyzed the effect of an assumed gasoline deflagration on the Station. FOE presented no evidence on this point. The Applicant conservatively assumed that the entire 5,000 gallons of spilled gasoline deflagrated in a 15-minute period, thus maximizing the heat generation rate. It determined that this scenario would produce a radiant heat load of 85 btu per square foot per hour ("$btu/ft^2/hr$") at the Unit 2 reactor enclosure. This level of exposure would only slightly warm the enclosure's concrete surface regardless of the time the deflagration lasted. By comparison, any flat surface exposed to the sun in the Limerick vicinity receives solar radiation at approximately 180 $btu/ft^2/hr$ averaged over an entire day. Walsh, ff. Tr. 5411, at 8-9.

51. The Applicant also examined a deflagration involving the postulated 21,000 gallon gasoline spill even though it did not believe such a scenario to be credible. The unrebutted evidence established that if a deflagration of 21,000 gallons of gasoline took place over a 15-minute period, the radiant heat load at the reactor enclosure would be 350 $btu/ft^2$ hr., which is well below the 500 $btu/ft^2$ hr constituting the human pain threshold. Walsh, ff. Tr. 5411, at 9. Moreover, this analysis assumed that the gasoline burned at a single point. In reality, it would burn in a line along the streambed and quickly retreat to the point of rupture. Tr. 5603-04 (Walsh).

52. The Staff also found that the effects of a gasoline deflagration would be insignificant. The Staff established that the vapor cloud would burn in less than a minute and that the fire would quickly retreat to the gasoline's point source. It determined that the more severe hazard would actually result from a deflagration a the breach itself. Based on a postulated 100 foot diameter vertical column of burning gasoline, the thermal flux was determined to be 265 watts per square meter ("$W/m^2$"). This figure is well within the range of solar radiation levels in the United States. For example, the average solar flux in Washington, D.C. is 170 $W/m^2$; the peak solar flux in Albuquerque, New Mexico is between 1,000-1,200 $W/m^2$. Ferrell et. al., ff. Tr. 7136, at 12-13; Tr. 7431 (Ferrell). Therefore, an assumed deflagration of gasoline vapor from a postulated breach of the ARCO pipeline would obviously not affect the Station.

Columbia Gas Pipelines

53. Columbia Gas pipelines numbers 1278 and 10110 run generally southwest to northeast through Montgomery County, Pennsylvania, bypassing Limerick Station at a distance of 3,500 feet. Brown, ff. Tr. 5261, at 3; Tr. 5272 (Brown). These lines carry only natural gas (methane). Tr. 5325 (Brown). Pipeline No. 1278, constructed in 1949, is 14 inches in diameter, operates at a normal pumping pressure of 750 psig and has a maximum pumping pressure of 938 psig. Pipeline No. 10110, constructed in 1965, is 20 inches in diameter, operates at a normal pumping pressure of 1,100

psig and has a maximum pumping pressure of 1,200 psig. The pipelines share a common right-of-way and run parallel to each other 20 to 30 feet apart. Brown, ff. Tr. 5261, at 4; Tr. 5264 (Brown).

54. The Columbia Gas pipelines carry methane only in its gaseous state. Tr. 5318, 5325-27 (Brown). There are no plans to transport either propane or butane through these lines and the existing compressors would have to be replaced before they could be transported in any event. Tr. 5325-26, 5341, 5350 (Brown). Additionally, Federal Energy Regulatory Commission approval would have to be obtained to transport anything other than natural gas through these lines. Tr. 5349 (Brown).

55. The compressor stations nearest Limerick on the Columbia Gas pipelines are Eagle Station, 9.7 miles south of the Schuylkill River, and Easton Station, 44.4 miles to the north. Eagle Station is manned at all times. Easton Station is manned eight hours a day on weekdays. Brown, ff. Tr. 5261, at 4; Tr. 5284, 5305-08 (Brown). The control center for the overall Columbia Gas system is located in Bethel Park, Pennsylvania. Brown, ff. Tr. 5261, at 5; Tr. 5285-86, 5306-09 (Brown).

56. The standard operating pressures on line 10110 range between 770 and 1,220 psig and between 425 and 750 psi on line 1278, with 1,100 and 750 psi being the normal pressure for each line, respectively. The maximum operating pressure on line 10110 is 1,200 psi; it is 938 psi on line

1278. The compressors on line 1278 automatically shut down whenever the pressure exceeds 750 psi. If the pressures fall below 425 psi on Line 1278 or 770 psi on Line 10110, alarms are triggered at the Control Center and Eagle Station. Brown, ff. Tr. 5261, at 5-6; Tr. 5321-22, 5324-25 (Brown).

57. During times of normal market operation, each line experiences an approximately 5 psi drop per mile. Therefore, in the ten miles between Eagle Station and Limerick there would be a 50-60 psi drop in operating pressure. Consequently, in the vicinity of Limerick Line 1278 would likely operate at an actual pressure of 650-700 psi; Line 10110 would operate at 1,000-1,050 psi. Tr. 5324-25 (Brown); see Tr. 5911 (Hasbrouck).

58. The uncontroverted evidence indicated that each line will automatically shut down without human intervention if its high pressure setting is surpassed, i.e., 938 psi on Line 1278 and 1,200 psi on Line 10110. If pressure falls below the lower level, 425 psi on Line 1278 and 770 psi on Line 10110, alarms are triggered at the Control Center and Eagle and Easton Stations and the operators from any one of those locations can shut down the line. Tr. 5306-09, 5320-23, 5345 (Brown). If there were a breach in the vicinity of Limerick, a low pressure signal would be sounded, the compressor units would be shut down and no more gas would be introduced into the lines. Tr. 5288 (Brown). There are also remotely controlled valves at Hellertown, 20

miles from Eagle Station, which can be used to further shut in the line and isolate leaks. Tr. 5301-02, 5346-47 (Brown).

59. Even when a line is automatically or remotely shut down, crews isolate the leak as closely as possible to the point source. Tr. 5318-19 (Brown). Line 1278 has manual valves at the Schuylkill River and four miles to the north. The valves on Line 10110 are located 4.3 miles north of the River. Brown, ff. Tr. 5261, at 6; Tr. 5330-31 (Brown). It would take less than one hour to close the valves during normal working hours and two hours at other times. Brown, ff. Tr. 5261, at 6; Tr. 5301-02, 5318 (Brown). No credit was taken for these valves however.

Analysis of Columbia Gas Pipeline Breach

60. Although the evidence conclusively established that the detonation of unconfined natural gas is impossible, the Applicant nonetheless analyzed this event. Tr. 5294-95, 5336-37, 5351 (Brown); Tr. 5592 (Walsh); Ferrell et al., ff. Tr. 7136, at 13-15; Ferrell, ff. Tr. 9041, at 1-2; Tr. 6156-57, 7166 (Campe). It assumed that the larger of the two Columbia Gas pipelines, Line 10110, experienced a double-ended rupture at its point of closest approach to the Unit 2 reactor containment. Walsh, ff. Tr. 5411, at 10. It further conservatively assumed that the pipe ends assumed a vertical parallel orientation. This position allows the least interference between the plumes, a gradual merging of the plumes and the least amount of dispersion through

turbulent mixing. Walsh, ff. Tr. 5411, at 10; Tr. 5422-25, 5556 (Walsh). The testimony indicated that if the severed pipes remained end to end, the mechanical turbulence generated by the interference of the plumes with each other would greatly increase the dispersion rate. This would cause the vapor's flammable limits to occur closer to the point of release, thus reducing the postulated overpressures on the Station. Walsh, ff. Tr. 5411, at 11; Tr. 5424 (Walsh).

61. The Applicant found that ultimately the entire contents of the pipeline between the Eagle and Easton Stations could be released to the atmosphere if the valves not closed. This would take time, however, as the release rate is limited by the diameter of the pipe and the sonic velocity of the gas. Thus, the Applicant properly based its analysis of this event upon the rate of release rather than the total volume that would ultimately escape from the line. Walsh, ff. Tr. 5411, at 11; Tr. 5469, 5581 (Walsh).

62. In determining the amount of gas that would be within flammable limits, the Applicant utilized very conservative atmospheric conditions of Pasquill F stability to minimize dispersion of the gas. Walsh, ff. Tr. 5411, at 12; Tr. 5432, 5435, 5458, 5470 (Walsh). Pasquill F stability is an inversion condition in which the wind speed was assumed to be one meter per second. In reality, Pasquill F is a night-time condition whose use is inconsistent with the assumption of a sunny day. Tr. 5432-34, 5458 (Walsh).

Moreover, Pasquill F and one meter per second wind speed is the 95th percentile meteorology, i.e., atmospheric conditions are more conducive to dispersion 95% of the time. Tr. 5433-34, 5544-45 (Walsh). The Applicant also assumed that the gas cloud moved directly towards the Station, even though wind from the direction that would carry the plume directly towards the Station during F and one meter per second conditions occurs only .004% of the time. Tr. 5433-34 (Walsh).

63. To allow the maximum concentration of gas within flammable ranges to occur as far downwind as possible, the Applicant assumed that the escaping gas rose above ground level and traveled directly toward the Unit 2 reactor enclosure. A cloud traveling at ground level would mix more rapidly and cause explosives concentrations to occur closer to the point of release and further from the plant. Walsh, ff. Tr. 5411, at 12; Tr. 5425-26, 5463-65 (Walsh). Based on the conservative meteorological conditions discussed above, the Applicant determined that the closest a flammable mass of natural gas vapor could approach the plant would be 350 meters. Tr. 5464-65, 5470-71, 5516-19 (Walsh). Other meteorological conditions would cause the flammable limits to occur closer to the point of release and further from the Station. Tr. 5464-65 (Walsh). For example, Pasquill D (50th percentile meteorology) would result in at least a factor of 10 increased dispersion. Pasquill A would result

in increased dispersion of a factor of 100 or greater. Tr. 5590, 5729-31 (Walsh).

64. The Applicant also examined a scenario in which both Columbia Gas pipelines were assumed to experience a simultaneous rupture. While this event is clearly not credible, it would not result in significantly higher overpressures since the plumes would enter the atmosphere at different elevations as a result of the different operating pressures and capacities of the two lines. Thus, their zones of flammability would occur at different distances downwind and the assumed blast waves would be separated by appreciable time intervals. There is no credible justification for the separate streams of gas to merge into one plume since this would require wind interference which would result in greater mixing and movement of the zone of flammability closer to the point of release, thus significantly lowering the resulting overpressure. Tr. 5604-05, 5609, 5726-31 (Walsh).

65. FOE postulated that the escaping natural gas would be much colder than the ambient air and thus negatively buoyant, enabling it to flow down Possum Hollow Run towards the Station and avoid dispersing. FOE's witness, Mr. Hasbrouck, posited that for the particular adibatic expansion of the escaping gas, the resultant temperature would be -276°F. Hasbrouck II, ff. Tr. 5750, at 1-2; Tr. 5945-46 (Hasbrouck). Although no basis was shown, he further assumed that air would mix with methane in a

worst-case ratio of nine to one and maintain itself in a quasi steady state condition 40° below that of the ambient air. Hasbrouck II, ff. Tr. 5750, at 1-2; Tr. 5955-58; 5962-67 (Hasbrouck). It was recognized, however, that the mixture would rise if it were not significantly colder than the ambient temperatures. Tr. 5962, 6085 (Hasbrouck). No basis was shown for the assumption that the air/gas mixture would maintain a constant ratio of nine to one. Tr. 6004-09 (Hasbrouck). Likewise, FOE's assumption that this mixture would remain 40° cooler than the ambient air was based on its unsupported supposition that valleys are significantly colder than surrounding areas. It cited no references in support of this theory and, in fact, Mr. Hasbrouck testified that the valley would be only 10° colder than the ambient in any event. Tr. 5968-69 (Hasbrouck). Clearly, a 10° differential would be insufficient to maintain the vapor 40° below that of the ambient.

66. FOE then hypothesized that each successive gas "bubble" would chill the ground before rising, thus allowing subsequent bubbles to travel further and further. In this manner, it believed that the delta T between the ambient and vapor could be maintained sufficiently long for the vapor to reach the nearest approach of Possum Hollow Run to the Station. FOE had not determined, however, through heat transfer calculations whether this delta T could indeed be maintained as assumed. Tr. 5990-94, 6085-86 (Hasbrouck).

67. Once the negatively buoyant flow of vapor reached the point providing it maximum access to the Station, FOE hypothesized that it would be bottled up by trees, underbrush and especially by a nearby railroad bridge. Again, it had not calculated the degree of blockage these postulated obstacles might provide. Hasbrouck II, ff. Tr. 5750, at 4; Tr. 5977-82, 5987-88, 6035-36, 6051-52 (Hasbrouck).

68. FOE then hypothesized that retained heat from the soil, trees and rising sun would increase the temperature of the accumulated vapor such that it would instantaneously rise above Possum Hollow Run as a compact mass and detonate. Hasbrouck II, ff. Tr. 5750, at 4; Tr. 6051-52, 6054-57 (Hasbrouck). The assumed sources of detonation were the corona from overhead wires or a strike of lightning. Hasbrouck II, ff. Tr. 5750, at 5; Tr. 5984-85 (Hasbrouck). Mr. Hasbrouck conceded that a source such as a cigarette would not cause a detonation. Tr. 5985 (Hasbrouck).

69. As to FOE's postulation that the gas would be negatively buoyant, the testimony indicated that gas exists in a pipeline at approximately ground temperature, i.e., 50°F. When a line is blown down to relieve pressure, a situation recognized by FOE to be analogous to a pipeline breach, the gas cools approximately 7°F. per 100 psi reduction in pressure. Tr. 6065-67 (Hasbrouck). As is borne out by practical experience, this reduction in temperature does not result in gas having negative buoyancy. Tr. 5296-98, 5345-46, 5352-54 (Brown).

70. As to FOE's assumption that the vapor could be bottled up behind the railroad bridge, the evidence indicated that the trestle bridge is approximately 50 feet high and that the opening under it is approximately 500 feet wide. Tr. 5980-81, 6018-20 (Hasbrouck). Obviously, this would not present a barrier to the passage of natural gas vapor, even when combined with trees and underbrush.

71. The Staff also disagreed with FOE's assumption that the escaping methane would be negatively buoyant. Tr. 7168-69, 7391-92 (Campe). There are no recorded indications that natural gas released from a pipeline breach achieves cryogenic temperatures. While there may be momentary localized cooling as gas exits the line, the mixing effect with the atmosphere quickly renders the temperature differential negligible and the gas rises into the atmosphere. Tr. 7363-64, 7369, 7393-96 (Campe).

72. FOE then postulated that the gas would stick to dirt particles created by the force of the escaping gas and thus be severed from the mainstream of gas escaping aloft. Tr. 7370. Although the evidence indicated the contrary, even assuming this event could occur and that the dirt particles would not quickly sink to the ground, the gas would not be detonable even if it approached the Station. Tr. 7371-76 (Campe).

73. Finally, FOE postulated that the methane cloud might unevenly entrain air such that discrete areas of the vapor cloud would remain unaffected and thus stay colder

than the ambient, enabling it to travel toward the Station. Tr. 7378-88. The Applicant and Staff both concluded that air would inevitably be entrained throughout the plume by wind action and the force with which the gas would issue from the rupture. As the methane travelled farther from its source, greater quantities of air would be entrained and the mixing process would quickly be completed. Tr. 7378-88 (Campe, Markee).

74. Even if the methane mixture approached the Station the uncontroverted evidence conclusively established that it could not possibly detonate. Unconfined natural gas can only be detonated with significant amounts of high energy explosives. Tr. 6156-58, 7166, 7423, 7450-52 (Campe). Sparks from an automobile exhaust, engine backfire, or the corona or sparking from overhead transmission lines could not possibly detonate this mixture. Tr. 6156-58, 7423 (Campe). Moreover, the explosion of a confined methane mixture could not detonate a nearby unconfined mixture. Thus, even if methane were confined in an outbuilding or automobile and detonated, the unconfined gas would not explode. Tr. 7497-00 (Campe).

75. The Board finds that the testimony presented by FOE in support of its conclusions regarding the amount of gasoline and natural gas vapor that would be available for a detonation has no basis in fact and, therefore, rejects its evidence. Likewise, its assertion that natural gas could detonate is totally unfounded and is also rejected. The

evidence presented by the Applicant and Staff on the other hand, while highly conservative and based on events that are not likely to occur, is authoritative and the Board concurs with their conclusions.

Deflagration Analysis

76. The Applicant and Staff also examined an assumed natural gas deflagration and found that it would have no impact on the Station. Utilizing the assumptions regarding vapor concentration, flammable limits and the travel of vapor towards the Station used in its detonation analysis, the Applicant determined that a deflagration would result in a heat load at the Unit 2 reactor enclosure of 250 btu/ft$^2$ hr. This load would cause only a slight warming of the outer concrete regardless of how long the deflagration continued. Walsh, ff. Tr. 5411, at 12-13; Tr. 5463-65 (Walsh). Moreover, this analysis conservatively assumed that the vapor cloud continued to burn at its point of closest approach to the Station. As admitted by FOE, the flame front would actually quickly retreat to the escaping gas' point source and greatly lessen the resulting load. Walsh, ff. Tr. 5411, at 13-14; Tr. 5517-19, 5558-59 (Walsh); Tr. 5988 (Hasbrouck).

77. The Staff also found that the radiant heat flux resulting from a natural gas deflagration would not exceed that accompanying solar radiation. Ferrell and Markee, ff. Tr. 6136, at 7, 16. FOE presented no evidence on this point. Tr. 5988-89 (Hasbrouck). Consequently, the Board

finds that the worst-case deflagration will have no adverse effects on the Station.

Diesel Generators

78. Intervenor also contended that flames from a deflagration or the explosive force from a detonation could enter the diesel generator exhaust pipes and incapacitate the generators. Tr. 5665-70. The evidence indicated that a deflagration or force from an explosion would be insufficient to reverse the discharge flow through these pipes if the generators were running. The exhaust system is isolated from the engine compartment by valves when the generators are not in operation. Even if an explosion or deflagration could hypothetically enter a generator's cylinders, it would be insufficient to harm the generator. Likewise, it could not cause a fire since the generators' fuel systems are separate from their exhaust systems. Moreover, the diesel fuel storage tanks, which FOE posited might explode or catch fire, are buried outside the diesel generator building and are impervious to deflagrations and detonations. Tr. 5665-70, 5732-33 (Boyer); Walsh, ff. Tr. 5411, at 10-14. Thus, the Board finds that heat and flames from a deflagration or the explosive forces from a detonation would not have any effect on the diesel generators or associated fuel storage facilities.

## II. Effect of Assumed Detonation on Safety-Related Features.

### Margin Analysis

79. The Applicant and Staff also analyzed the ability of safety-related structures to withstand postulated overpressures resulting from an assumed ARCO or Columbia Gas pipeline detonation, including the local and global response and the margins above the calculated blast overpressures inherent in the design of those structures. FOE presented no testimony on this matter. Preliminarily, the Applicant calculated the highest overpressures that would result from the worst-case ARCO or Columbia Gas pipeline explosion on the roof and bounding exterior wall of each safety-related structure. Utilizing the methodology set forth by Mr. Walsh, the Columbia Gas pipeline explosion was assumed to occur along a line of centroids parallel to the pipeline and approximately 1,100 feet from the Station, the closest the vapor could possibly approach. Vollmer, _et_ _al_., ff. Tr. 8213, at 6-10; Tr. 8985, 9017 (Walsh); _see_ Applicant's Exh. 18. The Applicant also assumed that the detonation occurred at points along this line such that its effect on each structure would be greatest. Tr. 8491, 8904 (Ashley); Tr. 9017 (Walsh).

80. The overpressures were calculated using a free air burst, an air burst and a surface burst. They were also calculated using the TNT-equivalency set forth in Reg. Guide

1.91 (Rev. 1) and four times that equivalency as used in the Applicant's original analysis. The highest possible overpressure each structure would be exposed to was determined and used to calculate its margin. In each instance, the postulated overpressures resulting from an assumed Columbia Gas pipeline detonation were found to bound the overpressures from an ARCO explosion and those results were therefore used in the Applicant's analysis. The equivalency factor provided in Reg. Guide 1.91 was included in this analysis inasmuch as the Board requested a realistic appraisal of the margins. For those structures for which the Reading Railroad explosion would produce a greater overpressure than the Columbia Gas detonation, the pressures generated by it were used in showing margin. Thus, there is even greater margin for those elements for a gas explosion. Vollmer, et al., ff. Tr. 8213, at 6-11.

81. The Applicant assumed that the airburst took place at 500 feet, the maximum height to which the natural gas could rise as a result of momentum from the postulated pipeline breach. Realistically, there are no ignition sources at 500 feet, let alone a source that could cause a detonation, even assuming that natural gas vapor could indeed detonate. In any event, a blast closer to the surface would lessen the effects of an explosion. Vollmer, et al., ff. Tr. 8213, at 9; Tr. 9066-67, 9135 (Ferrell). Thus, this approach is conservative.

82. Once the critical overpressure was determined, the Applicant identified the critical wall of each structure and the critical element of each wall. Vollmer, et al., ff. Tr. 8213, at 10; Tr. 8417, 8479, 8935 (Vollmer). In every case, the critical element was taken some distance from the corner so that, for analysis purposes, it was considered to no longer have support from the adjacent walls. Tr. 8947 (Palaniswamy); Tr. 8951 (Vollmer). The critical element was then examined as a one-foot wide beam element or isolated strip, taking into account the appropriate end conditions representative of such elements in that structure, and all margin calculations were run on that point. Vollmer, et al., ff. Tr. 8213, at 10; Tr. 8479-81, 8946 (Vollmer, Palaniswamy).

83. The wall strip was assumed to have a fixed end condition, i.e., a restraint against moment rotation at the end of the member. This assumption is quite reasonable inasmuch as the reinforcing bars passing between the wall, and the roof and intermediate floor slabs provide continuity that would restrain the wall from free movement. Tr. 8830-31 (Wong).

84. The physical properties of the elements, i.e., location, span, thickness, and amount of reinforcing steel were then determined from design values and factored into the analyses. Vollmer, et al., ff. Tr. 8213, at 10; Tr. 8416-19 (Vollmer). The minimum specified 28-day design concrete strengths were used except in the case of the spray

pond pumphouse roof and reactor building wall where actual 28-day concrete strengths were applied. Vollmer, et al., ff. Tr. 8213 at 10-11; Tr. 8417-18, 8819-20 (Vollmer); Tr. 9016 (Wong). None of these analyses utilized the additional strength of concrete that has resulted from years of additional aging since the concrete was 28 days old. The evidence indicated that this unaccounted for increase in strength is at least 20% above the values utilized in the Applicant's evaluation and thus represents a significant conservatism. Vollmer, et al., ff. Tr. 8213, at 13-14; Tr. 8818-21, 8993 (Vollmer, Wong).

85. Having isolated a wall panel strip as a unit element for analysis, the highest possible overpressure was then applied as a uniform load over the span of the element, taking into account the previously noted physical properties accompanying the span. These parameters were then used to derive a ductility ratio for that element. Tr. 8822-23 (Wong). Essentially, a ductility ratio measures the ability of an element to absorb energy resulting from a dynamic load. Tr. 8823 (Wong); see Kuo and Romney, ff. Tr. 9043, at 6). The resulting ductility ratio was then compared against the maximum code allowable, which is set in Reg. Guide 1.142 as a midspan ductility ratio of 3.0 and an end-point ratio of 10. Tr. 8426, 8822-24, 8948 (Vollmer, Wong, Palaniswamy). In each case, the ductility ratio at midpoint was found not to exceed 3.0 for any safety-related structure, thus establishing margin over the actual applied

pressures. Tr. 8945-48, 8974 (Wong, Palaniswamy). Shear design was not the limiting factor inasmuch as the Limerick designs are ductile mode designs and a ductility ratio of three in bending would therefore be reached before the building failed in shear. Tr. 8973-74 (Palaniswamy).

86. As a practical matter, a bounding ductility ratio of 3.0 is quite conservative for these kinds of buildings. Tr. 8426-27 (Vollmer); Tr. 8824 (Wong). Tests have indicated that beam elements do not actually fail until they reach ductility ratios of 20 and beyond. Tr. 9019-21 (Paliniswamy). The evidence also indicated that a one-way slab analysis, as this approach to evaluating structures is known, is very conservative. Tr. 8417, 8480, 8993, 9018 (Vollme[illegible] the entire slab had been evaluated as a whole, i.e., taking into account the support provided by the adjacent walls, each element would exhibit a great deal of additional margin. Tr. 8417, 8479-81, 9018 (Palaniswamy, Vollmer). Finally, the Applicant's margin calculations were based on a TNT-equivalency four times that which should properly have been used and thus embody a significant conservatism. Tr. 8935 (Vollmer). Even putting aside these conservatisms for a moment, the Applicant only determined how closely the overpressure would approach a given baseline margin. It did not determine the ultimate failure threshold of the structures. Therefore, although not demonstrated by the calculations, there is actually some additional factor

constituting the ability of these buildings to withstand the blast overpressures. Tr. 8991-93, 8995 (Vollmer).

87. The Applicant also investigated the global response margins inherent in the design of the safety-related structures. Given the large mass of these structures, an earthquake would result in much higher forces than an explosion, since an explosion generates forces primarily only on the external faces of buildings, and is, therefore, a more critical event. Consequently, the loading on the entire structure, i.e., story shear and overturning moment, was calculated and compared to that which would result from the Safe Shutdown Earthquake ("SSE"). In each case, the SSE loading was found to be controlling. Since there is margin even over an SSE, adequate global response margin is ensured with respect to the most severe pipeline detonation. Vollmer, et al., ff. Tr. 8213, at 11; Tr. 8824-27 (Wong, Vollmer); Kuo and Romney, ff. Tr. 9043, at 8-9.

88. The Staff calculated the maximum overpressure each critical element would be exposed to using its own pipeline scenarios. Ferrell, ff. Tr. 9041, at 6; Tr. 9147-50 (Ferrell). In each instance, the overpressures it derived, while similar, were lower than those calculated by the Applicant. Accordingly, the Staff did not independently determine the degree of margin inherent in the design of each structure. It did, however, review the Applicant's choice of critical elements, the properties associated with those elements and the methodology used to assess the

behavior of the structure and found them to be conservative. Kuo and Romney, ff. Tr. 9043, at 3-4; Tr. 9069-70, 9205-07, 9219-22 (Romney, Kuo). It also audited the Applicant's margin calculations. Tr. 9206, 9221 (Romney, Kuo). The Staff agreed that a ductility ratio of 3.0 is very conservative and that the elements in question have additional margin over that calculated by the Applicant. Tr. 9223 (Kuo).

Factors Allegedly not Considered in Margin Analysis

89. FOE contended that the Applicant's margin analysis did not account for a number of factors, including gravity and deadload. Tr. 8261-62, 8372, 8441-42, 9200. To the contrary, the evidence indicated that these factors were considered as appropriate. Tr. 8442 (Vollmer). The uncontroverted evidence established that the deadload consisting of the weight of the walls and equipment attached thereto is transmitted to the ground as a vertical compressive load. Since the postulated overpressures would act horizontally, and thus perpendicular to the walls, the effect of the deadload and the blast overpressure would not be additive. Tr. 8442-45 (Vollmer, Palaniswamy); Tr. 9201 (Romney). Additionally, the compression resulting from deadload is actually beneficial in terms of a wall's ability to withstand bending since it acts as a prestress. Tr. 8445 (Palaniswamy). The roof slab deadload acts in the same

direction as a downward acting blast pressure and was, therefore, considered as appropriate. Tr. 8372 (Vollmer); Tr. 8442-43 (Palaniswamy, Vollmer). Moreover, these forces were also considered in the design of these structures and in the appropriate margin calculations. Tr. 9202-03, 9245 (Romney).

90. Intervenor's contention that the vibratory load from equipment operating within the reactor building was not considered was likewise unsupported by the record evidence. Tr. 8372. The evidence indicated that vibratory loads were considered and found to be negligible. Tr. 8373, 8378-79 (Vollmer, Palaniswamy). Moreover, that portion of the vibratory load not eliminated by the damping effect of the 1½ to 2 foot thick floors would primarily be transferred from the floor slab to the supporting beams and columns, thus leaving the wall slabs largely unaffected. Tr. 8375-78 (Boyer, Wong, Palaniswamy). The roof slabs would not experience vibratory loading since there is no moving equipment on them. Tr. 8378-79 (Wong, Palaniswamy).

91. FOE also contended that the Applicant's margin calculations did not account for the pressure differential between the interior and exterior of the reactor building. Tr. 8446. The evidence indicated that the reactor building is operated with a negative pressure of about 1/100 of one psi to prevent releases from escaping that building. This factor was not calculated as a stress since it is so small

as to be beyond the accuracy of any calculation. Tr. 8446 (Boyer, Vollmer).

92. Intervenor then hypothesized that temperature differences inside and outside the structure could cause unaccounted for stresses. Tr. 8446-47. The evidence indicated that it is not necessary to take this factor into account since temperature variations create a thermal gradient that leaves concrete walls unaffected. Tr. 8447 (Walsh). Only an instantaneous temperature drop that is not reflected throughout a wall could potentially cause a problem. Tr. 8447-51 (Vollmer). No source for such a drop was shown to be possible. Moreover, temperature loading was accounted for in the design of the safety-related structures. Tr. 8450 (Vollmer); Tr. 9181-83.

93. FOE likewise asserted that hydrostatic pressures were not considered as part of the load impacting the external walls. Tr. 8463-64, 9189-9200. The unrebutted evidence conclusively established that groundwater does not apply above-ground loads. Tr. 8463-69 (Vollmer); Tr. 9190 (Romney); Tr. 9195-9200 (Romney, Kuo). Hydrostatic loads are non-existent at ground level and increase with depth. The shear forces created by hydrostatic loading are taken out of a wall where it meets the basemat. Therefore, the intersection of that wall and ground level could not possibly act as fulcrum with respect to above-ground forces, as was postulated by FOE. Tr. 9195-9200 (Romney, Kuo). Moreover, lateral earth and hydrostatic pressures were

accounted for in the design of the structure in any event. Tr. 8463-64 (Vollmer); Tr. 9189-92 (Romney).

94. Finally, FOE postulated that differential settlement had not been taken into account. Tr. 8469, 9215-16. The evidence was clear, however, that differential settlement exerts force on a structure only if settlement actually is taking place. The evidence was also clear that Limerick is located on a competent rock foundation and that there is no differential settlement. Tr. 8469 (Vollmer); Tr. 9215-17 (Romney). Again, the stresses that would be caused by differential settlement were factored into the design of the safety-related structures. Tr. 9215 (Romney).

Reactor Building Openings

95. Intervenor then postulated that the blast wave would enter the reactor building and damage safety-related equipment and systems contained therein. Specifically, it postulated that the blast overpressure would enter the reactor building through a louver in the south wall. Tr. 8955-88. The evidence indicated that this louver, which is nine feet high and 40 feet wide, is constructed of heavy gauge steel and is designed for wind loads of approximately 30 pounds per square foot. It does not provide structural support for the building and is not safety-related. Tr. 8955-57, 8964 (Wong). Therefore, its failure would in no way affect the integrity of the reactor building. Tr. 9110-11, 9132 (Kuo, Romney). Moreover, this louver opens into a compartment containing non-safety-related HVAC

equipment that is not needed for the safe shutdown of the plant. Tr. 9132 (Kuo). The walls surrounding this compartment are one foot thick and would resist any residual overpressure that is not absorbed by the louver. Tr. 8955-58, 8965 (Wong); Tr. 9114 (Kuo). Generally, inasmuch as the blast wave is relatively narrow, i.e., 50 milliseconds, the blast pressure would alleviate itself before the impacted surface could deteriorate. Thus, the blast wave would not affect the interior of any structure. Tr. 8496-97 (Ashley); Tr. 8963-64 (Vollmer).

96. The ducts inside the louver compartment pass into the reactor building through a sheetmetal plenum set in the interior wall. Tr. 8957-58, 8964-67 (Wong). Even if this plenum were damaged or distorted, there would be no harmful effect on the equipment inside the compartment. Tr. 8966-67 (Boyer). Even assuming that the pressure wave were not absorbed in any way, an incredible event given the louver, inner compartment walls and plenum, the average pressure inside the reactor building would increase by no more than .016 psi, which is insufficient to affect the structure. Tr. 8958, 8965-66 (Ashley, Walsh, Boyer). By comparison, it takes 0.1 psi to break a normal house window. Tr. 8958 (Ashley). The Staff agreed that even a pressure increase inside the building of .05 would be negligible and would not affect the building, the internal wall, or the

safety-related systems or equipment contained therein. Tr. 9113 (Romney).

97. There is also a two-foot square roof opening in the reactor building. This opening is covered by a sheetmetal blowout panel which is designed to relieve the pressure inside the building and which does not serve any structural purpose. Tr. 8253-54, 8959-60 (Wong). Even if it was displaced, the resulting pressure differential would last only a fraction of a second and would be insufficient to dislodge any pipes that might be nearby. The uncontroverted evidence indicated that the pressure wave would quickly become that of the ambient as it expanded inside the large volume of the reactor building and, at most, would increase the pressure within the building's interior by less than .01 psi. Tr. 8960-63 (Ashley, Wong).

98. There are also sheetmetal buildings on the north and south sides of the reactor building roof which could conceivably be damaged by a detonation. These buildings, which are roughly 40 feet square and 15 feet tall, are not required for the safe shutdown of the Station. The conduits going from these buildings into the reactor building are sealed and would not be affected by an explosion. Therefore, even if these buildings were swept away by a blast wave, they would not provide an opening into the reactor building. Tr. 8969-70 (Boyer, Wong).

Effect of Detonation on Underground Structures

99. It was also determined that the blast pressure would have no effect on buried safety-related features. The evidence indicated that buried safety-related pipes and ducts must have a minimum cover of four feet of soil or the equivalent in concrete or other material. Tr. 8864-65 (Boyer); Kuo and Romney, ff. Tr. 9043, at 11. The postulated overpressures will not affect safety-related buried pipes, manholes or duct banks since the soil coverage over these items can take a minimum of 3,000 to 4,000 pounds per square foot, which is a factor of ten over the load that would result from the worst-case explosion. The manhole and duct bank covers are at least that strong since they are designed for high impact loads such as would result from a tornado missile. Tr. 8805-06 (Wong, Vollmer).

100. As part of its investigation, the Applicant analyzed a worst-case scenario in which it postulated that a five-foot by five-foot by one-foot piece of concrete fell from a cooling tower directly onto buried safety-related features. The striking velocity of the piece of concrete was conservatively assumed to be 200 feet per second. This compares with a velocity of 188 feet per second for a free fall of approximately 550 feet from the top of the tower to grade level. Also, the worst orientation, i.e., a corner of the piece hitting the ground, was assumed. The Applicant found that the concrete section would only penetrate 2.8 feet into the soil and, therefore, would not affect the

safety-related facilities buried below. Vollmer, et al., ff. Tr. 8213, at 16; Tr. 8870B (Boyer, Vollmer). The Staff agreed with this conclusion. Kuo and Romney, ff. Tr. 9045, at 11-12. Moreover, the force propagated by a missile penetrating 2.8 feet into the soil would dissipate in the additional cover and would not affect the buried facilities. The force on the buried piping would not exceed 1,500 psi in bending versus an allowable of 24,000 psi. Tr. 8816-17 (Wong).

101. FOE then postulated various scenarios involving sections of falling cooling tower it speculated might have a greater impact on buried safety-related features. In its first scenario, FOE speculated that an individual steel reinforcing bar or concrete section with steel reinforcing bars sticking out of it might break away from a tower and penetrate the earth to a greater depth than the section postulated by the Applicant. Tr. 8875-77. The unrebutted evidence conclusively established that individual steel rods will not fall from the towers or protrude in significant lengths from pieces of falling concrete. Reinforcing bars are ductile and will, therefore, only fracture at the same point the concrete fractures. Moreover, the reinforcing bars are bonded over their length and since the towers will buckle at very low overpressures, the concrete will not be detached from the bars. Tr. 8875-78 (Vollmer, Wong, Buchert).

102. Intervenor also hypothesized that various other structures, including the 70 foot tall columns supporting the cooling towers and the 500 kv transmission towers, would fail and penetrate the buried safety-related facilities. Tr. 8912-15, 8921-24. To the contrary, the evidence established that the supports, which are anchored into the cooling tower foundations, would merely pivot around their bases and lay over. Since the nearest safety-related features are 100 feet away, the supports could not reach them. Moreover, the columns would penetrate no more than one foot in any event. Tr. 8912-15, (Vollmer, Boyer, Buchert). Likewise, the transmission towers, if they failed, would buckle and fold over, thus the impact would not occur at high speed and certainly would not be as severe as from other missiles the facilities have been evaluated for. Tr. 8921-24 (Vollmer); Tr. 9260 (Romney).

103. Finally, FOE's speculation that the falling cooling towers would cause a seismic effect was conclusively rebutted by testimony indicating that resulting motion, if any, would be quickly damped out by the intervening media. Tr. 9296-9300 (Kuo).

<u>Breach of Cooling Tower Basin</u>

104. Various scenarios were then postulated involving the failure of the cooling towers. The evidence indicated that the forces resulting from a detonation would cause the cooling towers to react in the direction opposite the blast wave. Based on evidence derived from a theoretical

analysis, model tests and actual cooling tower failures, it was determined that the thin shells would buckle at approximately 0.3 psi, long before the total blast pressure built upon them. Tr. 8834, 8878-79 (Buchert). Since their buckling load is so small, a tower could not possibly rotate as a rigid body and overturn as a whole or at half its height. Tr. 8884-85 (Buchert).

105. Intervenor then postulated that the falling towers would breach the cooling water basin, flooding the turbine building and allowing water to enter the reactor and control building through connecting doors or openings it speculated would be created when pipes passing between those structures were damaged by the blast pressure. The Applicant assumed that the cooling tower failure breached the south side of the Unit 1 cooling tower basin and opened a 50-foot gap releasing 300,000 gallons of water per minute for approximately 30 minutes. The uncontroverted evidence indicated that the size and direction of this assumed breach is conservative. If it were assumed that the entire basin failed, most of the water would flow away from the Station. By limiting the breach to the basin's south side, the escaping water is directed most effectively toward the turbine building. Vollmer, et al., ff. Tr. 8213, at 18; Tr. 9025-27 (Wong, Benkert).

106. The turbine building has three main openings at grade level including a roll-up railroad door and two personnel access doors. The personnel access doors are

maintained in a closed position and water could not enter them. Even if all doors were open, however, no more than four feet of water could enter the turbine building. The walls of the reactor and control buildings are water and steam tight to above this height and water could, therefore, not enter either of those structures. Tr. 9028-30 (Benkert). The evidence also indicated that the doors connecting these structures are airtight and are maintained in a closed position to preserve negative pressure in the reactor building. Tr. 8454-56 (Boyer, Vollmer). Moreover, the turbine and reactor buildings are separated by a four-inch seismic gap. Tr. 8381-82, 8453-54 (Wong); Tr. 9367 (Romney). Therefore, forces from the turbine building would not be applied to the walls of the reactor building and the piping running between the two buildings would, therefore, not be damaged. Tr. 8458-59 (Vollmer). In any event, this piping is designed to allow relative movement and the surrounding materials, which are leaktight, would prevent the influx of water. Tr. 8454-56 (Boyer, Vollmer); Tr. 8496 (Boyer).

107. The Staff likewise determined that a cooling tower basin breach would have no effect on safety-related structures. Lefave, ff. Tr. 9047, at 2. It, too, assumed a 50-foot wide breach in the direction of the turbine building, the optimum width maximizing the effect of escaping water, and that the turbine building roll-up and personnel access doors were open. On this basis, the Staff

determined that water in the area of the turbine building would be above elevation 217 for a short time and consequently assumed that some limited flooding of that building would occur. Wescott, ff. Tr. 9045, at 4. As a practical matter, it testified that no water would actually enter the building, but that it had conservatively assumed the contrary. Tr. 9302-15 (Wescott). The Staff similarly concluded that water could not enter the reactor or control buildings from the turbine building because of the watertight features separating those structures. Tr. Lefave, ff. Tr. 9047, at 3-4.

108. In response to FOE's postulation that damage to the north wall and roof of the turbine building would allow water to enter the reactor and control buildings, the Staff testified that an intervening floor between the first floor and the roof of the turbine building would negate any damage the roof's collapse might otherwise cause. Only two feet of the north wall would have to remain standing to deny water access to the building in any event. Even if that wall did not exist, the watertight interior wall inside the north wall would not be affected by the blast overpressure and would resist any influx of water. Tr. 9313-18 (Lefave, Kuo, Romney).

109. The evidence also conclusively established that it would be impossible for the cooling towers to fail in opposite directions and form a dam around the turbine building as postulated by the intervenor. Tr. 9302-12

(Romney). In any event, the testimony was clear that debris from the cooling towers would actually divert water away from the turbine building instead of towards it. Tr. 9302-12 (Wescott).

110. Finally, FOE postulated that pieces of the falling cooling towers would displace water from the basin and cause increased flooding. The Staff agreed that water could be displaced by the falling materials, but testified that it would disperse in all directions and not just south toward the Station. Moreover, not as much water could be lost this way as could be lost through an actual breach of the basin. Wescott, ff. Tr. 9045, at 3; Tr. 9388-90 (Wescott).

Effect of Escaping Water on Buried Safety-Related Features

111. The Applicant and Staff also examined the extent to which water escaping the cooling tower basin might erode the ground cover over the duct banks and pipes. The evidence indicated that the manhole access openings are protected from runoff by tight-fitting steel covers equipped with gaskets and that water penetration would therefore be minimal. Vollmer, et al., ff. Tr. 8213, at 19; Lefave, ff. Tr. 9047, at 3. Moreover, the electrical cables in the duct banks have been designed to function underwater and the electrical conduits that travel to electrical manholes outside those structures are watertight as well. Vollmer, et al., ff. Tr. 8213, at 19; Lefave, ff. Tr. 9047, at 3.

112. Since most seismic Category I piping is supported by rock, the effect of erosion, if any, would be insignificant. Portions of the seismic Category I buried pipes to the northwest of the Unit 1 cooling tower are supported by Type I granular fill. Most of the soil cover over this location is more than 10 feet thick, with a small portion having five feet of cover. This would be of no consequence, however, as the escaping water would run off quite rapidly and cause very little erosion. Although some cover might be washed away, it would take considerably longer than the 30 minutes it is calculated water would flow from the worst-case breach of the basin to completely expose any portion of buried piping. In any event, the seismic Category I piping is capable of spanning more than 30 feet without support and still carry the weight of the pipe and its contents without loss of function. Vollmer, et al., Tr. ff. 8213, at 19-20.

113. The Staff agreed with the Applicant's conclusions regarding erosion and the effect of water on buried safety-related features. Wescott, ff. Tr. 9045, at 2, 4; Lefave, ff. Tr. 9047, at 2. Its analysis indicated that the failure of the cooling tower basin would not cause erosion sufficient to affect the electrical ducts and piping. They determined that erosion, if any, would occur only in the immediate vicinity of the breach and would not erode more than a couple feet of cover. It definitely would not reach the buried concrete ducts and even if it did, would not

erode the concrete or under it. Wescott, ff. Tr. 9045, at 4; Tr. 9323-37 (Wescott).

## Conclusions of Law

Based upon the foregoing Findings of Fact, which are supported by reliable, probative and substantial evidence as required by the Administrative Procedure Act and the Commission's Rules of Practice, and upon consideration of the entire evidentiary record in this proceeding, the Board reaches the following conclusions pursuant to 10 C.F.R. §2.760a:

(1) The worst case rupture of the ARCO pipeline has been analyzed. The effects of siphoning have been examined as part of this consideration and found to be less than the scenario used in that analysis.

(2) The effect of radiant heat and explosive forces upon the diesel generators and associated diesel fuel storage facilities were specifically considered in the analysis of the deflagration or detonation of natural gas or gasoline resulting from an assumed pipeline rupture and found to be nonexistent.

(3) The overpressures that would result from a natural gas or gasoline explosion have been calculated and it has been determined that there is sufficient margin inherent in the design of the safety-related structures to withstand the highest possible overpressures that would result from such explosions such that they could continue to perform their safety function.

APPENDIX A

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APPENDIX B

Exhibit List

Applicant

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|---|---|---|---|
| PECO Ex. 7 | Limerick Generating Station Site Plan, AB-207392-5, August 31, 1970. | 5357 | 5357 |
| PECO Ex. 8 | Color Photograph of Cooling Tower Plumes Coming from the John Amos Plant. | 6236 | 6236 |
| PECO Ex. | Cooling Towers and the Environment, Major Contributors: Maynard Smith, Mark Kramer and David Seymour, October 1974. | 6413 | 6413 |
| PECO Ex. 10 | Amos Cooling Tower Flight Program, Test No. 48A, March 11, 1975. | 6649 | 6649 |
| PECO Ex. 11 | Douglas Point Power Plant Site Evaluation Final Report, Vol. 1, Part 2, L.C. Kohlenstein, Project Engineer, Published by the Johns Hopkins University Applied Physics Laboratory, January 1976. | 6650 | |

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| PECO Ex. 12 | John E. Amos Cooling Tower Flight Program Data, Conducted for the American Electric Power Service Corporation by Smith-Singer Meteorologists, Inc., December 1975-March 1976. | 6765 | |
| PECO Ex. 13 | Environmental Measurements of Power Plant Cooling Tower and Stack Plumes, Final Report for AEC, ERDA and DOE, Conducted by the Department of Meteorology, Pennsylvania State University, Edited by D.W. Thomson, R.G. de Pena, J.A. Pena, Updated. | 6868 | |
| PECO Ex. 14 | Table 2.2-3 of the Limerick Generating Station Final Safety Analysis Report, "Airports Within Ten Miles of the Site," Rev. 4, 05/82. | 6972 | |
| PECO Ex. 15 | Figure 1, One page document, Free Air-Burst Blast Environment | 8214 | 8214 |
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| PECO Ex. 19 | Figure 4, one page document entitled "Cooling Tower General Arrange-ment" | 8214 | 8214 |
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| PECO Ex. 23 | Figure 8, single page, large scale sheet entitled "Profiles of RHR & ESQ Pipes Showing Ground Cover" | 8214 | 8214 |
| PECO Ex. 24 | Figure 9, single page, large scale sheet entitled "Profiles of Cat. 1 Electrical Duct Banks Showing Ground Cover" | 8214 | 8214 |

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| PECO Ex. 25 | Figure 10, one page document entitled "Intense Storm Site Runoff Pattern: General Plan," Figure 2.4-4, LGS FSAR. | 8214 | 8214 |
| PECO Ex. 26 | Figure 11, one page document entitled "Intense Storm Site Runoff Pattern: Spary Pond and Cooling Tower Areas," Figure 2.4-5, LGS FSAR. | 8214 | 8214 |
| PECO Ex. 27 | Figure 12, one page document entitled "Duct Bank Sections" | 8214 | 8214 |
| PECO Ex. 28 | Figure 13, one page document entitled "Buried Pipe Bedding" | 8214 | 8214 |
| | **STAFF** | | |
| Staff Ex. 6 | NUREG-0911 "Safety Evaluation Report Related to the Operation of Limerick Generating Station," Section 2.2.2, August 1983. | 6137 | 6138 (Bound in ff. 6138) |
| Staff Ex. 7 | Regulatory Guide 1.91 (Revision 1), "Evaluations of Explosions Postulated to Occur on Transportation Routes Near Nuclear Power Plants,." February 1978. | 6150 | 6153 |

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| Staff Ex. 8 | VFR Terminal Area Chart for the Philadelphia Area, 18th Edition, September 2, 1983. | 7104 | |
| Staff Ex. 9 | National Transportation Safety Board Pipelines Accident Report. No. NTSB-PAR-76-8, Los Angeles, California, cover pg. and fig. 3, June 16, 1976. | 7145 | |
| Staff Ex. 10 | NUREG-0570, "Toxic Vapor Concentrations Control Room Following a Postulated Accidental Release," June 1979. | 7145 | |
| Staff Ex. 11 | Army Technical Manual, TM 5-1300, "Structures to Resist the Effects of Accidental Explosions," TM 5-1300, cover pg., fig.4-4 and 4-12, June 1969. | 7146 | |
| Staff Ex. 12 | National Transportation Safety Board Pipeline Accident Report No. NTSB-DAR-80-6. Bayamon, Puerto. Rico, cover pg., summary pg. and pgs. 5,12, January 30, 1980. | 7147 | |
| Staff Ex. 13 | U.S. Atomic Energy Commission, "Meteorology and Atomic Energy 1968," July 1968. | 7147 | |
| Staff Ex. 14 | NUREG/CR-1748, "Hazards to Nuclear | 7148 | |

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| | Power Plants from Nearby Accidents Including Hazardous Materials - Preliminary Assessment," Chemical Engineering, cover page and pgs. F-2, F-4, F-8 and F-11, Undated. | | |
| Staff Ex. 15 | "Unconfined-Vapor Cloud Explosions," V.C. Marshall, June 14, 1982. | 7148 | |
| Staff Ex. 16 | "Conditions of External Loading of Nuclear Power Plant Structures by Vapor Cloud Explosions and Design Requirements," W. Geiger, Undated. | 7149 | |
| Staff Ex. 17 | "Transactions of the 4th International Conference on Structural Mechanics in Reactor Technology," August 19, 1977. | 7151 | |
| Staff Ex. 18 | Department of Transportation, "Explosions Hazards Associated with Spills of Large Quantities of Hazardous Materials Phase II," Report No. CG-D-85-77, C.D. Lind and J.C. Whitson, November 1977. | 7151 | |
| Staff Ex. 19 | NRC Testimony of Jacques B.J. Read Relating to Safety Implications of the Natural Gas Pipelines which | 7152 | |

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| | Passes by the Hartsville Site, In the Matter of Tennessee Valley Authority (Hartsville Nuclear Plants Units 1A, 2A, 1B, and 2B), Undated. | | |
| Staff Ex. 20 | Army Technical Manual, TM 5-1300, "Structures to Resist the Effects of Accidental Explosions," dover page and figures 4-3, 4-4, 4-5, 4-6, 4-7 and 4-12, June 1969. | 9050 (Bound in ff. 9055) | |
| Staff Ex. 21 | One page graph, "Limerick Peak Positive Reflected Overpressure and Positive Phase Pulse Time Due to 56 Tons of TNT," Undated. | 9051 | 9054 (Bound in ff. 9055) |
| Staff Ex. 22 | U.S. Atomic Energy Commission, "The Effects of Nuclear Weapons," Samuel Gladstone, Editor, cover page and pgs. 147 and 151, April 1962. | 9051 (Bound in ff. 9055) | |
| Staff Ex. 23 | Table I, "Summary of Accidental Explosion Pressures," Undated. | 9051 | 9055 (Bound in ff. 9055) |
| Staff Ex. 24 | Figure 1 "Selection of Critical Element for Purpose of Analysis and Design," February 8, 1984. | 9052 (Bound in ff. 9055) | |
| Staff Ex. 25 | Figure 2, "Typical Load Deformation Curve Idealized | 9052 | |

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| | Elastic-Plastic System," February 13, 1984. | | |
| Staff Ex. 26 | 1979 Supplement "Code Requirements for Nuclear Safety Related Concrete Structures (ACI 349-76) and Commentary on Code Requirements for Nuclear Safety Concrete Structures (ACI 349-76), Appendix C, Undated. | 9053 (Bound in ff. 9055) | |
| Staff Ex. 27 | Memorandum from Norman D. Romney, Structural Engineer, NRC, to George Lear, Chief, Structural and Geotechnical Engineer Branch, NRC, "Limerick Conference Call Between NRC Staff, Bechtel Corporation and Philadelphia Electric Company," March 13, 1984. | 9071 | 9073 (Bound in ff. 9073) |
| Staff Ex. 28 | Regulatory Guide 1.142 (Revision 1) "Safety-Related Concrete Structures for Nuclear Power Plants (Other Than Reactor Vessels and Containments)," October 1981. | 9211 | |
| FOE Ex. 1 | Nuclear Power, Armory Lovins, pg. 161, Undated. | 5542 (Rejected) | |
| FOE Ex. 2 | National Transportation Safety Board Pipeline | 5257 | 5258 |

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| | Accident Report No. NTSB-PAR-73-2, Hearne, Texas. August 1, 1973. | | |
| FOE Ex. 3 | National Transportation Safety Board Pipeline Accident Report No. NTSB-PAR-75-3, Farmington, New Mexico, March 15, 1974. | 5758 | 5759 |
| FOE Ex. 4 | Transactions of the ASME "Decompression of Gas Pipelines During Longitudinal Ductile Fractures," G.G. King, March 1979. | 5768 (Rejected) | |
| FOE Ex. 10 | Journal of the Soil Mechanics and Foundation Division, "Depth Prediction for Earth-Penetrating Projectiles" C. Wayne Young, May 1969. | 8881 | |
| FOE Ex. 5 | Figure 6-2, "Structures to Resist the Effects of Accidental Explosions," Undated. | 8979 | |
| FOE Ex. 11 | "Nuclear Safety-Related Concrete Structures, ACI-349-80," pg 349-83, Undated. | 9007 | |
| FOE Ex. 9 | LGS FSAR Table 3.5-5, "Railroad-Accident-Generated Missile Parameters," Undated. | 9009 | |
| FOE Ex. 6 | Post Card Depicting Limerick Generating Station. | 9253 | |

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| | **AWPP** | | |
| AWPP Ex. 1 | The New Private Pilot, Published by Pan American Navigation Service, 8th Edition, Cover Page and Pages 53-54. | 6949 | |
| AWPP Ex. 2 | Those Icy Fingers in Your Carburetor, Aviation Consumer Magazine, January 1, 1982. | 7046 | |

UNITED STATES OF AMERICA
NUCLEAR REGULATORY COMMISSION

| | | |
|---|---|---|
| In the Matter of | ) | |
| | ) | |
| Philadelphia Electric Company | ) | Docket Nos. 50-352 |
| | ) | 50-353 |
| (Limerick Generating Station, | ) | |
| Units 1 and 2) | ) | |

## CERTIFICATE OF SERVICE

I hereby certify that copies of "Applicant's Proposed Findings of Fact and Conclusions of Law in the Form of a Partial Initial Decision," dated April 20, 1984 in the captioned matter have been served upon the following by deposit in the United States mail this 20th day of April, 1984:

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