UNITED STATES OF AMERICA
NUCLEAR REGULATORY COMMISSION

BEFORE THE ATOMIC SAFETY AND LICENSING APPEAL BOARD

In the Matter of VIRGINIA ELECTRIC AND POWER COMPANY (North Anna Nuclear Power Station, Units 1 and 2)	Docket Nos. 50-338 OL 50-339 OL

NRC STAFF MEMORANDUM OF PROPOSED FINDINGS REGARDING SERVICE WATER PUMPHOUSE SETTLEMENT AND TURBINE MISSILE RISK

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Upon *sua sponte* review of the Atomic Safety and Licensing Board's initial decision authorizing issuance of operating license for North Anna Nuclear Power Station, Units 1 and 2,[1/] the Atomic Safety and Licensing Appeal Board (Appeal Board) affirmed the decisons with respect to most matters but retained jurisdiction over three issues.[2/] The Appeal Board withheld its approval in connection with the following two plant safety issues: (1) settlement beneath the failities' pumphouse[3/] and (2) the probability of unacceptable damage from missiles generated either inside or outside the facilities;[4/] in addition, it continued to keep open the radon-release issue which is pending in a number of other proceedings as well.[5/] Subsequently, the Appeal Board called for an evidentiary hearing on the two plant safety issues[6/] and held

1/ LBP-77-68, 6 NRC 1127 (1977) and LBP-78-10, 7 NRC 295 (1978).

2/ ALAB-491, 8 NRC 245 (1978).

3/ *Id.*, at 247

4/ *Id.*, at 249-50.

5/ *Id.*, at 250, fn. 12.

6/ ALAB-529, 9 NRC 153 (1979).

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a public hearing on those issues on June 18, 19 and 20, 1979. At the conclusion of the hearing the Appeal Board indicated that an opportunity would be provided for the parties to submit memoranda indicating the specific findings of fact that should be included in the Board's decision (Tr. 620-23). The proposed findings of the NRC Staff (Staff) are set out below.

I. SERVICE WATER PUMPHOUSE SETTLEMENT

A. Introduction

At the time an operating license was issued for North Anna, Unit 1, it was known that settlement of the service water pumphouse (SWPH) was occurring and would continue to occur. "VEPCO's Testimony on Service Water Pumphouse Settlement" (hereinafter VEPCO's SWPH Testimony) at 9-16 following Tr.19. Accordingly, a technical specification was included in the operating license which contained limits on both average pumphouse settlement (that is, the average of the measurements of the monitoring points at the four corners of the structure) and differential settlement between the pumphouse itself and the service water piping on the north side of the expansion joints (Tr. 244, 258-59; Existing Technical Specifications 3/4.7.12 and 3/4.7.13 and Tables 3.7-5 and 3.7-6 for North Anna, Unit 1, served on the Board and parties with NRC Staff counsel's letter of December 22, 1978). The allowable differential settlement between the SWPH and the piping on the north side of the expansion joints was 0.25-foot. The total allowable settlement for the four points on the SWPH averaged from December 1975 was 0.15-foot.

In June 1978 VEPCO asked that the allowable average settlement be increased to 0.33-foot since December 1975 (VEPCO's SWPH Testimony 19), the 0.25-foot limit on differential settlement to remain unchanged (Tr. 261, 263). After conducting a detailed review, the Staff indicated in its evaluation[7/] several concerns and proposed revised Technical Specifications 3/4.7.12 and Table 3.7-5 (regarding settlement of Class 1 structures), 3/4.7.13 and Table 3.7-6 (regarding groundwater conditions under the pumphouse and service water reservoir) to allay those concerns. [By letter of January 9, 1979, the NRC Staff indicated corrections to Table 3.7-5.]

The Staff proposed, in contrast to VEPCO's proposal, a limit on differential settlement between pumphouse and service water lines of 0.22-foot since July 1977 ("NRC Staff Testimony Regarding Pumphouse Settlement by L. Heller, R. Kiessel, J. Lenahan, J. Wermiel, and D. Dromerick" (hereinafter Staff PH Testimony) at 36 following Tr.338, an absolute limit of 0.22-foot of settlement of the exposed ends of the service water lines since August 1978 (Id. 41; Tr. 410), and a limit of 0.17-foot differential settlement between the southeast corner of the pumphouse and the hangers that support the pipes supplying the service water reservoir spray system (Staff PH Testimony at 47).

Both the original and the revised technical specifications have a requirement that if settlement exceeds 75 percent of any allowable settlement value the Applicant must conduct an engineering review and submit a special report to the NRC within 60 days. If settlement reaches 100 percent of any allowable value, the station must be shut down.

7/ Safety Evaluation of Virginia Electric and Power Company's Request to Revise Technical Specifications of Section 3/4.7.12, served on the Board and parties December 22, 1978.

By the time of the public hearing the Staff and VEPCO had agreed on a technical specification incorporating the Staff's limits. The only disagreement between Staff and VEPCO concerned the frequency of monitoring the pumphouse settlement. The Staff maintains that monthly monitoring is necessary for the next three years (Staff PH Testimony 42-43) while VEPCO believes every six months will be adequate (Tr. 110-112, 265). This matter will be discussed below in Section G, Monitoring.

On May 17, 1979, VEPCO moved the Appeal Board either to direct or to authorize the NRC Staff to increase on an interim basis the allowable pumphouse settlement limits contained in the North Anna Technical Specifications "to the extent the Staff thinks justified on the basis of the Staff's own safety review." This motion was not opposed by either of the intervenors in the proceeding but was opposed by the Staff ("NRC Staff Answer to VEPCO Motion for Interim Technical Specification Change," dated June 6, 1979). The Staff argued that, by virtue of 10 CFR § 2.717(b), it was for the Director of the Office of Nuclear Reactor Regulation (NRR) to determine in the first instance whether the action sought by VEPCO is warranted. The Staff informed this Board that, based on its analysis, it was prepared to increase the allowable settlement limits for the pumphouse without abiding the event of this Board's ultimate decision on the settlement issue. However, the Staff informed this Board that it would defer any action on this amendment for a period of 20 days from the date of the Staff's response to provide this Board with an opportunity to consider the matter. Without deciding the correctness of the Staff's interpretation of 10 CFR § 2.717(b) the Appeal Board, in its Memorandum and Order of June 21, 1979, relieved the Staff of its commitment to withhold action for the prescribed period.

On June 28, 1979, the Staff issued Amendment No. 12 to the operating license for North Anna 1. This amendment institutes the technical specification limits on settlement proposed by the Staff and requires monthly SWPH settlement monitoring. Amendment No. 12, served on the Board and parties along with cover letter from the NRC's Olan D. Parr to VEPCO's W. L. Proffitt, June 28, 1979).

The Appeal Board called for evidentiary hearings on the issue of pumphouse settlement in ALAB-529 and set out areas of concern to be addressed by the parties. In response to ALAB-529, VEPCO submitted prefiled written testimony on this issue on April 27, 1979.8/ The Staff filed a portion of its testimony on this issue on April 27, 1979 and the remainder of its testimony on May 4, 1979.9/

8/ VEPCO submitted proposed testimony entitled "VEPCO's Testimony on Service Water Pumphouse Settlement," dated April 27, 1979 (attached to this testimony were proposed Technical Specification 3/4.7.12 and Table 3.7-5 for Units 1 and 2 and a copy of Tables and Figures for Pumphouse Settlement Testimony) and proposed testimony entitled "VEPCO's Supplemental Testimony in Response to NRC Staff Testimony on Service Water Pumphouse Settlement," dated May 31, 1979, and a document entitled "Geotechnical Investigations of Service Water Reservoir, North Anna Power Station, Units 1 and 2 for Virginia Electric and Power Company," dated December 23, 1975 (Exhibit AV-1 identified).

9/ The Staff's testimony entitled "NRC Staff Testimony Regarding Pumphouse Settlement by L. Heller, R. Kiessel, J. Lenahan, J. Wermiel, and A. Dromerick," as a result of the Staff filings of April 27, 1979 and May 4, 1979, as a single piece of proposed testimony.

Neither Mrs. Arnold nor the Commonwealth of Virginia submitted any written testimony. By stipulation of the parties, the Staff and VEPCO's proposed testimony and VEPCO's Exhibit AV-1 were admitted and received into the record in this proceeding following Tr.19 (for VEPCO) and Tr.338 (for Staff).10/

The written testimony as well as the oral presentations made by the Staff and VEPCO witnesses on direct and in response to cross-examination responds to all areas of concern raised by the Appeal Board in ALAB-529.

B. Description of Service Water System

The service water system for North Anna Units 1&2 is designed to provide cooling water to the safety-related systems for normal operating conditions, anticipated operational occurrences and accident conditions. Service water flow is provided to the charging pump coolers, control room air conditioners, instrument air compressors, and pipe penetration cooling coils for any of the above three conditions. During normal operation and cooldown, service water flow is also provided to the component cooling heat exchangers. In

10/ Also received as testimony in this proceeding on the pumphouse settlement issue were copies of the Professional Qualifications of the following witnesses for the Staff: L. Heller, R. Kiessel, J. Lenahan, J. Wermiel, and A. Dromerick following Tr.338. The Professional Qualifications of the following witnesses were received into evidence for VEPCO on the pumphouse settlement issue: Bruce N. MacIver, A. Stanley Lucks, Robert B. Bradbury and W. R. Cartwright following Tr.19.

The Staff presented its oral testimony on the issue of pumphouse settlement through a panel composed of L. Heller, R. Kiessel, J. Lenahan, J. Wermiel, and A. Dromerick. VEPCO presented its oral testimony through a panel which was made up of Bruce N. MacIver, A. Stanley Lucks, Robert B. Bradbury, W. R. Cartwright and D. Wert (see Tr 234).

the event of a loss-of-coolant accident, service water flow will additionally be provided to recirculating spray heat exchangers for cooling containment spray water during recirculation. The service water system provides seismic Category I backup water supply for the spent fuel pit makeup and the auxiliary feedwater system, and backup cooling flow for the spent fuel pit coolers and the recirculation air cooling coils (Staff PH Testimony at 1 following Tr.338).

The service water system is shared by both Units 1&2. It consists of two full capacity redundant trains each of which supplies water to both Units. The normal service water is supplied from the service water reservoir (SWR) by means of four service water pumps, of which two are required during all operational modes, while the other two pumps may be used for fast cooldown.

The entire system is designed to seismic Category I requirements. Sufficient redundancy is provided to meet the single failure criterion (Ibid. at 2; see also Tr.454).

The arrangement of the service water system is shown schematically in Fig- e 12 (VEPCO SWPH Testimony following Tr.19). The SWR is located about 600 feet south of the main power plant structure, more than 30 feet above the main plant grade (Ibid., Figure 1). The approximately 9.5-acre reservoir was constructed on naturally sloping ground by excavation at its western end and by construction of a U-shaped earth and rock-filled dike on its eastern end (Ibid. at 4, Figure 2). During normal operation, the depth of the reservoir is between 8 and 10 feet. The reservoir holds a thirty-day supply of service water for each of the four reactors at the North Anna station (Ibid. at 4).

F' re 3 of VEPCO's Testimony shows a typical cross-section of the SWR dike. The dike has two principle components: a core of cohesive earth fill (called "random fill") and a sur unding layer of rock fill. Between the random fill and the rock fill are two filter zones to ensure that seepage cannot cause internal erosion. Figure 3 also shows that the bottom of the SWR is lined with a two-foot layer of compacted soil (called "select fill") to minimize seepage. This clay liner extends up the inside slope of the dike to an elevation well above the normal water level in the reservoir (Ibid. at 4).

e location of the service water pumphouse (SWPH) for Units 1&2 is shown in Figure 2 of VEPCO's SWPH Testimony. The pumphouse is a squat, heavily reinforced concrete structure embedded in the inside slope of the dike. The northern face of the pumphouse coincides with the southern edge of the dike crest (see Figure 2 of VEPCO's SWPH Testimony). As shown in Figures 4 and 5 of VEPCO's SWPH Testimony, the SWPH is a massive monolithic structure founded on a three-foot thick concrete mat. The reservoir liner of the compacted select fill is increased to a three-foot thickness under and around the exterior walls of the structure, as shown in Figure 5 (Ibid. at 5).

The SWPH contains four pumps, which take suction from the reservoir and supply service water to two redundant supply headers. Each of the four pumps may be aligned to supply water to either header and each pump is powered by a separate emergency power source (Ibid. at 5).

Four buried 36-inch diameter service water lines carry water to and from the SWPH (two each way) as depicted in Figures 4 and 5 of VEPCO's SWPH Testimony. These pipes pass through the north wall of the pumphouse and into the dike above the top of the clay liner, then turn downward through the courser filter zone and into the ground beneath the outside toe of the dike. At this point the lines bend toward the northwest and run to the main plant structures under a soil cover at least six feet deep (Ibid. at 5).

The two return lines supply two interconnected headers inside the SWPH. Two 24-inch lines from each of these headers penetrate the south wall of the pumphouse below the water level and branch out across the bottom of the reservoir to arrays of spray nozzles. The nozzles spray the water into the air, transfering the heat to the atmosphere (Ibid. at 6).

As a backup, if the service water pumps in the SWPH are not available, service water can also be supplied from Lake Anna (Staff PH Testimony at 2). When Lake Anna is used as a source of service water, the water is provided to system components by two auxiliary service water pumps located in the circulating water intake structure, which is adjacent to Lake Anna (See Figure 1 of VEPCO's SWPH Testimony). Each of these pumps is identical to the service water pumps located in the SWPH and like those pumps is powered by a separate emergency power source. The pipe connections are such that water from these auxiliary service water pumps can be directed to either of the two service water supply headers. The service water returning from the cooled components is discharged into Lake Anna through the circulating water discharge tunnel and canal "A" (See Figure 1 of VEPCO's SWPH Testimony) (Ibid. at 6).

In summary, the service water pump requirements during power operation or under accident conditions can be met either by two service water pumps or two auxiliary service water pumps or one of each. The cold shutdown cooling requirements can be met by one service water pump or one auxiliary service water pump. All service water pumps are located in seismic Category I structures and are protected from tornado missiles as well as internal missiles. The pumps are powered by redundant emergency electrical buses (Staff PH Testimony at 1 and 2).

C. Soil Mechanics

Both the NRC Staff and VEPCO agree that the dominant overburden soils at North Anna are saprolites (Staff PH Testimony 18; Tr.58) and that the saprolite soil at the North Anna site is suitable for support of the service water pumphouse (Tr.307, 362). The saprolite at North Anna is derived from a granite gneiss rock through a natural weathering process that causes loss of bonding between mineral grains, chemical alteration of some minerals, and leeching by water flowing through the ground. The result is a material retaining the same structure and banding as the parent rock, but more compressible and somewhat more porous (VEPCO's SWPH Testimony at 37, 38). When thoroughly remolded, a sa e of the saprolite appears to be a silty sand, but a close examination of the undisturbed material shows an interlocked structure of: a) hard angular quartz grains, b) grains of the mineral feldspar that are partially altered into clay minerals, and c) bands of mica particles. The clay minerals in the saprolite occur largely in strongly cemented clumps that are the size of silt particles and that, therefore, behave more like inert silt grains than like clay particles (VEPCO's SWPH Testimony at 38). In fact, one of VEPCO's consultants indicated that the clay minerals constitute between 20 and 75% of the soil under the pumphouse and that the major clay mineral is Halloysite. This Halloysite causes the soil to behave like a silt rather than as a soil made up of clay particles (Tr.63). This was confirmed by both VEPCO's classification tests wherein VEPCO looked both at the gradation characteristics and the plasticity characteristics of the material and its tests of engineering properties such as the results of strength-test, consolidation test and cyclical triaxial tests, which simulate earthquake loadings. Both tests indicated that this Halloysite acts like a silt (<u>Ibid.</u>). VEPCO testified that this material would be a stronger mate ial, as far as loadings are concerned, than any clay material (<u>Ibid.</u>). VEPCO further testified that studies on Halloysite have been conducted which indicate that Halloysite has properties that are considerably better than any other clay types that are commonly used for embankment construction and are present in foundation materials (Tr.294).

Because the saprolite at North Anna is not a transported soil (transporated soils have been sorted, rounded, mixed then deposited through a process of sedimentation and consolidation), theories and analytical methods that have proven applicable to such soils have only limited applicability for predicting the behavior of saprolite (VEPCO's SWPH Testimony at 36-38). Thus, the time-rate of settlement of the service water pumphouse cannot be predicted but only monitored (VEPCO's SWPH Testimony at 42). However, VEPCO did testify that consistent with classical soil mechanics theory, which predicts that the rate of settlement will decrease with time which is basically what has been seen at the North Anna pumphouse over the last 20 months, they expect future settlement to only be approximately 5/8 of an inch over the rest of the lifetime of the plant (VEPCO's SWPH Testimony at 42, 43; Tr.311).

VEPCO and the NRC Staff independently investigated the engineering properties of the saprolited foundation soil. These investigations included mineralogy and resistance to cyclic loads such as those induced by earthquakes (VEPCO's SWPH Testimony at 38-41; Staff's PH Testimony at 18 and 19). VEPCO's investigations indicate that the saprolite soil is resistant to mechanical degradation; a test was conducted to an effective stress of 64 ksf, which is approximately 16 times higher than the contact stress that exists under the pumphouse, and no degradation was measured to occur (Tr.295). The Staff and VEPCO's investigations indicate that earthquake resistance of the saprolite soil supporting the dikes and the pumphouse would be adequate. (Staff's PH Testimony at 20, VEPCO's SWPH Testimony at 45).

A limited appearance statement submitted by Dr. Robert F. Mueller suggested that there was no consideration of possible "viscous fluid behavior." He stated that if the soil under the pumphouse has an incompressible fluid component in addition to the compressible component, local downward motion may be compensated by an almost imperceptible upward motion over a wide surrounding region (Statement, following, Tr. 5 at 2). Witnesses for both the Staff and VEPCO testified that such behavior was not likely for the soil under the SWPH (Tr. 65, 66, 373, and 374).

D. Settlement History

VEPCO submitted testimony, Figures 7A - 7G, which provides the time versus average pumphouse settlement along with the labelled construction sequence. VEPCO's SWPH Testimony, Figures 25A and 25B, provides the time versus settlement of the exposed ends of the service water pipes buried in the dike fill. The NRC Staff reviewed Figures 7A - 7G as well as Figures 25A and 25B, in addition to Part 5 of VEPCO's written testimony, and determined that the data presented appears to be generally accurate except for a few minor errors which do not affect the probative value of this testimony.11/

11/ The Staff noted: a) there are several minor errors in plotting of the magnitude of the average SWPH settlement on Figures 7A - 7G. These errors are on the order of .002 to .004 feet which results in the data plotted on the figures indicating slightly less average settlement than has actually occurred. b) the scale on the ordinate on the right side of Figures 7D, 7F and 7G labeled "Average Settlement since December 75 - Ft", is plotted incorrectly. The numbers shown on the scale should be increased by .005, i.e., 0 should read .005, .02 should read .025, .04 should read .045, etc (Staff PH Testimony at 14 and 15).

1. Activities Affecting Settlement of the Service Water Pumphouse

Excavation for the SWPH began in January 1972. Approximately 11 feet of soil and saprolite were removed and replaced by a three-foot liner of compacted select fill described earlier. In March 1972, Stone & Webster began to pour concrete for the bottom mat and the exterior and interior walls of the pumphouse. Concrete for the 2-foot operating floor slab was poured across the top of the walls on August 25, 1972. This date marks the start of the settlement monitoring record, because all measurements are made at the corners of the finished operating floor slab and compared to the elevation of the slab as of August 25, 1972 (Elevation 328.0) (VEPCO's SWPH Testimony at 8).

Concrete placement was discontinued to permit installation of equipment in the pumphouse and construction of the dike core of cohesive fill around three sides of the building. A 3-foot layer of select fill was compacted against the walls, and random fill was placed and compacted in equal stages outside the layer of select fill. On October 18, 1972, Stone & Webster completed the placement of cohesive fill on the sides and front of the pumphouse. At that point, most of the settlement-producing load had been applied to the underlying saprolite (VEPCO's SWPH Testimony at 9).

Settlement of the pumphouse was first detected in November or early December 1972. At that time it was observed that the SWPH had separated from its west wing wall at the construction joint, a development that indicated the building was settling. Measurements taken on December 4, 1972, indicated an average settlement of 0.12 foot, with a maximum settlement at the northwest corner of 0.22 foot. The dash-line in VEPCO's Figure 7A representing settlement before December 4, 1972 is only an estimate. However, it appears that the settlement before December 4, 1972 occurred rapidly (VEPCO's SWPH Testimony at 9).

In March 1973, Stone & Webster resumed pouring concrete for the walls of the pumphouse. The roof slab was completed on April 11, 1973. An additional load was applied when the four service water lines were installed on the north side of the pumphouse. Random fill was excavated from the northern slope of the dike core in June 1973 to permit installation of these lines and a trench toward the north was excavated beneath the toe of the dike. After the pipes were installed, filter material was compacted below and around them, so that by the end of August 1973, they were embedded in the outside slope of the dike. Filter material and fill were placed over the lines in late Fall 1973 and early Spring 1974. The four service water lines were embedded in the north wall of the pumphouse with concrete on April 22, 1974. The dike was brought to its crest on May 10, 1974, and with that the final structural load was added to the foundation (VEPCO's SWPH Testimony at 10).

As shown in VEPCO's Figure 7A and 7B, settlement continued throughout the period of construction. The measurements are somewhat erratic which VEPCO attributes to inaccuracies in optical surveying, and do not clearly correlate with additional loads that were being applied. Following placement of the final fill against the north wall of the pumphouse in early May 1974, there was a marked increase in the rate of settlement, as shown in VEPCO's Figures 7B and 7C (VEPCO's SWPH Testimony at 11). By May 1974, the SWPH had settled an average of 0.224 foot (VEPCO's SWPH Testimony at 11).

From December 1974 until early February 1975, the rate of pumphouse settlement showed a marked increase as indicated in VEPCO's Figure 7C. By mid-February, the SWPH had settled an average of about 0.38 foot (VEPCO's SWPH Testimony at 11). Appendix E to North Anna Units 1 and 2 FSAR suggested that the variation in the rate of settlement might have been due to the fluctuations in groundwater level, but no measurements of groundwater levels at the pumphouse were available to substantiate this (VEPCO's SWPH Testimony at 14). At the hearing VEPCO testified that the settlement occuring from December 1974 to February 1975 was caused by a delayed reaction to the final structural load applied for the founding material on May 10, 1945 (Tr.41; See Figure 7B).

In November 1975, the surveying firm of Moore, Hardee & Carrouth Associates began surveying the SWR as part of a commitment to VEPCO to monitor points of the crest of the dike for vertical and horizontal movements. This was a long-term program with surveys to be conducted every six months. The program included the settlement monitoring of the SWPH. Meanwhile Stone & Webster continued to conduct more frequent monitoring of the pumphouse settlement in order to provide information for engineering evaluations (VEPCO's SWPH Testimony at 14).

To alleviate the calculated excessive stresses in the service water lines, the lines were unearthed and cut immediately outside the pum :se on July 1, 1976. An expansion joint was installed on each of the pipes as indicated on VEPCO's Figure 8 in order to accommodate anticipated movements caused by future pumphouse settlement (VEPCO's SWPH Testimony at 15).

As indicated in VEPCO's Figures 7C, 7D and 7E, the settlement rate of the service water pumphouse through August 1976 appears to be relatively stable. Between August 1976 an December 1976, an additional 0.045 foot of average settlement was measured. It appears that this settlement was caused in part, if not entirely, by the filling of the reservoir (VEPCO's SWPH Testimony at 17). VEPCO speculates the settlement was also affected by the installation of the first of six horizontal drains that were installed beneath the pumphouse. This firs drain, designated drain 1, was installed in early October 1976 (Ibid.).

After December 1976, there was no further settlement of the pumphouse until the remaining five drains had been installed in July and August 1977 (See Figures 7F and 11B). During this period of installation there was additional average settlement of approximately 0.048 foot (VEPCO's SWPH Testimony at 17 and 18). VEPCO's testimony indicates that from August 1977 to May 1979, additional settlement of the SWPH has been gradual (approximately .02 foot) (See Figures 7F and 7G).

E. Dewatering

Due to the Staff's concern with the potential effect of groundwater level on the behavior of saprolite soils (that soaking these soils could soften them and that changes in effective stress could consolidate them), the Staff required a system and a program to measure and record the groundwater levels in the vicinity of the dikes and service water pumphouse (Staff PH Testimony at 30). The Staff also required a system to control the groundwater levels under the SWPH and the critical section of the dike (Ibid.). This Staff requirement was set forth in Regulatory Staff Position 3.8 (FSAR Amendment 53, pp. P3.8-1 and P3.8-2). In addition to controlling the groundwater level under the pumphouse, and the dike in the southeastern section of the reservoir, the Staff required an increase in the factor of safety of the dike foundation against liquifaction. This was provided by a trench drain along the toe of the dike. The drains under the pumphouse, on the other hand, were required solely for the control of settlement (VEPCO's SWPH Testimony at 45).

VEPCO satisfied this groundwater control requirement by installing an array of six horizontal drains under the pumphouse by drilling from a pit north of the toe of the dike, as shown in Figures 9 and 10 of VEPCO's Testimony. Each drain consists of a length of strong plastic pipe with closely-spaced slots. Each drain pipe slopes downward slightly toward its open end to permit the flow of water. These drains were designed to minimize the drawing of silt grains into the drain pipes with the groundwater. Monitoring of the outflow from the drains is continuing, and a permanent program of monitoring has been established. The Technical Specifications require that the suspended solid's content and turbidity of the effluent be determined at least once every six months, and if either the suspended solids content or the turbidity exceeds ten parts per million, a special report must be submitted to the N[illegible] within 30 days outlining possible causes and planned corrective actions (VEPCO's SWPH Testimony at 47, 48).

Although the need for installing the groundwater control system under the pumphouse was questioned by VEPCO, they testified that for the life of the plant the horizontal drains will ensure that seasonal variations of the groundwater level cannot induce further settlement and will provide the saprolite supporting the pumphouse and this section of the dike with an even greater factor of safety against instability due to earthquake vibrations (VEPCO's SWPH Testimony at 51).

Based on the results of cyclic loading tests performed in the saprolite soils by VEPCO's consultants and by the Staff's consultants, there is reasonable assurance that the dikes and their foundations will survive the effects of a safe shutdown earthquake assigned to this site (Staff PH Testimony at 32; VEPCO's SWPH Testimony at 45).

F. Protection of the Public Safety

The principal safety concern with the settlement of the service water pumphouse is to ensure that the buried service water lines are not overstressed. For that reason, the focus of the Staff's testimony was to assure that the pipes are not overstressed and not to attempt to predict how much future settlement might occur or to assure that some predicted value of settlemet is not exceeded (Tr. 349-351, 410). VEPCO's experts also indicated that they were not relying on the prediction of future settlement, but instead on the expansion joints and required procedures to obviate any potential safety problem resulting from settlement (Tr.291-92). Accordingly, the allowable settlement limits set out in Technical Specification Amendment No. 12 were to assure during the period of plant operation, that the stress levels in the service water piping did not exceed the allowable values defined by the ASME Boiler and Pressure Vessel Code, Section III, and that the movement of the expansion joints in the service water lines did not exceed the design values of the expansion joints (Staff PH Testimony at 35-36). The Technical Specification Amendment No. 12 limits absolute settlement of the exposed ends of the expansion joint to 0.22 feet (measured from August 3, 1978) (NRC Staff PH Testimony at 41, Tr.411).

1. Service Water Piping

The Staff arrived at the absolute limit of 0.22 feet for settlement of the service water piping in the following manner:

1. The NRC Staff assumed that the service water pipes could be modeled as being rigidly anchored in the soil at a point 60 feet from the exposed ends and that the deflected shape of the pipes due to dike settlement is the same as a cantilever beam with a concentrated load at its end (Staff PH Testimony at 38).

2. The NRC Staff used a value of 29 x 10^6 pounds per square inch as the modulus of elasticity for the service water piping at normal temperatures (Staff PH Testimony at 39).

3. The ASME Code would permit an allowable stress of 41,100 pounds per square inch for the effect of any single nonrepeated anchor movement. Allowing 4,000 pounds per square inch for friction loads, NRC Staff calculated a limiting stress of 37,100 pounds per square inch which equals a maximum deflection of 12.03 inches or 1 foot (Staff PH Testimony at 39).

4. In determining the displacement that had occurred since the pipes were buried in the fill, NRC conservatively assumed that the pipes were rigidly connected at the pumphouse with the top of the pipes at an elevation of 322.36 feet. NRC Staff assumed that this elevation was correct on August 25, 1972, and that no pumphouse settlement had occurred prior to the time that the pipes were connected (Staff PH Testimony at 40).

5. On August 3, 1978, the top of Pipe SM-18 (the pipe that had settled the most) was measured at an elevation of 321.59 feet. NRC Staff calculated the past settlement at .77 feet (322.36 feet minus 321.59 feet equals 0.77 feet). When substracting the .77 feet from the maximum deflection of 12.03 inches or one foot, the Staff arrived at the recommended Technical Specification limit of .22 foot for settlement of the exposed end of the expansion joint (Staff PH Testimony at 40, 41).

Additional conservatism is given to the Staff limit due to the fact that additional evidence provided by VEPCO indicates that the pipes were embedded in the fill on August 27, 1973. Thus, the allowable limit could be increased by .15 foot to a total limit of .37 foot (Staff PH Testimony at 41).

VEPCO's finding that, in essence, the expansion joint reaches its limit before the allowable limit of the service water pipes is reached (Tr. 176), is based on a computer model containing the following pertinent features:

1. The piping was modeled in the conventional manner as a sequence of segments that have the correct stiffness properties. The computer calculated the deflections, forces and stresses for each segment (VEPCO's SWPH Testimony at 55).

2. The expansion joint was represented by a special segment in the model that accounts for the great flexibility of the joint in axial compression, transverse deflection and bending (Ibid.).

3. The soil resists the motion of the pipe for movements perpendicular to the axis of the pipe. The forces imposed by the soil are treated as though caused by closely spaced springs between the pipe and the surrounding soil. Thus, the force on the pipe was assumed to increase in direct proportion to the perpendicular deflection of the pipe (VEPCO's SWPH Testimony at 55 and 56).

4. Movement of the piping in an axial direction was assumed to be resisted by friction between the soil and the pipe wall. The magnitude of the friction was determined from the depth of imbedment, the weight of the soil, the weight and diameter of the pipe, and the coefficient of friction between the soil and pipe (VEPCO's SWPH Testimony at 56).

5. Over 200 feet of the piping is included in the computer model. Further extension of the model is not necessary because the pipe is effectively locked into the soil by friction (VEPCO's SWPH Testimony at 56 and 57).

6. The model assumed settlement of the western most line since this is the line that would experience the most settlement of all four according to monitoring to date. Thus, this assumption makes the results conservative for all four lines (VEPCO's SWPH Testimony at 57).

7. The variation of settlement with distance from the pumphouse was determined by analyzing the distribution of settlement across the section of the dike and along the buried lines (VEPCO's SWPH Testimony at 58).

The slightly greater settlement of the pipes relative to the north wall of the pumphouse in recent months was not included in VEPCO's analysis because a) there is not a clear trend that can be extrapolated to large values, as in the case of pumphouse settlement; b) it is a small effect, and a low stress values calculated in the analysis leave sufficient margin for such effects; c) the differential motion between the pumphouse and the pipes does not, by itself, cause pipe stress because the expansion joints isolate that motion; and d) the stress in the pipe is not strongly sensitive to the actual amount of the settlement (VEPCO's SWPH Testimony at 59). The Staff agreed with VEPCO's methodology (Staff PH Testimony at 35).

The testimony further indicates that even should the allowable stress limit of the pipes be exceeded, sections of the piping could be replaced to relieve the stress (Tr.177).

2. Expansion Joint

The Technical Specification Amendment No. 12 differential limit of 0.22 foot of settlement for the expansion joint assures that the expansion joints in the service water lines will not exceed the design values for the expansion joints. Although VEPCO calculated an average settlement limit for the expansion joint of 0.33 foot in its testimony, it accepted the Staff's value of .22 differential settlement which is more limiting. The development of this .22 differential allowable settlement by the Staff is set forth below.

1. Based upon information from the manufacturer of the expansion joint, the Staff assumed that the expansion joint is designed for a lateral movement of one end with respect to the other end of 0.25 feet (neglecting twist about the axis of the coupling and rotation of the ends of the coupling in the axial plane) (Staff PH Testimony at 37).

2. The Staff conservatively assumed that the flexible joints were installed in December 1975, thereby setting that date as the initial reference point for settlement of the north wall of the pumphouse. In determining the settlement from December 1975 to July 1977 (the date after which the 0.22 differential settlement is measured from), the NRC Staff assumed that the top of the dike near the pipe markers settled at the same amount as the exposed ends of the pipes embedded in the dike (Staff PH Testimony at 36).

3. The July 1977 date was chosen as the first measurement of the pipes because this is the date that marks SM-15, 16, 17, and 18 were established on the pipes; no settlement readings were made on these pipe ends prior to July 1977 (Ibid.).

4. During the period of December 1975 to July 1977, the top of the dike settled 0.079 feet, SM-7 and SM-10 settled 0.046 foot and 0.089 foot respectively. Thus the estimated differential settlement across the joint that occurred during this time period was between 0.033 foot (0.79 minus 0.046) and minus 0.010 foot (0.079-0.089). A value of .03 foot was conservatively chosen to represent the differential settlement of SM-15, 16, 17 and 18 with respect to the north side of the pumphouse during this period of time (Staff PH Testimony, at 37). Subtracting this 0.03 foot figure from the .25 foot limit assigned by the manufacturer of the flexible joint arrives at a conservative differential stress limit of .22 feet (Staff PH Testimony at 37).

The Staff limitation of .22 foot is conservative for the reason that the expansion joints were not installed in December 1975 but as indicated in Figure 7E of VEPCO's testimony, these joints were installed in August and the beginning of October 1976 (Tr.89). Thus, the period allowed by the Staff for settlement (December 1975 to July 1977) would encompass a larger period of settlement than actually was experienced by the expansion joints. Therefore, the .03 figure arrived at by the Staff and later subtracted from the .25 manufacturer limit for the expansion joint is a conservative figure.

The VEPCO proposed Technical Specification would allow an average settlement of the pumphouse to be placed at .33 foot since December 1975. This figure was arrived at by modeling the piping system in the expansion joint into a computer program (Tr.211, and 100). This analysis combined the differential movements due to thermal, settlement, earthquake, and dead loads into a resultant movement (VEPCO's SWPH Testimony at 25). The computer code considers dimensions of the system, stiffnesses and characteristics of the joint and the pipe, the weight of the soil and other soil properties (Tr.101-103). The computer program is called NUPIPE. This is a nationally recognized program which has been verified against other calculations at Stone & Webster (Tr.101). The record indicates that this computer program was run three different times. First, the program was run when the expansion joint was designed by the manufacturer to accommodate three inches of lateral offset (Tr.304, 330). Then again, the computer program was run to check the integrity of the expansion joint in light of the concern of the pumphouse settlement. The purpose of this run was to determine how much additional margin there was in the expansion joints at the proposed Technical Specification limit of 0.33 feet (Tr.304, 330 and 331). Finally, an analysis was recently performed to evaluate the effects of the recently revised maximum service water temperature on the expansion joints (VEPCO's SWPH Testimony at 24, 25, 60 and 61; Tr.303, 304). In each of these analyses the manufacturer considered the effect of the combination of differential movements on the expansion joints (VEPCO's SWPH Testimony at 25). The analyses indicate that the differential movements superimposed on the expansion joints by the VEPCO proposed Technical Specification limit (0.33 foot since December 1975) represent about 54% of the dynamic allowable and 40% of the static allowable. At this compression, the calculated lifetime of the expansion joint is greater than 39,000 cycles ("Cyclic" events are those due to earthquakes and large thermal or pressure transients). The actual number of cycles that the system will experience during its lifetime is less than 1,000 (VEPCO's SWPH Testimony at 26).

Finally, the record indicates that the expansion joints were manufactured in accordance with a "quality one assurance program" and the joints were inspected for damage before their installation (Tr.313, 314).

3. Concerns Related to Settlement of the Pumphouse

As set out above, both the Staff's and Licensee's witnesses testified that they believe the settlement limits set out in Technical Specification Amendment No. 12 were conservative enough to assure that the service water system would not fail. However, in response to the Appeal Board's request set out in ALAB-529 that the Licensee and Staff discuss the possible effects of settlement that would be great enough to cause damage to the service water piping, the Licensee's testimony set out a scenario of what might occur (VEPCO's SWPH Testimony at '3-35). This testimony was reviewed and commented upon by the Staff (Staff ' Testimony at 9-11). The record shows that:

1. The monitoring p. ogram as well as the reporting requirement at 75% of allowable settlement limits provides ample time to bring the plant to a safe condition before the design value of the expansion joints is reached (Staff PH Testimony at 9, VEPCO's SWPH Testimony at 26).

2. In 1976, pressure-balanced stainless steel expansion joints were installed outside the service water pumphouse in the four supply and return headers in order to eliminate the possibility of overstress in these lines due to service water pumphouse settlement (see Figure 12, VEPCO's SWPH

Testimony). These expansion joints which are the limiting system components insofar as pumphouse settlement is concerned were analyzed by VEPCO at a proposed Technical Specification limit of 0.33 foot of settlement since 1975 and later analyzed taking into account the service water temperature's affect on these expansion joints. The results of this analyses indicated that the differential movement superimposed on the expansion joints by the proposed Technical Specification of 0.33 foot since December 1975 represents only about 54% of the dynamic allowable and 40% of the static allowable. At this compression the calculated lifetime of the expansion joint is greater than 39,000 cycles. The actual number of cycles that the system will experience during its lifetime is less than 1,000. Thus the expansion joints are conservatively designed for operation at the more limiting Staff proposed Technical Specification limit of 0.22 foot of differential settlement since July 1977 (VEPCO's SWPH Testimony at 25 and 26; Staff's PH Testimony at 9 and 35-38).

3. In spite of the conservative design of the expansion joints, even if it is assumed that there is a failure of an expansion joint, such failure will take the form of cracks of pinhole size rather than complete severance of the expansion joint (VEPCO's SWPH Testimony at 29; Staff's PH Testimony at 9 and 10). The resulting leakage would only be minor and would have no significant effect on the service water system's performance (VEPCO's SWPH Testimony at 30, see also Tr.298).

4. If failure of one of the expansion joints in a return header is assumed, the result would be only a reduction in the water level in the service water reservoir. VEPCO testified that should an instantaneous

separation of the expansion joint in a return header occur six days or more after the Technical Specification limit had been reached and the plant shutdown to Mode 5 (condition of cold shutdown), there would still be 40 hours to detect such a severance and correct it (Tr.181; VEPCO's SWPH Testimony at 31 and 32). VEPCO indicated that it would, at a maximum, take on the order of 4 hours to detect such a severance and it would only take realigning the valves to switch to the auxiliary service water pumps at Lake Anna to return the system to its required design capability (VEPCO's SWPH Testimony at 32; Tr.181). If failure of one expansion joint in the supply header is assumed, the affected supply header can be isolated and the redundant header placed in service. In this mode of operation one service water pump is still required, the other three in the service water pumphouse are available as spares (see Figure 19). (VEPCO's SWPH Testimony at 32). An immediate separation of the supply header expansion joint would most probably activate the low flow alarm in the service water system return line which annunciates in the control room (Tr. [illegible]). If the operator gets such a signal when the plant is in normal operation, the operator may operate the plant for a 72-hour period without redundant headers. Furthermore, the Technical Specifications do not require redundant headers while the plant is operating at Mode 5 (Tr.184). In any event, once detected, the affected supply header can be isolated and the redundant header placed in service in a matter of minutes (VEPCO's SWPH Testimony at 32; Tr.185).

Finally, if it is assumed that there is simultaneous instant separation of all four expansion joints, this situation would be countered by a switch-over to the auxiliary service water pumps and Lake Anna, which can be accomplished from the Control Room by positioning the necessary motor operated valves and starting the auxiliary service water pump. The time to detect this failure and to reestablish flow is estimated to be between 5 and 15 minutes (Tr.24). This interruption of service water flow in Mode 5 has no affect on safe operation of the plant in a shutdown condition (VEPCO's S.PH Testimony at 33; Tr.185, 186). The record further indicates that the operators have been trained specifically to recognize these kinds of incidents (Tr.186). The Staff considered the instantaneous severing of all four expansion joints to be so unlikely and incredible during both an operation mode as well as a cold shutdown mode (Mode 5) that an analysis of such an occurrence was not warranted. The Staff testified that the instantaneous failure of all four expansion joints is not part of the design basis for the system and it is not part of the normal licensing evaluation or review (Tr.378, 453, 454). However, the Staff did review and concur with VEPCO's analysis of postulated expansion joint failures in the cold shutdown mode (Staff PH Testimony at 9-11). Further, the Staff conducted an evaluation and approval of the service water system by accounting for a single failure of any component (including failure of an expansion joint) within the system (Tr.377, 452, 454, see also 284). The Staff concluded that adequate redundancy existed to maintain plant safety (Tr.377).

4. Other Concerns Related to Settlement of the Pumphouse

Another part of the service water system which could be affected by settling of the service water pumphouse is the spray system in the reservoir. This system is connected to the pumphouse. Settlement of the pumphouse could affect that connection and the piping (Tr.187). To assure that the stress in these pipes does not reach the stress allowed by the American Society of Mechanical Engineers Boiler and Pressure Vessel Code (which was calculated to be a differential of 0.175 feet), the Technical Specification Amendment No. 12 includes the differential limit of 0.175 feet. The evidence indicates, however, that the differential settlement has been negligible since June 1975, when the ends of the pipes were tied down (Staff PH Testimony at 47). Further, VEPCO testified that should there be an instantaneous failure of the piping, Lake Anna is available using auxiliary pumps to provide the necessary heat sink (Tr.188).

Settlement can also affect operation of the pumps in the SWPH. In May 1979, during a periodic test by VEPCO in accordance with an FSAR commitment, one of the pumps on the Unit 2 side of the SWPH was found to be tilting more than the .011 inches per foot acceptance criteria. The FSAR states that if such a condition is indicated it should be corrected by shimming which VEPCO indicated it is now investigating but as of yet has not accomplished (Tr.26, 188). It was further indicated that the No. 1 screen-wash pump, as well as the No. 2 screen-wash pump require shimming if the criteria .011 inches per foot is to be met. VEPCO indicated that these limits are very narrow and these pumps can remain operable on limits much larger than the acceptance criteria limits (Tr.189). The manufacturer has indicated that a total displacement of 0.5 inches would not adversely affect pump operability (Staff's PH Testimony at 43). In addition, VEPCO is measuring differential pressure, flow rate and vibration amplitude every thirty days as required by Article IWP-3000 of Section XI of the ASME Code. These pump performance parameters are to be maintained within the tolerances specified in Table IWP 3100-2 of Section XI, except that for the flow rate parameter, a tolerance of plus or minus 8 percent is acceptable (Staff PH Testimony at 43, 44). Maintaining the pump performance parameters within the specified tolerances provides adequate assurance that the pump will maintain its operability and that any effects of time will be accounted for.

Concern with potential leakage of the reservoir liner is alleviated by the Technical Specification Amendment No. 12 (specifically Technical Specification 3/4.7.13) which requires a) measuring and recording the quantity of groundwater flowing from the under drains on a monthly basis for five years; if flow rates for any month become more than three times the average annual flow rate, an engineering evaluation of the cause of the change of the changed flow rates should be conducted and a report filed with the NRC; b) monitoring and recording groundwater elevations on a monthly basis for a period of five years, and c) at the end of the five-year period, requiring an engineering report to be filed by VEPCO to determine if further measurements of groundwater levels are needed (Staff PH Testimony at 45).

To assure against potential significant cracking of the reinforced concrete pumphouse structure due to future differential settlement across the structure, Technical Specification 3.7.5 of Technical Specification, Amendment No. 12, sets forth an allowable out-of-plane distortion of 0.06 foot. This istortion limit, if reached, will indicate the onset of additional cracking in the structure (Staff's PH Testimony at 46).

The auxiliary pumps will be tested every 31 days, following June 1979 (Tr.31, 32). With this monthly testing, the concern regarding the inservice testing of the auxiliary service water pump for both Units 1 and 2 has been resolved (see Staff's PH Testimony at 49).

Finally, the 75% reporting requirement with regard to settlement of Class I structures, allows adequate time for remedial safety-related actions prior to reaching settlement values that would affect safety or plant operations (see Staff's PH Testimony at 42).

G. Monitoring

Settlement of Class I structures is monitored by determining the elevation of each designated point by "precise leveling", that is, by measuring the difference in elevation of each point from a bench mark of known elevation using a surveyor's level and rod. Technical Specification 3/4.7.12 requires the monitoring to be done with surveying instruments and methods that meet the requirements specified by the U.S. Department of Commerce's National Oceanic and Atmospheric Administration for "Second-Order, Class II" accuracy. Instrument requirements include the precision of the level and the material, construction, and graduation of the rod. Method requirements include the horizontal balancing of the backsights and foresights, the information recorded in the field, and the reduction of the field data to distribute the area of closure for each survey loop among the readings (VEPCO's SWPH Testimony at 52).

With respect to monitoring buried service water pipes, the only points on the service water lines that have been monitored for settlement are the ends of these lines inside the expansion joint enclosure. Moore, Hardee & Carrouth Associates measure the elevation on the top of each pipe by the same surveying methods used to monitor the other points (VEPCO's SWPH Testimony at 54; Tr.441, 442).

Moore, Hardee & Carrouth Associates satisfy the requirements for Second-Order, Class II accuracy. For each survey of the pumphouse, Moore, Hardee & Carrouth Associates used reference monument "B" (shown in Figure 2) as the benchmark and run the line of levels through reference monument "A". Although the previous Technical Specifications for Unit 1 required that Category I safety-related structures be surveyed every six months to assess settlement, VEPCO was monitoring the settlement of the service water pumphouse every month. The Unit 1 Technical Specifications for monitoring groundwater elevations near the pumphouse and beneath the service water reservoir dikes call for monitoring every month for the first five years of plant operation. The Staff testified that the frequency of monitoring settlement near the pumphouse should be the same as that now prescribed for measuring groundwater levels and drain flow rates. Accordingly, measurements of settlement markers SM-7, 8, 9, 10, 15, 16, 17, 18, H-569, and H-584 should be made at least once every thirty-one days until Unit 1 has been in operation at least five years. At the end of the five-year period, an engineering study should be made by VEPCO to determine the need for and frequency of continued monitoring of settlement, groundwater and drain flow rates (Staff PH Testimony at 42-43). The basis for the Staff's postion is that it believes there is still a potential for rapid settlement of the SWPH and that this potential for rapid settlement cannot be ruled out until five years of monitoring from the date of the issuance of the North Anna Unit 1 license has been completed and reassessed (Tr.339 and 341). The Staff witness testified further that such reassessment must be based on data that shows a correlation between settlement near the pumphouse and the flow rates from the horizontal drains and the groundwater levels. To do this, the Staff testified, requires conducting the monitoring of settlement every 31 days which is the same frequency for monitoring groundwater levels and drain flow rates (Tr.339).

VEPCO's witnesses, on the other hand, testified that once every six months would be adequate to monitor settlement of the SWPH (Tr.110,206, 265, 298-99). The basis for VEPCO's position was that the slow rate of settlement experienced over the last 20 months and its belief that the potential for additional rapid settlement of the pumphouse due to groundwater level changes does not exist (VEPCO's Supplemental SWPH Testimony at 3) indicate that a monitoring frequency of six months should be adequate to assure the safety of the public. However, VEPCO's witness testified that it believed a frequency of 31 days is appropriate for monitoring the settlement of the exposed ends of four service water lines which settlement rate VEPCO testified it does not understand. VEPCO's witness added that monitoring at a 31-day frequency should continue until this settlement is understood (Tr.109, 205). In sum, the record establishes that the causes of settlement of SWPH are not fully understood and there remains the potential for rapid settlement. In these circumstances, it appears that the more conservative 31-day frequency for monitoring settlement is preferable for assuring public safety. The Technical Specification amendment (Amendment No. 12) issued on June 28, 1979 effectuated this monthly monitoring period and the requirement for the engineering study at the end of the five-year period.

Counsel for Intervenor Arnold attempted to establish through cross-examination, that additional technical specifications are needed to ensure that the results from surveys taken are reported to VEPCO within a set period of time (Tr.81, 125 and 126). VEPCO's witness testified that it recognized that in the past there was a problem with timely reporting by the surveying firm (Tr.123-126). However, VEPCO's witness added that a new reporting procedure was established in February 1979 which requires the surveying firm to report the survey data to VEPCO within seven working days (Tr.122, 413-14). The Staff's witness, Mr. Lenahan from the Commission's Office of Inspection and Enforcement, testified that the surveying firm has been complying with the seven-day requirement (Tr.414). Further, Mr. Lenahan testified that this seven-day requirement is an internal procedure which VEPCO has committed to comply with. He further testified that such internal procedures are enforced by the Commission's Office of Inspection and Enforcement (Tr.415).

H. Conclusion

The record, based on the facts established therein and discussed above, supports the conclusion that the design of the North Anna Units 1 and 2 service water system as well as the requirements of the Technical Specifications 3/4.7.12 and Table 3.7-5 (regarding settlement of Class 1 Structures) and 3/4.7.13 and Table 3.7-6 (regarding groundwater conditions under the pumphouse and service water reservoir) assures that North Anna Nuclear Power Station, Unit 1 and 2 will operate without undue risk to the public health and safety.

II. TURBINE MISSILES RISK

A. Introduction

In August of 1976, the NRC Staff issued its evaluation of turbine missile risks for North Anna Power Station Units 1 and 2. "Safety Evaluation Report Related to Operation of North Anna Power Station, Units 1 and 2," Supplement No. 2, dated August 1976 (Staff Exh. 2 in proceeding before Licensing Board) (hereinafter SER, Suppl. 2). It was concluded in the evaluation that protection from turbine missiles for Units 1 and 2 is adequate to permit plant operation until the ongoing generic turbine missile study is completed. Id. at 10-3. Specifically, using conservative assumptions, the Staff estimated a probability of 2×10^{-5} per turbine year unacceptable damage by turbine missiles. It was noted by the Staff that consideration of known conservatisms regarding turbine failure probabilities and missile penetration and unacceptable damage probabilities would justify the expectation of a lower overall turbine missile risk. Nevertheless, the Staff believed that additional protection measures were required to assure that the turbine missile risk for North Anna would be acceptably low. Hence the Staff imposed the requirement that VEPCO commit to the turbine valve testing and inspection program and a turbine disk integrity program outlined in the Standard Review Plan. Turbine valve reliability and turbine rotor material findings stemming from the ongoing generic turbine missile study supported the view that improvements in these areas would have a significant effect in reducing the turbine failure probability, although quantitative numerical estimates were not available. In view of the preliminary nature of the findings regarding the effectiveness of these programs, the Staff included in its SER (Suppl. 2) the possibility of requiring additional protection measures pending the completion of the generic study.[12/]

12/ There are two task action plans relevant to the evaluation of turbine missile risk, Task Action Plans A-32 and A-37. The Appeal Board inquired into the role of task action plans in the regulatory process generally, and these two plans specifically.

The task action plans were instituted by the Staff in 1977 as part of a program to define, categorize and manage generic technical activities on a systematic basis. Some activities involve unresolved safety issues. However, a review of the issues by the Staff resulted in the conclusion that certain other tasks, including A-32 and A-37, did not involve unresolved safety issues. Task A-32 was included as part of a group of issues categorized as studies to confirm the adequacy of current Staff safety requirements. Task A-37 on the other hand, was identified as one of a group of generic issues devoted to improving guidance to applicants, licensees, and the Staff. Campe, et al., at 57-60. The purpose of Task A-37 is to assess the methods currently used to estimate the probability of damage to essential systems used in these case-by-case reviews, to quantify the effect of steps that can be taken by applicants to reduce the damage probability, and to recommend means of assuring that the probability of unacceptable damage is sufficiently small. Campe, et al., at 62. The Staff has downgraded this task in importance, and has no estimate as to the completion date for the task. Tr.577-78. Although this task will provide a more uniform review by providing better guidance to reviewers and applicants, the currently used case-by-case methods are judged by the Staff to be sufficiently conservative to assure adequate protection of the public health and safety. Campe, et al., at 62.

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In response to ALAB-529, the Staff and VEPCO submitted prefiled written testimony on the issue of the risk of turbine missiles on April 27, 1979. The Staff filed a single piece of proposed testimony entitled "NRC Staff Testimony Regarding Turbine Missiles" by K. Campe, M. Boyle, J. O'Brien, J. Burns, G. Arndt, and A. Dromerick (hereinafter Campe, et al.) which was received into evidence on Tr. 580. VEPCO submitted two pieces of proposed testimony entitled "VEPCO Testimony On Probability of Generating Turbine Missiles and Turbine Overspeed Protection System" (VEPCO P1 Testimony) and "VEPCO Testimony P2 and P3 and Turbine Inspection" (VEPCO P2 and P3 Testimony), as well as § 10.2.1 of VEPCO's Final Safety Evaluation Report (FSAR), which

(CONTINUED)

Task Action Plan A-32 is fundamentally a program intended to confirm that currently accepted missile protection approaches are indeed conservative - and, if possible, to determine or quantify the relative conservatisms inherent in the different analytical techniques now in use. This is to be done by collecting all available empirical data from a number of different missile impact test programs and comparing the observed results with the results which would be predicted by using a variety of analytical techniques. The comparison of empirical data and analytic methods is intended to provide a measure of the degree of conservatism inherent in the current analyses. The results could lead to the recommendation of other more accurate analytic methods that may be less over-conservative than those currently in use. Campe, et al., at 64.

For North Anna Units 1 and 2, the turbine missile risk evaluation was performed and the findings reported by the Staff in the Safety Evaluation Report at a time (1976) when the relevant Task Action Plans were not in existence. Some aspects of what is now within the scope of Task Action Plans A-37 and A-32 were being studied generically by various staff members at the time when the North Anna turbine missile risks were being evaluated by the staff. However, the generic study had not progressed to the point where any results were forthcoming for the staff's use. Thus, reliance was not made on either Task Action Plan A-37, or A-32, or the ongoing generic turbine missile study in estimating the turbine missile risks for North Anna Units 1 and 2. Campe, et al., at 66.

was designated as Exhibit AV-2. The VEPCO proposed testimony was admitted as testimony and received into the record of this proceeding following Tr. 19. Also received as testimony in this proceeding on the issue of the risk of turbine missiles were copies of the professional qualifications of the following Staff witnesses: K. Campe, M. Boyle, J. O'Brien, J. Burns, A. Dromerick, and G. Arndt, (Tr. 580) and the following VEPCO witnesses: W. R. Cartwright, D. Shaffer, J. Coombe, and M. Smith, following Tr. 19, and J. Schmerling, following Tr. 487. Neither Mrs. Arnold nor the Commonwealth of Virginia submitted any written testimony nor did they participate in the hearing on this issue.

The Staff presented its oral testimony on the issue of turbine missiles through a panel composed of Messers. Campe, Boyle, O'Brien, Burns, Arndt, and Dromerick. VEPCO presented its oral testimony through a panel which was made up of Messers. Coombe, Smith, Shaffer, Cartwright, and Schmerling. The Staff's proposed findings based on the written testimony, as well as the oral presentations made by the Staff and VEPCO witnesses on direct and in response to examination by the Appeal Board follows.

B. <u>Description at North Anna Units 1 and 2</u>

The turbine-generators for North Anna 1 and 2 were designed and manufactured by the Westinghouse Electric Corporation. Each turbine at North Anna is a conventional 1800 rpm tandem-compound unit, consisting of one double-flow high-pressure cylinder and two double-flow low-pressure cylinders. Each turbine is provided with four moisture separator reheaters. Turbine extraction connections supply steam to six stages of feedwater heaters. VEPCO P1 Testimony at 2.

The turbines contain several pieces of equipment that protect against overspeed. Each high-pressure steam pathway to the high-pressure cylinder contains a throttle valve and a governor valve. A reheat stop valve and an interceptor valve are provided in each crossover pipe between each moisture separator and each low-pressure turbine cylinder. VEPCO P1 Testimony at 2.

The turbine control system is of the electro-hydraulic type, ensuring rapid speed of response and control of turbine operation. The protective devices for the turbine include a low bearing oil pressure trip, a solenoid trip, overspeed trips, a thrust bearing trip, and a low vacuum trip. The solenoid trip is actuated by malfunctions of the Steam and Power Conversion System, such as a reactor trip, generator trip, or loss of electro-hydraulic governor power. VEPCO P1 Testimony at 3.

The control system includes an overspeed protection controller, which acts to limit turbine speed in case of a load separation. The controller operates to close the turbine governor valves and the interceptor valves until the overspeed condition is corrected. Non-return valves are installed in the turbine extraction steam lines to minimize turbine overspeed following a trip. The North Anna turbines are equipped with an overspeed protection system consisting of an overspeed protection controller anticipator and auxiliary speed channel, a mechanical overspeed trip, and an electrical overspeed trip. Each of these devices has as its function the cutoff of steam supply to the turbine in the event of a potential overspeed situation. VEPCO P1 Testimony at 3-5.

C. Generation of Missiles

1. Background

All known turbine failures that have resulted in the ejection of high energy missiles involved the failure of the low pressure rotor. Consequently, only fragments of low pressure turbine blade wheels or disks constitute turbine missiles of concern. Campe, et al., at 4.

Turbine failures can be grouped into two distinct modes. Failures at or below operating speed are caused by defects in the rotor material, typically leading to the brittle fracture of a low pressure turbine blade wheel. Turbines also can fail by exceeding the design speed. A sudden loss of load will cause the rotor to accelerate rapidly and, if the overspeed protection system fails to stop the flow of steam into the turbine, to exceed the design speed. Turbine rotors are designed and tested to operate up to 120% of rated speed. Moreover, the rotor can speed up to about 180% of normal speed at which point the most highly stressed wheel would fail in a ductile fashion. Campe, et al., at 4, 5; ,EPCO P1 Testimony at 6.

The Staff presented background testimony on typical turbine wheel fragments, deflection of the missiles, inflight orientation, and the development of secondary missiles. Campe, et al., at 5. This testimony also considered the trajectory of missiles with respect to plant structures. These include low trajectory and high trajectory missiles (LTM's and HTM's, respectively). The probability of HTM's striking plant safety systems is significantly lower than that for LTM's. Id., at 6.

General Design Criterion 4, of 10 CFR Part 50, Appendix A, is the regulatory requirement against which turbine missile risks at North Anna Units 1 and 2 must be evaluated. That criterion requires that structures, systems, and components important to safety "shall be appropriately protected against dynamic effects, including the effects of missiles, ...". Interpretation of General Design Criterion 4 with respect to protection against the effects of turbine missiles is provided in part by Regulatory Guide 1.115, which gives guidance to applicants on an acceptable means of protection against LTM's, and by the Standard Review Plan (SRP) Sections 2.2.3, 3.5.1.3, 10.2, and 10.2.3, which give guidance to the Staff. In particular, SRP 2.2.3 provides criteria on acceptable risk levels with respect to potential accidents.

The Staff and VEPCO provided testimony representing the results of their analyses of the probability of the generation of a turbine missile at North Anna Units 1 and 2, or P1. This probability, when multiplied by the probability of a given missile striking a safety related structure at North Anna Units 1 and 2 (P2), and by the probability, given a strike, that safety related equipment is damaged (P3), produces the overall probability of the risk of encountering unacceptable damage of safety-related equipment from turbine missiles at North Anna Units 1 and 2. VEPCO P2 and P3 Testimony, p.1. Both the Staff and VEPCO assumed that P1 represents the probability that a turbine would fail and would eject missiles, in either the design or destructive overspeed mode. The Staff utilized the guidance provided by SRP § 2.2.3 in evaluating turbine missile risks. The criteria in SRP § 2.2.3 indicate that an event need not be considered a design basis event if it can be shown, using conservative assumptions in the analysis, that the probability that the consequences of the event will exceed expo.ures in excess of 10 CFR Part 100 is less than about 10^{-6} per year. Moreover, judgment is used in determining the overall acceptability of the risk of the event in view of the inability to assign precise numerical values to the probability of occurrence of a hazard such as turbine missile generation. Campe, et al., at 7-10. VEPCO on the other hand, utilized a fault tree methodology, which is a logic diagram used to analyze circumstances that can directly lead to the event being considered, which are then subdivided until causal circumstances are identified at the equipment component level. VEPCO P1 Testimony, at 6-7. The two approaches for developing risk probabilities are analyzed in the following paragraphs.

The following is a description of the Staff's analysis used in the evaluation of turbine missile risks for North Anna. The turbine missile risk evaluation was done in terms of three probability components. The first of these, the turbine failure probability P_1 (considering design speed and destructive overspeed failure modes together), was assumed to be 10^{-4} per turbine year. This failure rate is taken from a study by Dr. Spencer Bush[13/]

13/ Bush, S. H., "Probability of Damage to Nuclear Components Due to Turbine Failure," Nuclear Safety, Vol. 14, No. 3, pp. 187-201, May-June, 1973.

which examined historically documented turbine failures corresponding to a cumulative experience of over 70,000 turbine years of operation. Campe, et al., at 9.

The second component of turbine missile risk is the strike probability P_2. VEPCO calculated the strike probabilities for each safety related area of the plant using a method acceptable to the Staff. This involves relating the solid angle subtended by each target to the total solid angle associated with missile ejection from the turbine. Separate values of P_2 were calculated for the design speed and destructive overspeed failure modes. The total strike probability is about 0.2. Campe, et al., at 9-10; see also, SER, Suppl. 2, § 10.7; and VEPCO P2 and P9 Testimony at 2.

With respect to the probability P_3 of penetration and/or damage, it was assumed that intervening barriers had a negligible effect on the missiles, and that each strike resulted in unacceptable damage. In other words P_3 was assumed to be unity. Campe, et al., at 10; VEPCO P2 and P3 Testimony at 5. Table B.1 of the Staff's Campe, et al. Testimony illustrates the individual probabilities that were used in the overall turbine risk evaluation for North Anna.

The overall turbine missile risk based upon probabilistic considerations was estimated to be 2×10^{-5} per year. SER, Suppl. 2, § 10.7. Although the Staff reported only the total value of the turbine missile risk, it is important to note that the evaluation included high trajectory missiles as well as destructive overspeed failures. Campe, et al., at 10.

The Staff separated the overall turbine failure rate of 10^{-4} into individual rates for each of the two failure modes. The individual values are based on the turbine missile study by Dr. Spencer Bush. The low trajectory turbine missiles dominate the risk with respect to strike probabilities. Viewing the product of the three probabilities for each type of missile trajectory and failure mode it can be seen that contribution to the overall risk is about the same for either type of turbine failure mode with respect to LTM's. Campe, et al., at 10, 11.

In view of the estimated risk of 2×10^{-5} per turbine year it was judged by the Staff that additional protection measures were necessary for North Anna. Reduction of the destructive overspeed turbine missile risks is achieved primarily through the overspeed protection system. Since the turbine steam valves are an integral part of the overspeed protection system, and since the malfunctioning turbine valves have been the principal cause of past destructive overspeed failures, their reliability is directly related to the probability of a destructive overspeed. It is the Staff's view that measures such as frequent valve testing have a substantial effect on increasing valve reliability. For this reason weekly valve testing and related inspection and maintenance requirements were imposed on the North Anna plant in order to reduce the destructive overspeed contribution to turbine missile risk. Campe, et al., at 11; see also, §§ 4.7.1.8.1 and 4.7.1.8.2 of North Anna Unit 1 Operating License Technical Specifications (Unit 1 OL Tech Specs).

Similarly, the imposition of turbine disk integrity requirements was expected to reduce the other principal contributor to the overall turbine missile risk, namely low trajectory turbine missiles due to failure near operating speed. The inspection program prescribes tests for detection of flaws or other defects that may exist or develop during operation within the turbine disks. Campe, et al., at 11; see also, § 4.7.1.7 of Unit 1 OL Tech Specs.

At the time the North Anna evaluation was made, it was the Staff's judgment that, although these requirements would improve turbine reliability, the uncertainties in the amount of improvement potentially available were too large to justify unqualified conclusory findings. Thus, it was stated in the SER, Suppl. 2, that the possibility for additional protection measures, pending the outcome of the generic study, may be necessary. Since that time, however, sufficient progress has been made within the generic study (Task Action Plan A-37) that some quantification of the reduction in the turbine failure rate that can be derived from operational and maintenance improvements can be made. Campe, et al., at 11, 12.

The Staff has concluded, based on information obtained from its generic studies on turbine missiles, that the imposition and effective implementation of a turbine disk integrity program in conjunction with a turbine valve testing program will provide a significant degree of reduction in the estimated probability of turbine missile damage for North Anna. The reduced probability is considered by the Staff to be acceptably small and within the guidance provided by SRP 2.2.3. Campe, et al., at 12. VEPCO estimates that the design overspeed turbine failure and missile generation rate is 1.05×10^{-10} per turbine year, and the destructive overspeed turbine failure probability is 1.7×10^{-6} per turbine year. VEPCO P1 Testimony at 8. The probabilities for failure of the components were derived from the turbine vendor (Westinghouse) service experience. Id. at 10. Pursuant to a protective order, the Westinghouse report containing this data was submitted to the Board and parties.

Although the Staff did not present an evaluation of the Westinghouse report on the record, it did testify that VEPCO's fault tree analyses, which were based on the Westinghouse report, do not appear to take into account common mode failure mechanisms (e.g., adverse environmental components, degrading valve performance, and rotor integrity). Campe, et al., at 67. In view of these types of uncertainties, the Staff believes it is more appropriate to use the historically observed system level data (i.e., turbine failures). Hence the values of 4×10^{-5} per turbine year and 6×10^{-5} per turbine year (a total of 10^{-4} per turbine year) for destructive and design overspeed failure probabilities, respectively, were used by the Staff in the turbine missile risk analysis.

The VEPCO and Westinghouse analyses indicate significantly lower turbine failure rates than those used by the Staff. The Staff's derived turbine failure probabilities are inherently more conservative, since they are based on data derived from actual turbine experience with turbines of older technology. Thus, the record establishes that the use of the Staff's probabilities are acceptable in assessing the risk of unacceptable damage from turbine missiles at North Anna Units 1 and 2.

2. North Anna Turbine Valve Testing and Inspection Program

The Staff presented detailed testimony regarding the conservatism included in the estimate of P_1. The first consideration is that the overspeed sensing and tripping systems for turbine generators, as described above, have undergone many improvements in the turbine generator control system. For example, the two parallel signal channels of the North Anna Units 1 and 2 turbine control systems are sufficiently redundant to minimize the possibility of common mode failure from developing. Tr. 467-68. The Staff concluded that the systems have adequate redundancy and independence, and that, based on the good performance record of the systems, it agreed with Dr. Bush that the value of additional overspeed instrumentation is marginal at best. Campe, et al., at 15, 16.

The Staff testified that the risk of steam control valves not operating when needed is greatly reduced by following the operational test procedures recommended by the valve manufacturer. These procedures include inservice valve testing at recommended intervals, recognition of valve malfunctions during the tests, and the identification and prompt correction of the cause of the malfunction. The turbine steam valves for North Anna 1 and 2 are required to be tested once a week. This frequency of testing was calculated by the Staff to result in a factor of improvement of valve failures of 26 over the corresponding failure rate at a test frequency for turbine valves of twice a year, which is the frequency assumed by the Staff of turbines analyzed by Dr. Bush in his study, and which form the basis of the Staff's estimate of P_1. Further reduction in the failure rate for North Anna 1 and 2 over that experienced in the vintage of turbines involved in Dr. Bush's study results from the requirement that the valves must be dismantled and inspected at 3-1/3 year intervals. Campe, et al., at 18-20, see Unit 1 OL Tech Specs., § 4.7.1.8.2d.

VEPCO testified that additional improvements in modern turbine systems results from the current use of techniques of fabrication and testing, advanced metallurgy, and improved control and overspeed protection systems that were either unknown or not generally available in the time period from which much of the data that Dr. Bush collected. VEPCO P1 Testimony at 9; see also Tr. 488-91 re metallurgy techniques.

3. North Anna Turbine Disk Integrity Program

One of the sources of turbine failure and missile generation is while the turbine is operating at design speed. In this situation, a disk failure can be caused by a non-ductile material failure at nominal stresses lower than the yield stress of the material. The probability of turbine missile generation in this mode can be reduced primarily by improving turbine disk integrity. This can be achieved by providing adequate toughness of turbine disk materials, preservice and inservice inspection of the disk, and control of secondary water chemistry. Campe, et al., at 22.

Melting and fabrication control and careful inspection for flaws of turbine disks has reduced the incidence of disk failure since the mid 1950's, which results in a factor of improvement in disk integrity over the turbines that make up the data base used by Dr. Bush in his study. Campe, et al., at 24; VEPCO Pl Testimony at 9. In addition, the selection of disk material with an adequate ratio of fracture toughness to stress assures that critical flaw sizes are limited in size, thereby reducing the possibility of brittle fracture failures below design overspeed caused by stress corrosion effects. This factor, coupled with the modification of operating limits for cold startup to allow sufficient warmup times for metal temperatures to reach a point well above their transition temperatures, results in a reduction in the incidence of turbine failures. Cample, et al., at 24-26; see also Tr. 469-71. These factors all serve to characterize Bush's probability of turbine missile ejection of 10^{-4} per turbine year as being conservative, since the improvement factors have the effect of reducing the probability of missile generation from the vintage of turbines that were considered by Bush. Id.

VEPCO indicates in its FSAR that the toughness of the turbine disk material is in excess of 155 ksi$\sqrt{in}$. This toughness is sufficient to ensure that the ratio of the fracture toughness of the disk and rotor materials to the maximum tangential stress at speeds from normal to design overspeed would be at least approximately 2$\sqrt{in}$ at minimum operating temperatures. This in turn ensures that the critical flaw size for the disk will be above one inch deep a surface flaw. Campe, et al., at 28. A flaw greater than critical size can grow rapidly, causing the material to fail.

The Staff presented testimony in which it developed a quantitative analysis of estimating the improvement in the probability of a North Anna turbine failure at design overspeed of a modern turbine with high fracture toughness such as exists at North Anna, over turbines of the vintage that were studied by Bush with lower fracture toughness. As an example, the Staff estimated that the factor of improvement from a comparison of the turbine disk material at North Anna with that used at Shippingport facility, which experienced a turbine failure in 1974, is about 27. Campe, et al., at 32. The Shippingport turbine is similar to units made prior to 1958, which formed the basis for the Bush study. Id. at 33.

Turbine disk material of modern nuclear turbines such as that at North Anna meet the provisions of SRP § 10.2.3 and have a fracture toughness of about 160 ksi$\sqrt{in}$ which translates into a critical flaw size of approximately 1.87 inches. With such a critical flaw size over the lifetime of an operating nuclear power plant with a conservative estimate of 1000 stress cycles where the facility is started up or shut down and crack growth can occur, the Staff calculated that an initial flaw originating a key location in the disk would have to be about 1.56 inches deep and 10 inches long. Since buried flaws of less than 1/2-inch can be reliably detected using preservice inspection, it is extremely unlikely that a surface flaw 1.56 inches deep and several inches long would escape detection. Campe, et al., at 33.

Preservice inspection requirements also serve to reduce the number of cracks in the finished disk that can grow to critical size. Ultrasonic, visual, fluorescent magnetic partial, and other types of inspection are performed on the turbine disks. Tr. 490. Additionally, the disks are spin tested at the maximum speed anticipated during a turbine trip following a loss of full load. Preservice inspection was estimated by the Staff to result in a factor of improvement of 6 of turbine failure of a turbine with a fracture toughness of K_{1C}=155, such as North Anna, over a turbine with K_{1C}=100. Campe, et al., at 34, 35; see also Tr. 490. As indicated earlier, the turbines that formed the basis for the Bush study had low fracture toughness such as the Shippingport turbine, which had a K_{1C}=55. Id. at 32.

The record supports the positions of both the Staff and VEPCO that improved material fracture toughness and preservice inspection in modern turbines such as the ones used for North Anna 1 and 2 result in a significant factor of improvement in the probability of turbine failure at design overspeed over the standards used with respect to turbines of the vintage that formed the basis of the Bush study. These factors lend additional conservatism to the Staff's use of Bush's estimate of the probability assigned to P_1 of 10^{-4}. The record also established other factors of improvement in design overspeed failure probability that do not lend themselves to quantitative analysis, including improved startup procedures that involve a prewarming of the turbine which prevents high thermal stresses and helps to prevent failure initiated by low cycle fatigue, the monitoring of secondary water chemistry to ensure that harmful impurities are not entering into the turbine steam, and periodic inservice inspection. Campe, et al., at 35-39.

In sum, the record establishes that the use of materials with a high fracture toughness, together with a preservice inspection, can reduce the estimated probability of 6×10^{-5} per turbine year estimated by Bush for design overspeed failures resulting in missiles by at least a factor of 272. This value is a conservative estimate of the factor of improvement attributable to the turbine disk integrity requirements imposed on North Anna. Campe, et al., at 40.

D. Conservatisms in Staff Evaluation of P_2 and P_3

The Staff presented testimony on the conservatisms that are inherent in its turbine missile analysis that resulted in overall risks estimated to be 2×10^{-5} per turbine year. Campe, et al., at 47-55. In addition, VEPCO presented testimony on the conservatism involved in the Staff's estimates of P_2 and P_3. VEPCO P_2 and P_3 Testimony. Discussing these factors in turn, we first analyze P_2, the probability that a selected target will be struck by a missile, given the fact that the missile has been ejected from the turbine.

In calculating P_2, the Staff assumed that a wheel breaks into four 90° segments, or quadrants. Larger size fragments would result in fewer missiles leaving turbine. This would lower the probability that a missile would be striking a given target. The chance of striking a target is proportional to the number of fragments. For fragments smaller than 90° segments, the Staff postulated that the kinetic energy requirements for penetrating through the turbine internals are higher than the available initial kinetic energy possessed by each fragment. Estimates based on the modified Ballistic

Research Laboratory (BRL) formula for penetration in steel support this. Campe et al., at 49. VEPCO testified that an additional conservatism involved in the Staff's estimates of P_2 is the use of the entire cross-sectional area of the entire safety-related structures instead of the area of the equipment itself and its components. VEPCO estimates that this assumption lends a factor of conservatism of at least 10 to the Staff's calculations. VEPCO P_2 and P_3 Testimony, at 2, 3. In addition, VEPCO concluded that approximately one additional factor of 10 conservatism is involved in the Staff's estimate of P_2 because of shielding provided by intermediate walls that is not accounted for. Id. at 5. The record establishes finds the Staff assumption to be reasonable that a four piece wheel break maximizes the number of energetic external missiles and that P_2 is estimated conservatively. Id.

The third probability component P_3, is a measure of the chance that a missile, on its way to a given target, will penetrate intervening barriers (if any), damage or otherwise incapacitate the functional integrity of the target, cause a release of radiation, and lead to radiological doses in excess of 10 CFR Part 100 guidelines. The Staff assumed that P_3 was unity in the turbine missile risk evaluation for North Anna. That is, it was assumed that the above sequence of events leading to unacceptable damage and radiological dose consequences occurs with total certainty every time a missile is ejected in the direction of a given target. Campe, et al., at 50.

One of the conservatims implicit in the Staff's approach is the assumption that intervening structural walls and equipment do not offer any resistance to the missiles. The Staff testified that for operating speed failures this assumption is extremely conservative, since estimates using the modified National Defense Research Committee formula indicate that the turbine missiles generated by a 120% overspeed failure would be stopped by about five feet of 3,000 psi concrete. The 3,000 psi concrete compressive strength corresponds to concrete which is about 70% or less of the compressive strength that it attains ultimately when aged. Campe, et al., at 50, 51. Also, the penetration estimate is based on the assumption that the turbine missile impacts the barrier with a minimum cross-sectional area and a bullet-like point of contact. Since a missile rotates about its center of gravity while in flight, other missile orientations (i.e. larger cross-sectional areas and blunt points of contact) can occur at the point of impact. For example, using the average cross sectional missile area and assuming a blunt nose impact into aged concrete (4286 psi), the barrier thickness for stopping the same 90° missile is about 4 feet. The North Anna concrete containment wall is 4-1/2 feet thick. Thus 120% overspeed missiles are not expected to penetrate the North Anna containment wall.

Further conservatism results from the fact that one safety-related part of the plant, the control room, has walls and a ceiling consisting of 2 feet of concrete. Since the control room elevation is 9 feet below the turbine building floor elevation, missiles traveling in the direction of the control room have to contend with a 12-foot thick concrete turbine pedestal in addition to the control room walls or ceiling. Hence, it is unlikely that any low trajectory turbine missile (120% or 180% overspeed) would enter the control room or even impact its walls. Campe, et al., at 51, 52; Tr. 502-06, 607-08. The Staff also testified that one of the two turbine wheels that have the potential for striking the Unit 1 auxiliary feed water pump house has to interact with the moisture separator unit which is located at the side of the turbine and which nominally has a one inch thick steel shell (thus presenting an effective steel thickness of about 2 inches). The pump house itself is surrounded by two foot thick reinforced concrete. Tr. 516. Thus the probability that a 120% overspeed missile from one of the two eligible turbine wheels would enter this area is much less than one. Considerations of this type with respect to existing barriers within the North Anna plant design provide the basis for the Staff's view that the assumption of the total absence of barriers is conservative. Campe, et al., at 52. VEPCO presented testimony corroborating the Staff conclusion that the assumption that $P_3 = 1$ is a conservative one. VEPCO P_2 and P_3 testimony at 5; Tr. 563.

Beyond penetration considerations, however, additional conservatism associated with P_3 is inherent in the assumption that every missile strike on a safety related target causes unacceptable damage. For example, every time a missile is postulated by the Staff to have entered the auxiliary feed water pump house it is assumed that the auxiliary feed water pumps are totally destroyed. Realistically, however, it is expected that sometimes the missile or scabbing fragments may miss the pumps, or strike them peripherally without total loss of functional capability. Quantification of this effect would require extensive probabilistic analyses. Hence, to simplify the analysis, the

Staff assumed that unacceptable damage occurs every time with a qualitative understanding that the actual probability is something less than unity. Similarly, the probability that every damage of each safety related equipment (for example damaged auxiliary water pump, damaged control room console) leads to radiological doses in excess of 10 CFR Part 100 guidelines is expected to be less than certainty. Campe, et al., at 52, 53. VEPCO testified that yet another conservatism inherent in the Staff's assumption of $P_3 = 1$ is that there is redundancy of safety related equipment, with some replacement equipment available. VEPCO P_2 and P_3 testimony at 5, 6. Accordingly, even if a piece of safety related equipment were damaged by a missile strike, it might not lead to unacceptable consequences.

The Staff testified that a measure of one of the conservatisms, namely the penetration of all barriers being a certainty, can be obtained through the use of available penetration formulas with respect to existing barriers. The Staff estimated that a more realistic estimate of P_3 with respect to the reactor primary system boundary, the control room, and the auxiliary feedwater pumphouse is as follows:

P_3 = 0.1 for 120% overspeed missiles

P3 = 0.5 for 180% overspeed missiles

Camp, et al., at 53.

The Staff prepared a table summarizing the expected probability components for North Anna Units 1 and 2 when the quantifiable conservatisms for P_1, P_2 and P_3 are removed. Campe, et al., Table E.1, p.55. Even though the values in that Table do not include the effects of the North Anna turbine disk integrity and valve testing and inspection requirements, they suggest that the realistic estimate of P_1 is less by a factor of 27. This factor is obtained by assuming that the increased fracture toughness of the North Anna low pressure turbine disks is ten times less effective in lowering the probability of brittle fracture failure than what is estimated. Campe, et al., at 53 and 40-46. The realistic estimate of the destructive overspeed probability is shown to be lower by a factor of six, based on the current valve testing practice of at least once a month. Older practice, as represented by the turbines in Bush's data set, ranged from once a month to once every few years. A testing frequency of once every six months was assumed for the older turbines, so that monthly testing represents an improvement factor of six. The reduced values of P_3 for both failure modes are in recognition of the effects of existing barriers as discussed earlier. As indicated in the Staff's Table 6-1 (Campe, et al., at 55), the overall probability for unacceptable damage by turbine missiles for the North Anna Plant, when estimated on a more realistic basis, is about 7.3×10^{-7} per turbine year. Campe, et al., at 53, 54. The record establishes that this estimate is reasonable.

The Staff also prepared a table summarizing the expected probability components (P_1, P_2, and P_3) for North Anna Units 1 and 2 which took into account the turbine disk integrity and valve testing and inspection requirements. Campe, et al.; Table H.1, at 69. As indicated in the Staff's Table H.1, the overall probability for unacceptable damage by turbine missiles for the

North Anna facilities, when estimated on a conservative basis, is 3.58×10^{-7} per turbine year (Campe, et al., Table H.1 at 69) an expected reduction from the 2×10^{-5} per turbine year set out in the Staff's SER. SER, Suppl. 2, § 10.7. VEPCO's estimate is 4.22×10^{-7} per turbine year (VEPCO's Exhibit AV-2, Table 10.2-3).

E. Conclusion

The record, based on the facts developed therein and discussed above, establishes that the site-specific turbine missile analysis performed for the North Anna facilities, together with the improvement factors attributable to the North Anna turbine disk integrity and valve testing and inspection requirements, support the conclusion that the risk of unacceptable turbine missile damage to systems important to safety is acceptably small within the guidance of SRP 2.2.3. On this basis, the record supports the conclusion that the North Anna structures, systems and components important to safety are appropriately protected against the effects of turbine missiles, and therefore General Design Criterion 4 is satisfied. See Campe, et al., at 68, VEPCO's P2 and P3 Testimony at 6.

Respectfully submitted,

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Dated at Bethesda, Maryland
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