USNRC July 23, 1979

UNITED STATES OF AMERICA
NUCLEAR REGULATORY COMMISSION

BEFORE THE ATOMIC SAFETY AND LICENSING APPEAL BOARD

In the Matter of	)
	) Doc. Nos. 50-338 OL
VIRGINIA ELECTRIC AND POWER COMPANY	) 50-339 OL
	)
(North Anna Power Station, Units 1 and 2)	) (Pumphouse Settlement) and Turbine Missiles)

VEPCO'S MEMORANDUM OF PROPOSED FINDINGS

Pursuant to ALAB-529, 9 NRC 153 (1979), a public hearing was held in this proceeding June 18, 19, and 20, 1979. It was limited to evidence on two matters: (1) the settlement of the service water pumphouse (SWPH) for North Anna Units 1 and 2 and (2) the probability of unacceptable damage from turbine missiles at those units. At the conclusion of the hearing the Appeal Board invited the parties to submit memoranda indicating the specific findings of fact that should be included in the Board's decision (Tr. 621). In its memorandum and order of June 21, 1979, the Board noted the schedule for submitting those proposed findings. The applicant, Virginia Electric and Power Company (Vepco), sets out its proposed findings below.

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I. PUMPHOUSE SETTLEMENT

Under 10 C.F.R. § 50.57 an operating license may be issued upon a finding (among other things) that there is reasonable assurance that the activities authorized by the license can be conducted without endangering the health and safety of the public and will be conducted in compliance with NRC regulations and that the issuance of the license will not be inimical to the health and safety of the public. See 10 C.F.R. § 50.57(a)(3) and (6).

A. Settlement History

1. Behavior of saprolite

Settlement of the service water pumphouse for North Anna Units 1 and 2 was first noticed in late November or early December 1972 (Vepco's Testimony on Service Water Pump House Settlement, hereinafter "Vepco's SWPH Testimony," 9). A certain amount of settlement had been expected because of foundation conditions (see Vepco's SWPH Testimony 8), and indeed heavy structures routinely experience settlement (hearing of June 1, 1977, Tr. 3283-84). Since December 4, 1972, the amount of settlement has been measured, first by Vepco's architect-engineer, the Stone & Webster Engineering Corporation (Stone & Webster), for the purpose of making engineering evaluations, and more recently by the surveying

firm of Moore, Hardee & Carrouth Associates (MH&C) under contract to Vepco (Vepco's SWPH Testimony 9, 14, Figs. 7A-7G).

The North Anna Units 1 and 2 pumphouse is founded on saprolite, a residual soil-like material resulting from the weathering of the bedrock (Vepco's SWPH Testimony 37-38). The peculiar nature of saprolite (which does not behave in accordance with classical soil mechanics theory (id. 37, 38)) has frustrated the applicant's attempts to predict the precise time-rate of settlement (id. 1-2, 37-42); in fact, the settlement of the saprolite has tended to be stepwise, rather than a smooth curve as classical soil mechanics would predict (id. 42; Tr. 40, 41, 48, 49, 191).

In retrospect, however, the applicant's geotechnical experts have been able to correlate many of the increments of settlement with the settlement-causing events occurring at the site (id. 42). Those events include the construction of the pumphouse itself, the filling of the service water reservoir, and the changes in the level of groundwater beneath the pumphouse (see, e.g., id. 17, 36-37, 38-39, 53-54). Of these settlement-inducing factors, the most controversial has been the groundwater level (see generally Vepco's Supplemental Testimony in Response to NRC Staff Testimony on Service Water Pump House Settlement, hereinafter "Vepco's Supplemental

Testimony"). It is that subject that these proposed findings will address next.

2. Groundwater

At the NRC Staff's insistence the applicant has installed a system of horizontal drains for the purpose of controlling the groundwater level beneath the service water pumphouse (Vepco's SWPH Testimony 44, 45-51). The lowering of the groundwater level by the drains at the time of installation resulted in some additional settlement of the pumphouse (id. 49, 50; Tr. 53-54).

It is undisputed that a further lowering of the groundwater level beneath the pumphouse would induce additional settlement by increasing the "effective stress" on a plane at the midheight of the foundation material (see Vepco's Supplemental Testimony 5-6; Tr. 53, 358-59). On cross-examination the intervenor's counsel attempted to establish that therefore a period of extreme drought at the North Anna site could cause additional settlement (Tr. 52-53, 364-72).

The evidence shows, however, that the possibility of drought does not present a risk of significant rapid settlement. The applicant agreed that a period of sparse rainfall could cause a lowering of groundwater level but

testified that this would be a slow change, extending over several months, especially since the impermeable reservoir liner protects the area against water losses due to evaporation (Vepco's Supplemental Testimony 18). Moreover, the horizontal drains that the applicant has installed to control the groundwater level beneath the pumphouse have lowered the groundwater below the lowest level that would be expected even during a drought (Tr. 52, 192). The applicant's witness, Mr. MacIver, testified that the summer of 1977 was a period of severe drought at the North Anna site but that nevertheless the horizontal drains continued to flow, indicating that the groundwater level had not dropped below the level of the drains (Tr. 52-53; see also Tr. 365, 372).

3. Prediction of future settlement

Because of the complex behavior of the saprolite, Vepco's experts do not rely overmuch on predictions of how much future settlement might occur (see, e.g., Tr. 291-92). They have chosen instead to install flexible expansion joints (about which more will be said below) that will accommodate a large amount of additional settlement, more than the applicant deems credible, and to continue monitoring the settlement to ensure that the allowable amount is not exceeded (Vepco's SWPH Testimony 2, 41-42; see also oral testimony of C. M. Robinson,

Jr., hearing of June 1, 1977, Tr. 3283-84). The NRC Staff was also reluctant to make a prediction (see Tr. 341, 344).

Vepco's witnesses did testify, however, that there is no theoretical reason to expect significant additional settlement:

> All construction activities and changes in loading that would be expected to influence settlement have been completed, and no significant variation in groundwater level under the pump house is possible. Hence there is no theoretical basis for anticipating any future settlement beyond a possible long-term, slow settling due to secondary compression.

(Vepco's SWPH Testimony 50-51.) Vepco's witnesses also testified that the settlement over the last 20 months has been small and gradual, as one might expect from classical soil mechanics (Vepco's SWPH Testimony 2, 42-43). And it does appear, to the layman's eye, that the settlement of the pumphouse has "flattened out" in recent months (see Figs. 7F and 7G). The applicant's witnesses testified that the "steps" in the stepwise settlement should be smaller and smaller as time goes on (Tr. 192, 298-99; see also Tr. 19/). When pressed, they testified that they estimate only about 0.05 foot of settlement over the rest of the life of the plant, due to secondary effects (Tr. 311).

A geologist named Dr. Robert F. Mueller submitted a limited appearance statement in which he suggested the

possibility of "viscous fluid behavior." Dr. Mueller said 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 of Dr. Robert F. Mueller, following Tr. 5, at 2). Vepco's witnesses testified that such a phenomenon would not occur at the North Anna site (Tr. 65-66). The NRC Staff agreed that such "viscous fluid behavior" would be unlikely for the saprolite under the pumphouse (Tr. 373-74). (See also Tr. 64-65, 436.)

The evidence suggests, in short, that any future settlement will be relatively small. It is not necessary to rely on this prediction, however, because the applicant has placed its reliance instead on (1) accommodating whatever settlement does occur and (2) monitoring to ensure that unexpected settlement does not go unnoticed.

B. Technical Specification 3/4.7.12

This philosophy of accommodation and monitoring is embodied in Technical Specification 3/4.7.12, which deals with settlement of the pumphouse and other Class 1 structures. The original technical specification for North Anna Unit 1 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 average settlement was 0.15 foot since December 1975, and the allowable differential settlement was 0.25 foot.

In June 1978 the applicant 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). The NRC Staff, after review, concluded that the allowable settlement could safely be increased, though not to the limits the applicant had proposed (see Safety Evaluation of Virginia Electric and Power Company's (Vepco's) Request to Revise Technical Specifications of Section 3/4.7.12, served on the Board and parties December 22, 1978, and January 9, 1979, and including "Revision 1" of the technical specification). Instead the Staff proposed, among other things, a limit on differential settlement between pumphouse and service water lines of 0.22 foot since July 1977 (NRC Staff Testimony

Regarding Pumphouse Settlement, hereinafter "Staff SWPH Testimony," 36), a 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 SWPH Testimony 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.

By the time of the public hearing the Staff and applicant had agreed on a technical specification incorporating the Staff's limits, and this was submitted to the Board by the applicant and made a part of its testimony. The only disagreement between Staff and applicant was over how often the pumphouse should be monitored. The Staff maintains that monthly monitoring is necessary for the next three years (Staff SWPH Testimony 42-43) while Vepco believes every six months will be adequate (Tr. 110, 206, 265). This matter will be discussed below.

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 that were included with the applicant's testimony (see above) and requires monthly 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).

C. Accommodation of Settlement

1. Pipe stress analysis

The principal safety concern with the settlement of the service water pumphouse is to ensure that the buried 36-inch-diameter service water lines that run from the pumphouse to the plant proper and back (see Vepco's SWPH Testimony 5) are not overstressed (see, e.g., Tr. 410; Staff SWPH Testimony 35). The four of these lines carry water to and from the pumphouse (two each way), passing through the north wall of the pumphouse and into the dike above the top of the clay liner and then turning downward through the coarser filter zone and into the ground beneath the outside toe of the dike (Vepco's SWPH Testimony 5). They are used during normal operation to provide cooling water for heat exchangers that remove heat from the Component Cooling System (Vepco's SWPH Testimony 3). Service water is also used in the Main Control

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Room air-conditioning condensers, the charging pump lubricating oil and seal coolers, the service and instrument air compressors, and the pipe penetration cooling coils (id.). The system also provides a backup water supply for the steam generator feed system, the fuel pit coolers, and the recirculation air cooling coils (id.). In the event of an emergency, such as a pipe rupture in the reactor coolant system, the Service Water System might be called upon to supply cooling water to the recirculation spray heat exchangers in order to remove heat from the containment (id.; see also Tr. 28-29, 118-21).

Stone & Webster has performed a stress analysis of the buried 36-inch service water lines using a computer model (NUPIPE) that calculates the piping stresses due to soil interactions (Tr. 101, Vepco's SWPH Testimony 55). The goal of the analysis was to assure that the stress levels in the service water piping do not exceed the allowable values defined by the American Society of Mechanical Engineers (ASME) Boiler and Pressure Vessel Code, § III, and that the movements of the expansion joints in the service water lines (mentioned above) do not exceed the design values of the joints (see Staff SWPH Testimony 35-36).

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The computer analysis of stresses on the buried service water piping done by Stone & Webster in 1978 showed that, even if the pumphouse were to have experienced average settlement of 0.33 foot since December 1975, the stress level would be below the ASME Code allowable of 41,100 psi (Vepco's SWPH Testimony 60). Additional analysis taking into account the recently revised maximum service water temperature shows that the piping stresses still remain smaller than the allowable limit by a large margin (id. 62).

The NRC Staff did not disagree with the parts of Vepco's testimony regarding the assumed loads and methodology for analyzing the stress limits for the service water piping (Staff SWPH Testimony 35), and the Staff itself performed a rough check of Vepco's conclusion that 0.33 foot of additional pumphouse settlement since December 1975 would not overstress the buried pipes (Staff SWPH Testimony 38). Using certain conservative simplifying assumptions, the Staff concluded that 0.22 foot of additional settlement of the ends of the pipes since August 3, 1978, would not exceed the ASME Code allowable stresses (id. 40-41; Tr. 411-12). Subsequent to this analysis the Staff learned that the service water lines had been embedded in the coarse dike filter about a year later than the Staff had previously understood; this means that if anything

the ends of the pipes have settled less than the Staff assumed, and so the Staff believes there is additional basis to believe that the 0.22 foot limit is conservative (Staff SWPH Testimony 41).

2. Expansion joints

After analyses of the pipe stresses in 1975 indicated that the allowable stresses in the service water piping might have been exceeded (Vepco's SWPH Testimony 13), Stone & Webster unearthed and cut the service water lines immediately outside the pumphouse on July 1, 1976, and installed pressure-balanced stainless steel expansion joints in the supply and return headers in order to accommodate movements caused by future pumphouse settlement (id. 15, 24, Figs. 8, 12, 15). These expansion joints are the limiting system components insofar as pumphouse settlement is concerned (Vepco's SWPH Testimony 24; Tr. 175, 176), and so the analyses of stresses caused by further settlement have concentrated on them.

Vepco has had the expansion joints analyzed for average pumphouse settlement of 0.33 foot since December 1975 (Vepco's proposed technical specification limit, discussed above) and then reanalyzed taking into account the revised maximum service water temperature and additional hypothetical settlements well in excess of the 0.33-foot mark (Vepco's SWPH Testimony 24-25).

In order to analyze an expansion joint, the manufacturer must combine the differential movements due to thermal, settlement, earthquake, and dead loads into a resultant movement. This resultant movement is calculated using the rules and equations of the "Standards of Expansion Joint Manufacturers' Association" (in particular, computer codes that have been accepted by the ASME (Tr. 237)) and is referred to as an "equivalent axial compression." "Allowable equivalent axial compression" represents the elastic limit of the expansion joint, that is, the amount that each convolution can be compressed before becoming "solid" and touching the adjacent convolution (Vepco's SWPH Testimony 25, Fig. 15). The equivalent axial compression is composed of lateral displacement, compression, and rotation components (see Tr. 237-38).

The expansion joints at the North Anna pumphouse have an allowable equivalent axial compression of 0.525 inch per convolution, assuming all movements are dynamic, and 0.7130 inch per convolution, assuming all movements are static. Because earthquake movements are the only dynamic movements and represent less than 10 percent of the total movement, the expansion joints can be considered to behave like static devices (Vepco's SWPH Testimony 25; Tr. 240). At compressions

less than 0.7130 inch per convolution the expansion joints absorb movements without significant distortion (Vepco's SWPH Testimony 29).

Although at the time Stone & Webster anticipated only about 0.15 foot of additional settlement from December 1975 (Vepco's SWPH Testimony 13), the expansion joints were designed based on 0.25 foot of additional settlement. The resulting design can accommodate a lateral motion of three inches in addition to a certain compression and rotation (Tr. 97, 237-38). Later on, when Vepco was requesting an increase in the technical specification settlement limit for average service water pumphouse settlement to 0.33 foot since December 1975, Stone & Webster went back to the manufacturer and asked him to reanalyze the joints assuming that the proposed 0.33-foot limit had been reached (Tr. 212, 237).

The manufacturer reported that the differential movements superimposed on the expansion joints by the Vepco-proposed technical specification limit of 0.33 foot since December 1975 represent only about 54 percent of the dynamic allowable and 40 percent 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 conservatively estimated by Vepco as 1,000 (Vepco's SWPH Testimony 26, Tr. 237). To reach the 0.33-foot mark the pumphouse would have to have settled approximately four inches since the installation of the expansion joints (Vepco's SWPH Testimony 28). By comparison, the average settlement since the expansion joints were installed is now about 1.3 inches (cf. Vepco's SWPH Testimony, Fig. 7E, with Fig. 7G).

Vepco's witnesses testified that if, after the proposed technical specification limit of 0.33 foot were reached, enough additional settlement were to occur to double the differential movements at the joint (this would be approximately four additional inches of settlement beyond the 0.33-foot mark), the resulting compression would still be less than the 0.7130 inch-per-convolution design limit (id. 28).

Even if additional settlement were to occur such that the design limit (0.7130 inch per convolution) were reached, the expansion joints would remain intact (id. 29). The manufacturer of the joints artificially imposed movements corresponding to 0.7130 inch per convolution on the joint and showed that the joint was still suitable for 2,585 additional cycles, a number far exceeding the 1,000 cycles expected over

the lifetime of the plant (id.).

Finally, expansion joints similar in design to the ones at North Anna have been physically tested at conditions that exceeded the design limit (total allowable equivalent axial compression) by 10 percent of the design cyclic lifetime. The manufacturer's tests indicate that movements greater than the allowable compression will cause the convolutions to become highly stressed and that cyclic movements superimposed on them in this condition will cause small fatigue cracks to occur. In the tests these fatigue cracks were approximately pinhole size, and in no case did the cracks propagate to the extent that there was any concern that a guillotine failure would occur (id. 29-30; Tr. 239-41, 247-48, 281-82).

The NRC Staff has proposed a limit on differential settlement (that is, differential motion between either corner of the north side of the pump house and the exposed ends of the pipes on the north side of the expansion joints) of 0.22 foot since July 1977 (Staff SWPH Testimony 37). As noted above, the expansion joints were designed to accommodate a lateral movement of 0.25 foot (three inches) (id.). The Staff conservatively assumed that the expansion joints were installed in December 1975, subtracted the differential settlement estimated to have occurred between December 1975 and July 1977

(0.03 foot), and concluded that the difference (0.25-0.03 = 0.22 foot of additional differential settlement since July 1977) can safely be accommodated (id. 36-37; see also Tr. 396-97).

3. Accident scenario

Given the considerable margin of conservatism in the design of the expansion joints, it is apparent that a great deal of additional settlement could occur before the joints would be expected to fail. The applicant's testimony set out a scenario of what would happen as the settlement increased beyond what the applicant believes credible. As noted above, the applicant and Staff propose to retain the requirement that if the actual settlement reaches 75 percent of any allowable value an engineering evaluation must be made and a report submitted to the NRC (Vepco's SWPH Testimony 27). If necessary, physical modifications such as the cutting and rewelding of the pipe section of the expansion joint could be made to regain the original flexibility of the joints (id. 27; Tr. 178).

If the settlement reaches 100 percent of the allowable value, both units are required to go to cold shutdown (Mode 5) (Vepco's SWPH Testimony 28), even though at 100 percent of the applicant's proposed 0.33-foot technical specification limit,

as noted above, the flexible expansion joints are well within their design limit (id. 28-29). In Mode 5 the reactors are shut down and the primary coolant temperature is reduced well below the boiling point of water. In this mode of operation the service water system is required to remove decay heat from the reactors and to cool some additional small components. Only one service water pump (at reduced flow rate) and one supply and return header are required to meet these cooling requirements. This would leave three spare pumps at the service water reservoir, one spare supply header, one spare return header, and two auxiliary service water pumps at Lake Anna (id. 28).

If further settlement beyond the elastic limit of the expansion joints were to occur, the expansion joints would eventually start to leak, but the failure mechanism is by fatigue and not catastrophic (id. 30). As noted, in the manufacturer's tests the first pinhole-sized fatigue cracks occurred at conditions that exceeded the design limit (total allowable equivalent axial compression) by 10 percent of the design cyclic lifetime (id. 30). If the leaks approached a magnitude of perhaps 1,000 gallons per minute, they would fill the expansion joint enclosure and pour out onto the ground around the pumphouse, alerting the station employees, who are

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required to inspect the pumphouse twice each shift (approximately once every four hours) (Tr. 113, 224, 229, 249). The leakage would have to exceed approximately 3,000 gallons per minute to affect system cooling capacity with one service water pump (assuming that the technical specification limit had been reached and the station shut down at least six days before), and a leak of this size would be detectable by changes in temperature and/or flow in the service water system (Vepco's SWPH Testimony 31) as well as by observation of the leak (Tr. 224).

The next step in the applicant's scenario was to assume that the expansion joints failed catastrophically. Because the service water system is designed so that no single failure will prevent it from performing its required functions (Vepco's SWPH Testimony 6; Tr. 377), a catastrophic failure of one expansion joint could be tolerated even while the station was in full operation (Tr. 283, 285, 453-54). A catastrophic failure (i.e., a guillotine break) is unlikely, because tie rods would hold the joints together even in the event of a complete circumferential break, and a substantial amount of service water would continue to flow (Tr. 223, 298).

Even if all four expansion joints were to break, isolating the pumphouse, sufficient service water could still

be provided by two auxiliary service water pumps located on the Circulating Water Intake Structure next to Lake Anna. Only two service water pumps are needed to meet system design requirements, even in the event of a design basis accident in one of the units (Vepco's SWPH Testimony, Table 4). It would take some 5-15 minutes to detect the loss of the pumphouse and switch to the auxiliary pumps (Tr. 24, 31), however, and the applicant did not analyze what would happen if this occurred during full operation, because it believes that a sudden isolation of the pumphouse is not a credible event (Tr. 283). The NRC Staff agreed with that assessment (Tr. 378).

Assuming that the plant had gone to cold shutdown before the break occurred, however (as it is required to do when the technical specification limit is reached), the interruption of flow would have no effect on the safe operation of the plant (Vepco's SWPH Testimony 33). The two auxiliary service water pumps would be capable of providing the system design requirements in a shutdown condition even without repair of the failed expansion joints (id. 34). Once the failed expansion joints were plugged or capped, either of the two auxiliary pumps could provide flows in excess of the system requirements (id. 35).

D. Monitoring

Settlement of Class 1 structures at the North Anna station 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 benchmark of known elevation using a surveyor's level and rod. The technical specifications require the monitoring to be done with surveying instruments that meet the requirements specified by the U. S. Department of Commerce National Oceanic and Atmospheric Administration for "Second-Order, Class II" accuracy (Vepco's SWPH Testimony 52). Since November 1975 the surveying firm of Moore, Hardee & Carrouth Associates has been performing the survey work (id. 14).

The settlement monitoring program and data for the service water pumphouse and other Class 1 structures were reviewed by the NRC Office of Inspection and Enforcement, Region II, during special inspections on December 6-8, 1978, and March 5-15, 1979. The Staff testified that the results of those inspections were in substantial agreement with the applicant's testimony (Staff SWPH Testimony 33). In particular, the Staff testified that the surveying instruments and procedures used by Moore, Hardee & Carrouth Associates meet the requirements for a Second-Order, Class II survey (see Tr.

419, 423, 442). There seems to be no disagreement about this. Instead, most of the questioning at the hearing concentrated on (1) the frequency of monitoring that should be required and (2) the speed with which survey results should be reported.

1. Frequency of surveys

The NRC Staff contends that the frequency of the monitoring of the settlement of the pumphouse should be the same as that prescribed for measuring groundwater levels and drain flows, that is, at least once every 31 days until Unit 1 has been in operation at least five years (Staff SWPH Testimony 42-43; Tr. 339). Vepco's witnesses, on the other hand, testified that once every six months would be adequate (Tr. 110, 206, 265, 298-99), except for the exposed ends of the 36-inch service water lines, for which monthly monitoring may be desirable for a while longer (Tr. 206).

The Staff's rationale was expressed by its witness Dr. Heller:

> The reason we're asking for the settlement monitoring to be conducted every month for the next three years, which will make a total time span of five years from the issuance of the license for Unit 1, is that the ground water levels and the piezometers are read at this frequency, the flow rates from the drains are read at this frequency, and it's necessary to get a good correlation between all of these measurements to assure ourselves that we have in fact found the cause of the rapid settlement that occurred in 1974 and 1975.

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(Tr. 339.) Vepco's Supplemental Testimony, however, goes to some lengths to establish that the potential for additional rapid settlement of the pumphouse due to groundwater level changes does not exist (see Vepco's Supplemental Testimony 3). In light of that testimony and the slow rate of settlement of the last 20 months or so, the Staff's desire to understand the rapid settlement that occurred in 1974 and 1975 would seem to be largely academic. A monitoring frequency of six months should be adequate to assure the safety of the public.

2. Reporting the survey results

Counsel for Intervenor Arnold attempted to establish on cross-examination that additional measures are needed to ensure that the survey data are reported promptly (Tr. 81, 125). He made essentially two points: (1) in the past there have been delays of several months in relaying the Moore, Hardee & Carrouth Associates survey results to Vepco and (2) Vepco could have required MH&C to make more frequent surveys in the fall of 1977, before the technical specifications went into effect.

It is true that in the past there were delays in reporting the MH&C data (Tr. 123-24, 129). In early 1979, however, the applicant established a new reporting procedure (Tr. 124), which requires that MH&C report the survey data to Vepco within seven working days (Tr. 122, 413-14, 430). The

Staff testified that Vepco will be required to comply with this operating procedure (Tr. 415-16). A Staff witness testified that since the new procedure has gone into effect, in the spring of 1979, the reporting has improved and Vepco has been getting the data within seven days (Tr. 414; see also Tr. 451). Vepco testified that recently complete settlement records of the pumphouse have been received from MH&C in as little as two or three days (Tr. 81, 125).

Intervenor Arnold's counsel questioned the witnesses at some length about the conduct of settlement monitoring by both MH&C and Stone & Webster in the summer and fall of 1977, before Technical Specification 3/4.7.12 was issued, but the events of those months have little relevance to the conduct of the more formal settlement monitoring program in effect today (see Vepco's SWPH Testimony 53; Tr. 125, 430).

The station manager for North Anna Units 1 and 2 testified that one of his prime responsibilities is to enforce the technical specifications (Tr. 207-09, 277), and the evidence shows that the applicant has complied with its technical specification. During 1977 MH&C were, at Vepco's direction, performing surveys at three-, four-, and five-month intervals (Staff SWPH Testimony, App. C, at 5), more often than the semi-annual requirement of the technical specification,

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which in any event did not go into effect until November 26, 1977 (Tr. 154, 387).

When the review of the MH&C survey data for December 12, 1977, showed that average settlement of the pumphouse had reached 65 percent of the limit, the Stone & Webster lead geotechnical engineer notified Vepco in early March 1978 (Staff SWPH Testimony, App. C Summary of Inquiry at 8). Vepco then told MH&C to perform monthly surveys (see id.; Vepco's SWPH Testimony 18). The March 30 survey revealed to the applicant that pumphouse settlement had exceeded 75 percent of the 0.15-foot limit, requiring the special report called for by the technical specification. The NRC was notified of the settlement, and members of the Staff visited the site April 13 to review the matter. Vepco submitted a Licensee Event Report on April 28, 1978, and the special report required by the technical specification on May 31, 1978 (Staff SWPH Testimony, App. B at I-5, App. C Summary of Inquiry 8). The NRC Office of Inspection and Enforcement, Region II, conducted an investigation and concluded that Vepco had met the requirements of the technical specifications (Staff SWPH Testimony, App. A at I-7 and I-8, Tr. 419).

Since the spring of 1978 the applicant has had surveys made about once a month, and when average settlement neared 100

percent of the limit at which the plant would have to be shut down, surveys were made every week (Vepco's SWPH Testimony, Figs. 7F, 7G). The settlement monitoring records are open to inspection by I&E inspectors (Tr. 273-74), and there is a resident NRC inspector at North Anna (Tr. 273).

On this evidence there is no reason to believe that the applicant will not comply with its technical specification on settlement. In short, the record supports the conclusion that the settlement monitoring program will adequately protect the public health and safety and that full-power, full-term operating licenses for North Anna Units 1 and 2 may be issued.

II. TURBINE MISSILES

In ALAB-529 the Appeal Board directed the NRC Staff to elaborate on its analysis of the turbine missile risk and invited the applicant to furnish its own views on the subject (9 NRC at 155). The standard by which the Staff reviews and evaluates turbine missile risks is General Design Criterion 4, of 10 C.F.R. Part 50, Appendix A, which requires that structures, systems, and components important to safety "shall be appropriately protected against dynamic effects, including the effects of missiles" (NRC Staff Testimony Regarding Turbine Missiles, hereinafter "Staff Turbine Missile Testimony," 8).

Interpretation of General Design Criterion 4 is provided by Regulatory Guide 1.115, which gives guidance to applicants on an acceptable means of protection against low-trajectory turbine missiles, and by the Standard Review Plan §§ 2.2.3, 3.5.1.3, 10.2, and 10.2.3, which give guidance to the NRC Staff (id.).

The Staff and applicant have taken a probabilistic approach in analyzing the turbine missile problem. Although there is no regulation that specifies an acceptable probability (see Tr. 594), Regulatory Guide 1.115 says that the NRC Staff considers 10^{-7} per year an acceptable hazard rate for the loss of an essential system from a single event (Regulatory Guide 1.115, Rev. 1, at 1.115-3). Standard Review Plan § 2.2.3 provides that an event need not be considered as a design basis event if it can be shown, using conservative assumptions in the analysis, that the probability of exceeding exposures in excess of 10 C.F.R. Part 100 is less than about 10^{-6} per year. Standard Review Plan § 2.2.3 also says that judgment must be used in determining the overall acceptability of the risk in view of the inability to assign precise numerical values to the probability of occurrence of a hazard such as a turbine failure (Staff Turbine Missile Testimony 8-9).

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Both the Staff and the applicant calculated the probability of unacceptable turbine missile damage by multiplying together three probabilities P1, P2, and P3 to calculate the overall probability of unacceptable damage P4. P1, as defined by the Staff, is the probability that a turbine will fail and missiles be ejected (Staff Turbine Missile Testimony 7). P2 is the probability that, given a turbine failure, a selected target (for example, the control room) will be struck (id.). P3 is the probability of damaging safety-related plant equipment, given a missile strike (id.). The product of the three probabilities is P4, the overall probability of unacceptable damage.

The Staff analyzed the probability of both high- and low-trajectory turbine missiles for two failure modes, design speed and destructive overspeed (see id. 4-5, 7). The Staff adds up these several probabilities to calculate a single cumulative probability. For its analysis in the Safety Evaluation Report (SER Supp. 2, Staff Exhibit 3, at 10-2), the Staff estimated this cumulative probability to be 2×10^{-5}, which the Staff breaks down as follows:

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Staff Table B.1

Failure Mode	Missile Trajectory	P1	P2	P3	P1xP2xP3
Operating Speed	Low	6×10^{-5}	0.2	1	1.2×10^{-5}
Operating Speed	High	6×10^{-5}	0.02	1	1.2×10^{-6}
Destructive Overspeed	Low	4×10^{-5}	0.2	1	8×10^{-6}
Destructive Overspeed	High	4×10^{-5}	0.0009	1	3.6×10^{-8}
				TOTAL	2×10^{-5}

(Staff Turbine Missile Testimony at 13, Table B.1.) This is higher than the 10^{-6} criterion of Standard Review Plan 2.2.3, and the Staff imposed the requirement that the applicant commit to the turbine valve testing and inspection program and a turbine disk integrity program outlined in the Standard Review Plan (Staff Turbine Missile Testimony 1). In its testimony in this proceeding the Staff attempted to quantify, first, the improvements that can be expected from the valve testing and disk integrity programs and, second, the conservatisms in the original probability estimate of 2×10^{-5} (id. 2).

A. Probability of Missile Generation (P1)

1. Staff approach

The Staff began by assuming a probability of missile generation of 10^{-4} per turbine per year. This figure comes from Regulatory Guide 1.115, which in turn is based on a paper by Spencer H. Bush. Dr. Bush arrived at this estimate of turbine failure by examining the historical record of actual turbine failures in the past. The Staff feels, however, that a valve testing and disk integrity program can improve P1, and it has derived some quantification of the improvement.

a. Destructive overspeed. First the Staff addressed the probability of destructive overspeed, which is caused by a failure of the overspeed sensing and tripping system or of the valves that control steam flow. The Staff testified that since 1960 the overspeed sensing and tripping systems for turbine generator units of large central power stations have undergone many improvements (Staff Turbine Missile Testimony 14). These improvements, according to the Staff, include redesigned control systems and improved test capabilities (Staff Turbine Missile Testimony 14, 15). The applicant's witnesses agreed that modern turbine-generators supplied to the nuclear industry employ "improved control and overspeed protection systems that were either unknown or not

generally available prior to the mid-1950's, the time period from which much of the Bush data were collected" (Vepco Testimony on Probability of Generating Turbine Missiles and Turbine Overspeed Protection System, hereinafter "Vepco Pl Testimony," 9; see also Tr. 467, 481-85, 609). The applicant's witnesses described the overspeed protection system for the North Anna turbines, which provides an overspeed controller including a mechanical overspeed trip and an electrical overspeed trip (Vepco Pl Testimony 3-5).

The Staff also addressed the reliability of the valves that control steam flow to the turbines. The Staff testified (Staff Turbine Missile Testimony 17-18) and Vepco's witnesses agreed (Tr. 468-69) that modern valves, such as those at North Anna, are readily accessible for inspection and maintenance and that the steam lines at North Anna are such that the steam valves can be tested under actual operating conditions (see also Tr. 610).

The Staff also testified that the risk that steam control valves will not operate when required can be greatly reduced by following the operational test procedures recommended by the valve manufacturers (NRC Staff Testimony 18). The Staff has required Vepco to test the North Anna turbine steam valves once a week (id. 19-20; Vepco's Testimony

on P2 and P3 and Turbine Inspection, hereinafter "Vepco's P2 and P3 Testimony," 6-8), as compared to a testing frequency of twice a year, which is representative of the turbines in Bush's study that failed at destructive overspeed due to valve malfunction (Staff Turbine Missile Testimony 20). Because valve failure is mitigated by the requirement for valve testing, the Staff calculates a factor of improvement of 26 (id. 20). This is conservative, the Staff believes, because the additional requirement of periodic valve dismantling and inspection at 3-1/3-year intervals provides an additional reduction in the expected destructive overspeed occurrence rate (id.). Accordingly, a more realistic but still conservative estimate of the probabilities of missile generation at destructive overspeed can be calculated by multiplying the P1 figures for destructive overspeed by 1/26.

b. Design overspeed. Whereas destructive overspeed is primarily the result of a failure of the overspeed protection system or the steam valves, a design overspeed missile results from non-ductile failure at design overspeed (120% of normal operating speed) (Staff Turbine Missile Testimony 22; Vepco P1 Testimony 6). Modern turbine-generators, such as those at North Anna, employ techniques of fabrication and testing and advanced metallurgy that were unknown or not generally

available when many of the Bush data were collected (Vepco Pl Testimony 9). The Staff identified five things that should contribute to decreasing the risk of brittle failure of turbine disks at design overspeed: improved fracture toughness of the disks and rotor materials (Staff Turbine Missile Testimony 28), preservice inspection (id. 34-35), improved startup procedures (id. 35-37), control of water chemistry (id. 38), and inservice inspection (id. 38-40).

(1) Improved fracture toughness. The Staff testified that older turbines, such as the Shippingport turbine, which failed in 1974 in a non-ductile manner near the normal operating speed without producing missiles, were not designed and manufactured to the higher standards used today. For example, twenty years ago fracture mechanics concepts were not adequately developed, and so fracture mechanics analyses were not used in turbine design. Turbine components made in this era often had low material toughness properties and were placed in service with initial flaws that would be unacceptable by today's standards. Also, the poor keyway design in the Shippingport turbine disks augmented the crack growth (Staff Turbine Missile Testimony 33; see also Tr. 489, 612). From the theory of fracture mechanics the Staff calculated a factor of improvement of North Anna over Shippingport of 327, and a

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factor of 45 for North Anna over older turbines with an assumed toughness (K_{IC}) of 100 (Staff Turbine Missile Testimony 31, 32, Table D.5).

(2) Preservice inspection. A second "factor of improvement" in calculating the probability of design overspeed comes from modern preservice inspection techniques. The Staff testified that normally, after heat treatment, the rough machined turbine disks are ultrasonically inspected on the flat surfaces of the hub and the rim. If ultrasonic indications are detected, additional ultrasonic testing is required in the web section. The finished bores are given a visual examination followed by a wet magnetic particle inspection. The finished surfaces of the machined disks are inspected by the fluorescent magnetic particle method. After each disk is shrunk onto the shaft and cooled, equally spaced round-bottomed holes or keyways are drilled, reamed, and then inspected using dye penetrant techniques. No flaw indications are allowed in the bore or keyway regions (Staff Turbine Missile Testimony 34). Each turbine rotor assembly typically is spin tested at a speed greater than the maximum speed anticipated during a turbine trip following a loss of full load (id.; Vepco Pl Testimony 6).

The Staff calculated a factor of improvement due to preservice inspection by taking the ratio of the effect of

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preservice inspection on the density function of cracks in the turbine disk made of tougher material to that of the weaker material. A factor of improvement of 6 is calculated by comparing North Anna to older turbines of an assumed material fracture toughness (K_{IC}) of 100. By comparing North Anna turbine disk materials to the Shippingport turbine disk material, a factor of improvement of 15 is obtained (id. 35).

(3) Combined factor of improvement. The overall factor of improvement in the design overspeed failure probability can be calculated by multiplying together the individual factors of improvement from improved fracture toughness and improved preservice inspection (id. 40). Comparing North Anna to older turbines having an assumed fracture toughness of 100, the Staff calculated an overall factor of improvement of approximately 272 (id. 40). Compared to Shippingport (K_{IC} = 55), the overall factor of improvement for North Anna is approximately 4900 (id.) (The Shippingport turbine is of the 1950's vintage and thus representative of the majority of the turbines in Bush's data set (id.).)

The Staff used the factor of improvement of 272 to reduce the estimated probability of 6×10^{-5} per turbine year for design overspeed failures (id.) down to 2.21×10^{-7}. The Staff believes this factor of improvement is a conservative

estimate for a number of reasons (id.). For example, this factor of improvement of 272 is based on a fracture toughness of 100, which is higher than that of, for example, the Shippingport turbine materials (id.). For another thing, the effects of spin testing, improved startup procedures, water chemistry control, and inservice inspection make no quantitative contribution to the factor of improvement even though in fact they reduce the probability of failure (id. 41).

(4) Startup procedures, water chemistry control, and inservice inspection. The cold startup of a nuclear turbine is the most likely time for misoperation, because rapid startup may cause rapid heating and consequently high thermal stresses; because the material of the low-pressure disk is less ductile, and more susceptible to brittle failure, when cold; and because rapid heating can lead to excessive differential expansion between rotating and stationary components in the high-pressure turbine (id. 36). Startup procedures presently recommended by turbine manufacturers for nuclear plants are more extensive and explicit than the procedures used during the 1950's (id. 35-36). Vepco's witnesses testified that the low-pressure turbine transition temperature for the North Anna turbines is somewhere in the zero degree Fahrenheit range, which means that in any startup mode the turbines are already

above the transition temperature. Also, there is some warming of the turbines during startup, and there are procedures (supplied by the turbine manufacturer and required by Vepco's operating procedures) that specify turbine loading times and schedules according to the metal temperature of the turbine (Tr. 470-71, 474).

The Staff testified that monitoring of secondary water chemistry, along with other measures, can decrease the probability of turbine disk failure due to stress corrosion (Staff Turbine Missile Testimony 38). Secondary water chemistry monitoring for North Anna will provide additional assurance that harmful impurities are not entering the turbine steam (id.).

Finally, the Staff testified that inservice inspections can provide additional assurance of turbine disk integrity throughout the turbine's service life (id.). Current industry practice for periodic maintenance inspection of turbines is based on surface examination techniques, such as dye penetrant, magnetic particle, or visual inspection (id. 39).

When the probabilities of missile generation P1 for destructive overspeed are reduced by 1/26 and the probabilities for operating speed by 1/272, the probabilities of missile damage come out as shown in the following table:

Staff Table H.1

Failure Mode	Missile Trajectory	P1	P2	P3	P1xP2xP3
Operating Speed	Low	2.21×10^{-7}	0.2	1	4.42×10^{-8}
Operating Speed	High	2.21×10^{-7}	0.02	1	4.42×10^{-9}
Destructive Overspeed	Low	1.53×10^{-6}	0.2	1	3.08×10^{-7} [1]
Destructive Overspeed	High	1.53×10^{-6}	0.0009	1	1.38×10^{-9}
			TOTAL		3.58×10^{-7}

(Staff Turbine Missile Testimony at 69, Table H.1.) The reduced overall estimate of the probability, 3.58×10^{-7}, is demonstrably conservative and below the Standard Review Plan criterion of 10^{-6} (*id*. 68).

2. Applicant's approach

The applicant took a different approach to estimating the probability of missile generation. It relied on a fault-tree analysis by the turbine manufacturer, Westinghouse Electric Corporation (Vepco P1 Testimony 6). Dr. Shaffer of Westinghouse, who performed the analysis, testified that

1/Multiplying 1.53×10^{-6} by 0.2 actually gives 3.06×10^{-7}.

fault-tree methodology is acceptable in engineering practice by the industry and recognized by the NRC Staff (id. 6-7). The Westinghouse fault-tree analysis makes use of a number of conservative assumptions (see Exhibit AV-3 at vii, Tr. 474, 522-24, 553).

Dr. Shaffer constructed fault trees, which are logic diagrams used to analyze circumstances that can lead to undesired events, for both destructive overspeed and design overspeed. The undesired event (destructive overspeed or design overspeed) is shown at the top of the tree, the first-level causes of the event are shown immediately below, the circumstances that lead to the first-level causes are shown at the next lower level, and so on (Vepco P1 Testimony 7).

The fault tree branches are terminated when all equipment component events that could eventually lead to the undesired event are accounted for and shown (id.). In the case of the Westinghouse fault trees, these equipment component events are the failures of the individual components in the overspeed protection system. These basic probabilities were determined from actual Westinghouse service experience or conservative estimates (Exhibit AV-3 at 23).

The results of the Westinghouse analysis were as follows: assuming one load separation per year, the

probability of generating a destructive overspeed turbine missile is calculated to be 1.7 x 10^{-6}/unit/year or 1.7 x 10^{-6}/unit/load separation. Assuming one load separation per year, the probability of generating a design overspeed turbine missile is calculated to be 1.05 x 10^{-10}/unit/year or 1.05 x 10^{-10}/unit/load separation. Assuming the governor valve control system would not be effective in preventing design overspeed, the probability of generating a design overspeed turbine missile becomes 5.5 x 10^{-9}/unit/year or 5.5 x 10^{-9}/unit/load separation (Vepco P1 Testimony 8; Exhibit AV-2, Table 10.2-1).

3. Comparison of Staff and applicant approaches

Dr. Shaffer testified that in his opinion the Westinghouse approach provides "a more representative value for probability of generating a turbine missile for the North Anna turbines" than the Bush approach using historical data (Vepco P1 Testimony 10). This is because Westinghouse limited its statistics to those obtained from Westinghouse's experience and from Westinghouse's designs, analyzing the electro-hydraulic control and protection system as it now appears on nuclear units (id.). The Westinghouse witnesses also testified, as noted above, that modern turbine-generators supplied to the nuclear industry employ techniques of fabrication and testing,

advanced metallurgy, and improved control and overspeed protection systems that were either unknown or not generally available prior to the mid-1950's, the time from which much of the Bush data were collected (*id.* 9).

Finally, Dr. Shaffer testified that he would expect the Staff estimates of the probability of generating turbine missiles to approach those of Westinghouse as the conservatisms in the Staff's estimates are quantified:

> It is also our judgment that when the conservatism in the estimate of probability of generating turbine missiles from a modern nuclear turbine as obtained solely from historical statistics on turbine failures (*i.e.*, 10^{-4}) can be fully quantified, the resultant probability will be comparable to a probability value calculated from a fault tree approach as described here.

(Vepco P1 Testimony 10.) This prediction appears to be coming true. The Staff estimate of the probability of generation of missiles at destructive overspeed, taking into account the turbine disk integrity and valve testing and inspection requirements, is 1.53×10^{-6} (Staff Turbine Missile Testimony 69). This is very close to the Westinghouse estimate of 1.7×10^{-6} (Exhibit AV-2, Table 10.2-1).

The Staff nevertheless had two criticisms of the Westinghouse analysis. First, the Staff said that the fault-tree analyses do not appear to take into account common mode failure mechanisms (*e.g.*, adverse environmental

components, degrading valve performance, and rotor integrity) (Staff Turbine Missile Testimony 67). Responding to this position, Dr. Shaffer testified as follows:

> The common mode failure which would be due to a failure in the overspeed protection systems was taken into account through the fault tree analysis. The common mode failures due to the sticking, direct sticking of the steam valves, was considered, but the statistics obtained showed that this has never occurred in the Westinghouse experience. So this was not included.

(Tr. 466; see also Tr. 468.)

The Staff's second reservation was that Westinghouses' service experience (e.g., repair records) was not avai'able for Staff review (Staff Turbine Missile Testimony 67). The Appeal Board was concerned about this, and so Westinghouse offered to provide the Westinghouse service experience to the Board and Staff for their review, provided that the information was protected from public disclosure by a protective order. There being no objections, the Appeal Board issued such an order in ALAB-555 (July 13, 1979), and Westinghouse provided the data to the Board and Staff.

B. Probability of Strike (P2)

The second probability component identified in the analysis of turbine missile risk is the strike probability P2 (Staff Turbine Missile Testimony 49). P2 is the probability that a selected target will be struck by a missile in the event

of a turbine failure (id.).

The applicant calculated P2 by a solid angle method. That is, the solid angle that encompasses the area of safety-related structures was compared to the total solid angle in which a turbine missile could be launched (Vepco's Testimony on P2 and P3 and Turbine Inspection, hereinafter "Vepco's P2 and P3 Testimony," 2). This method is acceptable to the NRC Staff (Staff Turbine Missile Testimony 9). The strike probabilities for each critical plant region, for both low- and high-trajectory missiles and for both design and destructive overspeed, are given in Table 10.2-2 of the applicant's Exhibit AV-2. They sum to the cumulative P2 probabilities given in the NRC Staff's tables B.1, E.1, and H.1 (above).[2] The total strike probability, as given by the Staff in its Safety Evaluation Report, is about 0.2 (id. 10).

The Staff testified that P2 is estimated conservatively, because in calculating P2 it is assumed that

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2/The first number in Table 10.2-2 of applicant's Exhibit AV-2 (1.1641E-01, the probability of a low-trajectory, design overspeed missile striking the control room) is a typographical error. It should be 1.1641×10^{-2} instead of 1.1641×10^{-1}, as can be seen by dividing the corresponding P4 from Table 10.2-3 (1.2223×10^{-12}) by the Westinghouse P1 number 1.05×10^{-10}, or by comparing the probability of strike for a low-trajectory destructive overspeed missile (1.1571×10^{-2}, from the third column, first line, of Table 10.2-2).

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the turbine disk breaks into four 90-degree segments or quadrants (Staff Turbine Missile Testimony 49), an assumption that tends to maximize the energy of the exiting missiles (see id.). The applicant agreed that P2 is estimated conservatively. The applicant's testimony pointed out that in calculating the probability ratio the cross-sectional areas of the entire safety-related structures were used, rather than the areas of only the actual safety-related equipment and components. The applicant estimated that this would lend a factor of conservatism of at least 10 to the calculations (Vepco's P2 and P3 Testimony 2-3).

Another conservatism in the calculation is that no credit was taken for objects that could stop or slow a missile before its impact on the safety-related structures (Vepco's P2 and P3 Testimony 3). Many of the obstructions between the turbines and the safety-related structures would stop a missile or greatly reduce its energy and in many cases convert the primary missile to a secondary concrete missile with lower energy. Vepco's witness estimated that shielding by intermediate walls, floors, and equipment may afford at least an additional factor of 10 of conservatism to the calculations of P2 (id. 5).

C. Probability of Damage (P3)

The third probability component P3, as defined by the Staff, is 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 C.F.R. Part 100 guidelines (Staff Turbine Missile Testimony 50). Both the Staff and Vepco assumed that P3 was unity in the turbine missile risk evaluation for North Anna (id. 50; Vepco's P2 and P3 Testimony 5). Vepco's witness testified that this is quite conservative, indeed as conservative as one can get (Tr. 532), because the striking of safety-related components does not necessarily result in serious consequences. All active safety-related systems are redundant, and in many cases other systems can be made to serve the safety functions even if the redundant systems fail (Vepco's P2 and P3 Testimony 5-6). For example, the emergency switch gear room, one of the "critical plant areas," has two redundant trains separated by a missile wall approximately two feet thick. The applicant's witnesses testified that there is no chance that a single missile could hit both trains (Tr. 508-09).

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The Staff agreed that the assumption P3 = 1 is conservative and noted a number of specific conservatisms (Staff Turbine Missile Testimony 50-54). The Staff testified, for example, that the assumption that intervening structural walls and equipment offer no resistance to missiles is "extremely conservative" (id. 50), especially since penetration estimates make use of conservative assumptions (id. 5, 51). The applicant agreed that conventional penetration calculations are conservative (Vepco's P2 and P3 Testimony 4). (As noted above, though, the applicant considered barriers as reducing P2 instead of P3.)

The Staff also testified that additional conservatism 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 to have entered the auxiliary feed water pumphouse it is assumed that the auxiliary feed water pumps are totally destroyed. Realistically, however, it is expected that sometime the missile or scabbing fragments may miss the pumps, or strike them peripherally without total loss of functional capability.

(Staff Turbine Missile Testimony 52.)

The Staff estimated the magnitude of one of the conservatisms (the assumption that the penetration of all barriers is a certainty) by using available penetration

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formulas with respect to existing barriers. The resulting more realistic estimate of P3 with respect to the reactor primary system boundary, the control room, and the auxiliary feedwater pumphouse, says the Staff, is P3 = 0.1 for 120% overspeed missiles and P3 = 0.5 for 180% overspeed missiles (id. 53). (As noted above, the applicant estimated a 1/10 reduction in probabilities by considering the effect of barriers.)

The Staff used these estimates of P3 to quantify some of the conservatisms in probability analysis, ignoring the effects of the turbine disk integrity and valve testing and inspection requirements (id. 53). As indicated in the following table, the overall probability for unacceptable damage, when estimated on this basis, becomes about 7.3×10^{-7} per turbine year:

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Staff Table E.1

Failure Mode	Missile Trajectory	P1	P2	P3	P1xP2xP3
Operating Speed	Low	2.22×10^{-6}	0.2	0.1	4.44×10^{-8}
Operating Speed	High	2.22×10^{-6}	0.02	0.1	4.44×10^{-9}
Destructive Overspeed	Low	6.80×10^{-6}	0.2	0.5	6.80×10^{-7}
Destructive Overspeed	High	6.80×10^{-6}	0.0009	0.5	3.06×10^{-9} 3
				TOTAL	7.32×10^{-7}

(Staff Turbine Missile Testimony at 55, Table E.1.)

D. Summary

The situation, then, is this: Beginning with a very conservative probability for unacceptable turbine missile damage of 2×10^{-5} per turbine year, based on Dr. Bush's historical data, the NRC Staff calculates that the valve testing and disk integrity programs required of the applicant provide an overall reduction factor of 56 (resulting from a factor of 26 for valve testing, which

3/The Staff's testimony says 3.60×10^{-9}, which appears to be a typographical error. The sum of 7.32×10^{-7} is correct in either case.

reduces the likelihood of destructive overspeed, and of 272 for preservice inspection and the use of materials with a high fracture toughness, which reduce the chance of failure at design overspeed), which brings the 2 x 10^{-5} down to well within the Staff's 10^{-6} criterion (Staff Turbine Missile Testimony 68). Additional conservatism is provided by the requirement of periodic valve dismantling and inspection (id. 20), improved startup procedures (id. 35-37), monitoring of water chemistry (id. 37-38), the assumption of fracture toughness for the disks of older turbines higher than experienced (id. 40), and others (id. 41).

The 2 x 10^{-5} number itself is conservative to begin with, the Staff believes, calculating that a more realistic estimate is 7.32 x 10^{-7} per turbine year. This estimate is based on the conservatism resulting from the presence of barriers (0.1 for design overspeed missiles and 0.5 for destructive overspeed missiles with respect to the reactor primary system boundary, the control room, and the auxiliary feedwater pumphouse) (id. 53) and the conservatisms in P1 resulting from improved fracture toughness and the current valve testing frequency of once a month (id.). Another conservatism is the assumption of

a four-piece disk break (id. 49).

The applicant's calculations, on the other hand, yield a cumulative probability of about 4.22×10^{-7} per turbine per year. (This can be seen by adding the probabilities in Table 10.2-3 of the applicant's Exhibit AV-2.) This number does not reflect the conservatism of a factor of at least 100 that the applicant feels is justified based on the presence of barriers and the conservative use of entire structures, rather than just the safety-related parts, as targets, nor does it reflect the redundancy of the safety-related systems.

The applicant's cumulative probability of about 4.22×10^{-7}, calculated without taking into account the conservatisms in P2 and P3, is quite close to the Staff's Figure of 3.58×10^{-7} (Staff Table H.1), which likewise does not take into account reductions in P2 and P3. (As noted above, there remain unquantified conservatisms in P1 as well.) Thus the Staff, starting with historical data and quantifying some of the conservatisms, and the applicant, starting with modern turbine systems, have come up with similar results.

In any case, these more realistic probabilities turn out to be less than the Standard Review Plan

criterion of 10^{-6}, with a number of conservatisms still not accounted for quantitatively. The applicant's (Vepco's P2 and P3 Testimony 6) and Staff's witnesses (Staff Turbine Missile Testimony 68) concluded that the North Anna structures, sys s, and components important to safety are appropriately protected from turbine missiles. Thus the record supports the conclusion that the probability of turbine missile damage at North Anna Units 1 and 2 is acceptably low.

Respecfully submitted,

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DATED: July 23, 1979

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CERTIFICATE OF SERVICE

I certify that I have served a copy of Vepco's Memorandum of Proposed Findings on each of the persons named below by first-class mail, postage prepaid:

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