UNITED STATES OF AMERICA
NUCLEAR REGULATORY COMMISSION

BEFORE THE ATOMIC SAFETY AND LICENSING APPEAL BOARD

In the Matter of

VIRGINIA ELECTRIC AND POWER CO.

(North Anna Nuclear Power Station Units 1 and 2)

Docket Nos. 50-338 OL
50-339 OL

NRC STAFF RESPONSE TO UCS SUPPLEMENTAL BRIEF

On December 14, 1978, the Union of Concerned Scientists (UCS) submitted Union of Concerned Scientists Reply Brief, Amicus Curiae (Supplemental Brief). Pursuant to the Appeal Board's Order dated December 7, 1978, UCS was permitted to file a supplemental brief on the single point of why the USC believes that the turbine missile question cannot be resolved for the North Anna facility independently of the outcome of the generic inquiry.

In its Supplemental Brief, the UCS asserts that the Staff assumes, without technical support, the outcome of the generic task action plan regarding turbine missiles, and that the plant-specific analysis for North Anna is fundamentally based on assumptions whose truth are the subject of the generic study. Supplemental Brief, pp. 2, 15-16. It further attempts to make the case that the Staff must rely on the outcome of the generic study for its North Anna analysis, and that the generic study somewhow must depend on WASH-1400's probabilities to justify continued operation of North Anna pending completion of the generic task. Id. p. 16.

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The Staff, in the accompanying affidavit of Kazimieras M. Campe, expands on the discussion previously provided to the Appeal Board regarding the site-specific review performed for North Anna regarding the risks from turbine missiles, as well as the status of Task A-37 and its relationship to the North Anna review. See, Response to Atomic Safety and Licensing Appeal Board's Request for Information on the North Anna Units 1 and 2 Regarding Missiles, dated September 15, 1978 (Staff Response), pp. 4-6.

The attached affidavit does not specifically rebut the UCS's renewed claim that the Staff relied on Task A-37 and WASH-1400 for the North Anna turbine missile analysis. This argument was previously made by the UCS in its original Brief Amicus Curiae, and was responded to by the Staff in NRC Staff's Response to UCS Brief Amicus Curiae dated November 16, 1978 (at pp. 24). Similarly, the affidavit does not specifically discuss certain arguments made by UCS which are outside of the scope of the narrow issue that the Appeal Board has permitted the UCS to comment on in its Supplemental Brief. These arguments are briefly discussed below.

On pages 2-3 of its Supplemental Brief, the UCS claims that the identification of turbine missiles as a Category A unresolved safety issue represents the Staff's acknowledgement that the probability of a turbine missile causing substantial damage to safety-related structures, systems or components is unacceptably high, based on the best present understanding of the behavior of turbine missiles. However, the placement of a generic task within this category does not in and of itself indicate the level of safety significance for that task. The definition of Category A, restated by the UCS in its Supplemental Brief, page 2, note 1, provides that Category A matters could include those technical activities, the resolution of which could "...(2) have a significant impact upon the licensing process." This aspect of Category A has been addressed previously by the Staff before the Atomic Safety and Licensing board in the Matter of T.V.A. (Yellow Creek, Units 1 and 2), Docket Nos. 50-566 and 50-567. On pages 12 & 13 of the Affidavit of Michael B. Aycock, et al., submitted on August 15, 1978 in that proceeding, the Staff concluded the following:

> "Other generic tasks are not relevant to the Licensing actions for any particular facility because they deal with improving the efficiency and/or effectiveness of the licensing process rather than plant safety. These types of tasks include (1) efforts to improve guidance to Applicants, Licensees or Staff reviewers, and (2) efforts to consider the relaxation of certain Staff requirements that may be overly conservative. Category A tasks that fall into the first group are:
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> . . . .
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> . . . .
>
> A37 Turbine Missiles ..."

Accordingly, Task A-37 was placed in Category A within the context of the above objectives, rather than as an acknowledgement of a significant safety issue.

The affidavit details the bases for the Staff's conclusion that the turbine missile risks at the North Anna Units 1 and 2 facility are acceptably low, and explains why the Task A-37 is not expected to produce results which will cause the Staff to impose additional requirements on the North Anna facility.

On page 8 of its Supplemental Brief, the UCS claims that the Staff neglects to mention several factors with respect to overspeed pro-tection improvements. The Staff submits that the UCS is not raising any substantive issues with these points. In reference to factor 1 on page 8, the UCS claims that overspeed protection improvements do not affect the probability of design overspeed failures. What UCS fails to recognize is that the Staff considers these two elements to be separate. As is indicated in the attached affidavit, the Staff, as part of its turbine missile review, considers design and destructive overspeed turbine failures as being two distinct, independent modes of failure, each invoking different measures for controlling the failure rate. The affidavit contains a description of the separate elements, as well as the combined missile risks from both types of failure, as well as from both high and low trajectory missiles resulting from these two types of failures.

Factor 2 restates the same point: that improvements in overspeed protection may not reduce the historically-observed rate of destructive overspeed failures, since such failures have been caused by failure of the steam supply valves to close. In response to this point, the Staff notes that it considers the turbine steam valves to be an integral part of the overspeed protection system. This fact is demonstrated by the Staff's turbine valve testing requirement imposed on the North Anna plant in recognition of the need for increasing the reliability of the valving as a component of the turbine overspeed protection system. This requirement was identified in the Staff's SER, Supplement 2, as well as in the Staff Response of September 15, 1978.

Factor 3 merely indicates what the Staff stated in its September 15, 1978 Response, that the quantification of various improvement factors associated with turbines is one of the objectives of Task A-37. As is indicated in the attached affidavit, however, the Staff does not consider the quantification of improvement factors to be a significant safety issue which is awaiting resolution by the generic task.

CONCLUSION

The Staff concludes that is has adequately reviewed the effect of turbine missile failure at North Anna Units 1 and 2, and that the effects are acceptably low in accordance with the requirements of General Design

Criteria 4 (10 CFR Part 50, App. A). Furthermore, the Staff has concluded that the outcome of Task A-37 will not result in increased requirements for the North Anna facility, and that the site-specific review performed by the Staff for the facility is independent of the ultimate results of the generic study. For the reasons discussed above and in the attached affidavit, the Staff urges the Appeal Board to find that the allegations raised by the UCS in its Supplemental Brief are without merit.

Respectfully submitted,

Daniel Swanson

Daniel Swanson
Counsel for NRC Staff

Dated at Bethesda, Maryland
this 5th day of January, 1979

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NUCLEAR REGULATORY COMMISSION

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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

AFFIDAVIT OF KAZIMIERAS M. CAMPE

STATE OF MARYLAND) SS
COUNTY OF MONTGOMERY)

I, Kazimieras M. Campe, being duly sworn, depose and state:

1. I am a nuclear engineer, Accident Analysis Branch, U.S. Nuclear Regulatory Commission, Washington, D.C. 20555.

2. A copy of my professional qualifications was submitted to the Appeal Board as an attachment to the Response to the Atomic Safety and Licensing Appeal Board's Request for Information on the North Anna Units 1 and 2 Regarding Missiles, dated September 15, 1978.

3 I authored the attached document and hereby certify that the information contained in this affidavit is true and correct to the best of my knowledge and belief.

K. M. Campe

Kazimieras M. Campe

Subscribed and sworn to before me
this 5th day of January, 1979

Nadine C. Sides

Notary Public

My Commission expires: July 1, 1982.

A. INTRODUCTION

The Staff's view is that response to the UCS Reply Brief warrants an articulation of the specific technical considerations which are essential to an understanding of the turbine missile risks. Accordingly I am providing the following:

a) A background discussion on turbine failure modes generation of turbine missiles and probabilistic analysis methods used by the Staff.

b) A detailed discussion of the turbine risk evaluation performed for North Anna which shows that the Staff has considered both high and low trajectory turbine missiles as well as operating and destructive overspeed missiles in its evaluation of the plant.

B. TECHNICAL BACKGROUND

1. Failure Modes

Power station main steam turbines consist of one high pressure and one to three low pressure stages. All known turbine failures that 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 constitute turbine missiles of concern.

Turbine failures can be grouped into two distinct modes. Failures at or below operating speed are caused by defects in the rotor, 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, the design speed will be exceeded. In the absence of defects, the rotor can speed up to 180% to 190% of normal speed at which point the most highly stressed wheel would fail in a ductile fashion.

2. Missiles

The spectrum of possible wheel breaks ranges from a multiple fragmentation (e.g. many relatively small pieces, typically less than 100 pounds each) to a wheel splitting into essentially two halves, each piece weighing several thousand pounds.

The missiles initially travel within the plane of rotation of the original turbine wheel. However, interactions with turbine internals can deflect them from their flight paths. For a failed inner wheel (i.e. a wheel with neighboring wheels on either side) one can expect missiles ejected anywhere within about 5 degrees of the wheel's plane. End wheel fragments typically can be deflected up to 25 degrees from the plane of the wheel. The deflection in this case is limited to one side of the wheel, since an end wheel has only one neighboring wheel.

Wheel fragments can retain some of the kinetic energy in rotational form, tumbling in flight around its center of gravity. Since wheel fragments are usually irregular in shape, the inflight rotation presents a number of different missile orientations. Thus, at the moment of impact the target may be struck by a "sharp" or "blunt" portion of a missile, or any other intermediate orientation.

If the angle of incidence of a missile relative to a barrier (i.e. the angle between the normal to the barrier surface and the missile trajectory) is sufficiently large (e.g. greater than 60 degrees), the missile may ricochet rather than penetrate the barrier.

Missile impacts on concrete barriers can produce secondary missiles on the back side of the barrier, even though the missile itself may have insufficient energy to penetrate the barrier. This process is known as scabbing.

Turbine missiles ejected directly towards plant structures are described as low trajectory missiles (LTM's). Since they are ejected approximately at right angles to the turbine shaft, protection against LTM's can be achieved by appropriate placement and orientation of the turbine relative to the plant structures, systems, and components. Missiles ejected in a nearly vertical direction (within about 2 or 3 degrees from the vertical) are known as high trajectory missiles (HTM's) and can strike plant structures upon the descent portion of their flights. In contrast to LTM's, turbine placement and orientation is not an effective means of protecting plant systems against HTM's, since their descent is not strongly dependent on turbine orientation. However, the probability of HTM's striking plant safety systems is significantly lower than that for LTM's.

3. Probabilistic Considerations

The probabilistic aspects of turbine missile risks typically are grouped by the Staff into three principal probability components. These are described briefly below:

a. Turbine Failure Probability (P_1) - This is the probability, usually expressed as an annual failure rate, that a turbine will fail and that missiles will be ejected. It can refer to either or both of the failure modes described earlier. The probability of failure at or below the operating speed can be affected by design errors, turbine rotor material properties, fabrication techniques, preservice and inservice inspection, and operating conditions. Destructive overspeed failures stem from loss of turbine load situations attended by a malfunction in the overspeed protection system. The malfunction is usually associated with respect to the turbine steam valves.

b. Missile Strike Probability (P_2) - This is the probability that, given a turbine failure, a selected target (e.g. a plant structure) will be struck. For LTM's, the strike probability is governed by turbine placement and orientation, missile ejection angles, target size, and presence of intervening barriers. For HTM's the strike probability is primarily related to target size, and missile speed, and to a much lesser extent to turbine placement and orientation.

c. Missile Penetration and Damage Probability (P_3) - Given a missile strike, this is the probability of damaging safety related plant equipment. If the equipment is inside a structure or is otherwise shadowed by some barrier, P_3 is the probability that a missile impact will both penetrate and damage the equipment behind the struck barrier. In absence of barriers, it is simply the probability of damage to the equipment. Inherent in this definition is the assumption that damage of safety related structures, systems, of components will always lead to radiological doses in excess of 10 CFR Part 100 guidelines. This is a conservative assumption as will be shown later.

C. STAFF REVIEW METHODOLOGY

The Staff reviews and evaluates turbine missile risks for nuclear power plants in accordance with General Design Criterion 4, of 10 CFR

Part 50, Appendix A, which indicates that structures, systems, and components important to safety "... shall be appropriately protected against dynamic effects, including the effects of missiles, ...". Interpretation of General Design Crite.ion 4 with respect to aspects of protection against the effects of turbine missiles has been provided in part by Regulatory Guide 1.115,[1/] which gives guidance to applicants on an acceptable means of protection against LTM's, and !_ the Standard Review Plan (SRP's) 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 uses the guidance within this section in evaluating turbine missile risks. Accordingly, 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 CFR Part 100 is less than about 10^{-6} per year. As noted in SRP 2.2.3, 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.

D. North Anna Turbine Missile Risk Evaluation

The following is a description of the analysis and conservatisms used in the evaluation of turbine missile risks for North Anna. As indicated in the technical background discussion, the turbine missile

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[1/] North Anna was not reviewed against Regulatory Guide 1.115 as the construction permit was issued for the facility prior to the implementation of the guide.

risk evaluation was done in terms of three probability components. The first of these, the turbine failure probability P_1, was assumed to be 10^{-4} per turbine year for all modes of failure. This failure rate is taken from a study[2/] which examined historically documented turbine failures corresponding to a cumulative experience of over 70,000 turbine years of operation. It is in sharp contrast to the theoretically predicted failure rates by the industry, which typically are two or more orders of magnitude lower. The Staff views 10^{-4} failures per turbine year as a conservative rate since it is based largely on experience with older turbines. More than half of the failures reported in the study were due to poor fabrication practice existing prior to about 1956. As a result of these failures, the turbine industry in the United States and Euorpe developed better metallurgical techniques and inspection procedures so that turbine failures due to material defects were expected to be much lower for turbines fabricated after 1956. Contrary to the USC claim (pp. 7-8, USC reply brief, December 13, 1978) that "...improvements in materials was a necessary development in order to construct the turbines now used in nuclear power plants " this was a turbine industry-wide development aimed at eliminating the causes associated with the turbine failures in the early 1950's. Hence the inclusion of the turbine failures prior to 1956 into the data base used to derive the annual failure rate expectation of 10^{-4} and the application of this failure rate to modern turbines is conservative. In the past (Regulatory Guide 1.115, Revision 0), the Staff had indicated that the improvements associated with modern turbines may be offset by the increased turbine

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2/ S. H. Bush, "Probability of Damage to Nuclear Components," <u>Nuclear Safety</u>, Vol. 14, No. 3, May-June, 1973.

power output and the increased number of wheels per unit. Both factors are related to the operating speed failure mode. Larger size wheels have been presumed to be made difficult to inspect for flaws which can lead to brittle fracture. A larger number of wheels per unit can imply a higher probability of having some one wheel fail. Precise quantification of these results currently is not available. However, this aspect has been examined by the generic study and although the study may provide means of quantifying the margin of conservatism, it has been concluded qualitatively that its effect on the turbine failure probability is not significant. Hence the Staff believes that the conservatism inherent in the use of the 10^{-4} failure rate will not be impacted by the final results of the generic study.

The second component of turbine missile risk is the strike probability P_2. The applicant 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.

In calculating P_2 the assumption is made that the wheel breaks into four 90° segments. The conservatism in this assumption stems from consideration of wheel fragment interactions with turbine internals prior to exiting the turbine.

The turbine internals which offer major resistance to the fragments and slow them down are the stationary blade rings and the turbine casing. The effectiveness of these internals in slowing down the missiles can be significant, especially if the contact area between the fragment and the internals is large. This is why the assumption of segments significantly larger than 90° is non conservative. For example, the failure of a low pressure wheel at the Shippingport Nuclear Plant did not lead to any missiles ejected from the casing. Two approximately 150° segments and a large number of smaller fragments were contained completely within the turbine.

Conversely, it can be shown that the assumption of a wheel breaking into many small fragments is also non conservative, since due to their small size the fragments do not have sufficient kinetic energy to penetrate the turbine internals and be ejected as missiles. Fragments in the vicinity of 90° have the greatest potential for escaping the turbine as high energy missiles. Thus, the assumption of a four piece wheel break maximizes the number of high energy missiles in a turbine missile analysis.[3/] Separate values of P_2 were calculated for design speed and destructive overspeed failure modes. The total strike probability, as indicated in Section 10.7 of the SER (Supplement No. 2) is about 0.2.

With respect to the probability P_3 of penetration and/or damage, it was assumed conservatively that intervening barriers had a negligible effect on the missiles, and that each strike resulted in unacceptable

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3/ The UCS claims in its reply brief on page 10 that "...The Assumption of four wheel fragments is identical to that used in developing the information which forms the basis for Regulatory Guide 1.115." On the basis of the above, the UCS concludes in the next sentence that the four wheel fragment assumption is nonconservative. The Staff does not agree that the used of an assumption, if used in the development of a Regulatory Guide, makes the assumption nonconservative. In fact, conservatism with respect to the four wheel fragments was shown by the Staff to be based on technical considerations rather than on whether it is involved in the development of a guide.

Failure Mode	Missile Trajectory	P_1	P_2	P_3	$P_1 \times P_2 \times P_3$
Operating Speed	Low	6×10^{-5}	0.2	1	1.2×10^{-5}
	High	6×10^{-5}	0.02	1	1.2×10^{-6}
Destructive Overspeed	Low	4×10^{-5}	0.2	1	8×10^{-6}
	High	4×10^{-5}	0.0009	1	3.6×10^{-8}
				TOTAL	2×10^{-5}

As indicated in the above table, the overall turbine missile risk based upon probabilistic considerations was estimated to be 2×10^{-5} per year. This was the value reported in the Staff's SER. Although the Staff reported only the total value of the turbine missile risk, it is important to note that the Staff evaluation included high trajectory missiles as well as low trajectory missiles, and included missiles from design speed failures as well as destructive overspeed failures. Upon examination and comparison of this value with the acceptance criteria given in SRP 2.2.3, it was determined that the risk from turbine missiles at North Anna exceeded the acceptance value of about 10^{-6} per year and the Staff therefore required and imposed additional measures to reduce the risks from turbine missiles.

In order to examine the analysis in greater depth, it is useful to go back to the table listed above. The first thing to note is that the overall turbine failure rate of 10^{-4} has been separated into individual rates for each of the two failure modes. The individual values are based on the turbine missile study cited earlier.[5/] With respect to strike probabilities, it should be noted that the low trajectory turbine missiles dominate the risk. 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.

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 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 in decreasing the probability of valve malfunction. For this reason weekly valve testing and related inspection and maintenance requirements were imposed on the North Anna plant with the view that the destructive overspeed contribution to turbine missile risk would be reduced substantially.

Similarly, the imposition of turbine inspection requirements is expected to reduce the other principal contributor to the overall tur-

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5/ See note 2, supra.

bine missile risk, namely low trajectory turbine missiles due to failure near operating speed. This will be achieved by detection of flaws or other defects that may exist or develop during operation within the turbine rotor. In reference to operating speed failures it should be noted also that the assumption of $P_3 = 1$ is extremely conservative. As indicated in the missile study,[6] for barriers 3 to 6 feet thick it is more reasonable to assume $P_3 = 0.5$. In the case of North Anna this would apply to the Containment Building whose sidewall is 4 1/2 feet thick.

The conservatism goes beyond the question of barrier penetration or equipment damage. As indicated earlier in the technical background discussion, the assumption is made that penetration or damage always leads to radiological doses in excess of 10 CFR Part 100 guidelines. This is clearly conservative since damage of safety related structures, systems, or components does not necessarily cause the release of significant radioactivity. For example, suppose it is assumed that a turbine missile damages some of the ECCS equipment such that it is rendered inoperable. This in itself would not cause the release of radioactivity unless a LOCA is also assumed to have occurred. Similarly, the penetration of the containment in itself does not cause a release unless the missile also succeeds in achieving additional damage (such as a rupture of the primary system pressure boundary).

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

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6/ See note 2, supra.

available were too large to justify unqualified conclusory findings. Thus, the SER recognized the possibility for additional protection measures pending the outcome of the generic study. Since that time, however, sufficient progress has been made within the generic study that some quantification of turbine failure probability reduction that can be derived from operational, and maintenance improvements can now be made. The generic study preliminary findings indicate that weekly valve testing can reduce the probability of a destructive overspeed turbine failure by a factor of ten or more below that associated with turbines whose valves are tested only once every few months. The Staff has been following this progress and has been taking into consideration new findings when conducting case reviews.

The above site-specific probabilistic analysis performed for North Anna, coupled with relatively recent but unpublished information obtained from the Staff's generic studies on turbine missiles, has led the Staff to the conclusion that the imposition and effective implementation of a turbine inspection program in conjunction with a turbine valve testing program will provide a significant degree of reduction in the probability of turbine missile damage to systems important to safety, and that this probability is now considered to be acceptably small within the guidance provided by SRP 2.2.3. Accordingly, 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.

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(North Anna Nuclear Power Station,	)	
Units 1 and 2)	)	

CERTIFICATE OF SERVICE

I hereby certify that copies of "NRC STAFF RESPONSE TO USC SUPPLEMENTAL BRIEF" and "AFFIDAVIT OF KAZIMIERAS M. CAMPE" in the above-captioned proceeding have been served on the following by deposit in the United States mail, first class, or, as indicated by an asterisk, through deposit in the Nuclear Regulatory Commission's internal mail system, this 5th day of January, 1979:

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Daniel F. Swanson

damage. In other words P_3 was assumed to be unity.[4/]

The following table is used to illustrate the individual probabilities and the conservatisms that entered into consideration in the overall turbine risk evaluation for North Anna.

4/ On page 11, in reference to the Staff's assumption of structural penetration probability by turbine missiles being , the UCS "agrees that there is some conservatism in this assumption" but disagrees that "the current state of knowledge permits a determination of the degree of conservatism." It is not clear to the Staff as to the source of disagreement referred to in the latter quote, since it is precisely the lack of quantification of the conservatism that has prompted Task Action Plan A-32, Missile Effects. Qualitatively, however, the Staff believes that plant structures such as the reinforced concrete containment side wall can offer significant resistance to turbine missiles (e.g. missiles due to failures near operating speed) and that the use of penetration formulas such as the modified NRDC equations is overly conservative.