UNITED STATES OF AMERICA
NUCLEAR REGULATORY COMMISSION

BEFORE THE ATOMIC SAFETY AND LICENSING APPEAL BOARD

In the Matter of	)	
	)	
METROPOLITAN EDISON COMPANY, ET AL.	)	Docket No. 50-320
	)	
(Three Mile Island Nuclear Station,	)	
Unit 2)	)	

JOINT AFFIDAVIT OF ROGER H. MOORE
AND LEE R. ABRAMSON

STATE OF MARYLAND) SS
COUNTY OF MONTGOMERY)

I, Roger H. Moore, being duly sworn, depose and state:

1. I am the Chief, Applied Statistics Branch, Office of Management and Program Analysis, U.S. Nuclear Regulatory Commission, Washington, D.C. 20555.

2. I have previously testified in this proceeding and my Statement of Professional Qualifications is incorporated in the transcript (following Tr. 373).

I, Lee R. Abramson, being duly sworn, depose and state:

3. I am a statistical adviser, Applied Statistics Branch, Office of Management and Program Analysis, U.S. Nuclear Regulatory Commission, Washington, D.C. 20555.

4. I have previously testified in this proceeding and my Statement of Professional Qualifications is incorporated in the transcript (following Tr. 374).

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We, the affiants Roger H. Moore and Lee R. Abramson, being duly sworn, depose and state:

5. We are jointly responsible for and participated in the preparation of the attached document entitled "Analysis of the Effects of Updated Data on the Previously Submitted Testimony and Supplemental Testimony of R. Moore and L. Abramson", and, if called upon, we would testify as set forth therein.

Roger H Moore

Roger H. Moore

Lee R. Abramson

Lee R. Abramson

Subscribed and sworn to before me this 1st day of February, 1980

Nadine C. Sidler

Notary Public

My Commission expires: July 1, 1982.

ANALYSIS OF THE EFFECTS OF UPDATED DATA ON THE PREVIOUSLY SUBMITTED TESTIMONY AND SUPPLEMENTAL TESTIMONY OF R. MOORE AND L. ABRAMSON

Since the hearing on December 11-12, 1978, an additional year's worth of data (1978) has become available. We were provided with this updated data and requested to examine the effects of this additional data on our testimony as submitted November 30, 1978 and revised December 8, 1978 (to be denoted by "T") and on our supplemental testimony submitted March 16, 1979 (to be denoted by "ST").

With the addition of the 1978 data, Table I in "T" is updated as follows:

	SCHEDULED			NONSCHEDULED		
	OPERATIONS $(\times10^6)$	HITS	RATE $(\times10^{-6})$	OPERATIONS $(\times10^6)$	HITS	RATE $(\times10^{-6})$
TAKEOFFS	90.9	11	0.12	2.47	2	0.81
LANDINGS	90.9	26	0.29	2.47	14	5.67

Table I (updated). Off-runway destruct accidents for all U.S. carrier aircraft, 1956-1978.

Since there were no off-runway destruct takeoff accidents in 1978, our estimate of the conditional crash density for takeoffs as given in "T" does not change. From Table 4 Addition, the 1978 data increases the total number of takeoff accidents from 40 to 42 and the number of hits in the interval $2.0 \leq r < 3.5$ surrounding TMI from 8 to 10. The updated values for $g_L(r_o)$ and $h_L(\theta_o)$ are

$$g_L(r_0) = \frac{10}{42} \cdot \frac{1}{1.5} = .159 \text{ per mile}$$

$$h_L(\theta_0) = \frac{3}{42} \cdot \frac{180}{15\pi} \cdot \frac{1}{2} = .136 \text{ per radian .}$$

As on page 8 of "T", the updated estimate of the conditional crash density for landings is

$$D_L(r_0, \theta_0) = \frac{(.159)(.136)}{2.7} = .00801 \text{ per square mile .}$$

The estimate areal crash densities based on the 23-year period 1956-1978 is given by Table III (updated).

	SCHEDULED	NONSCHEDULED
TAKEOFFS	4.6×10^{-9}	30×10^{-9}
LANDINGS	2.3×10^{-9}	45×10^{-9}

Table III (updated). Estimated areal crash densities at TMI-2 for a U.S. carrier aircraft engaged in a relevant operation (probability per square mile).

The inclusion of the 1978 data results in a decrease of 6 percent[1/] in the estimated areal crash densities for takeoffs and an increase of 15 percent[2/] in the areal crash densities for landings. The magnitudes of these changes are not at all surprising, since they are well within the uncertainty bands on the estimates given in "T".

1/ Scheduled takeoffs decrease from 4.9×10^{-9} to 4.6×10^{-9} and nonscheduled takeoffs from 32×10^{-9} to 30×10^{-9}.

2/ Scheduled landings increase from 2.0×10^{-9} to 2.3×10^{-9} and nonscheduled landings from 39×10^{-9} to 45×10^{-9}.

Since the uncertainty results in "T" were replaced by the revised uncertainty analysis of "ST," we see no point to updating the confidence limits given in "T".

The inclusion of the 1978 data has very little effect on our supplemental testimony of March 16, 1979. Since there were no off-runway destruct takeoff accidents in 1978, the estimated crash densities for takeoffs from Figures 1 and 2 remain unchanged. The updated estimated crash densities for landings look very much like their counterparts in "ST" and are given in Figures 1 and 2 (updated). No change in the discussion is necessary.

In the uncertainty analysis, the bounds on the exact confidence limits change by a maximum of 16 percent[3/] and are presented in Table IV (revised and updated). In this table, the two columns headed "Upper Bound (Table IV)" have been updated with the 1978 data.

BOUNDS ON EXACT CONFIDENCE LIMITS($\times 10^{-9}$)

		70%	80%	85%	90%	
SCHEDULED	ESTIMATED RATE	Upper Bound (Table IV)	Upper Bound (revised)	Upper Bound (Table IV)	Lower Bound	Upper Bound (revised)
TAKEOFFS	4.6×10^{-9}	34.2	22.1	50.3	14.6	30.6
LANDINGS	2.3×10^{-9}	10.2	7.7	14.0	5.9	9.7
NONSCHEDULED						
TAKEOFFS	30×10^{-9}	401	261	640	98	390
LANDINGS	45×10^{-9}	224	168	312	117	215

Table IV (revised and updated). Estimated values and bounds on exact confidence limits for areal crash densities at TMI-2 for a U.S. carrier aircraft engaged in a relevant operation (probability per square mile)

[3/] The bounds for takeoffs decrease by about 5 percent and the bounds for landings increase from 8 to 16 percent.

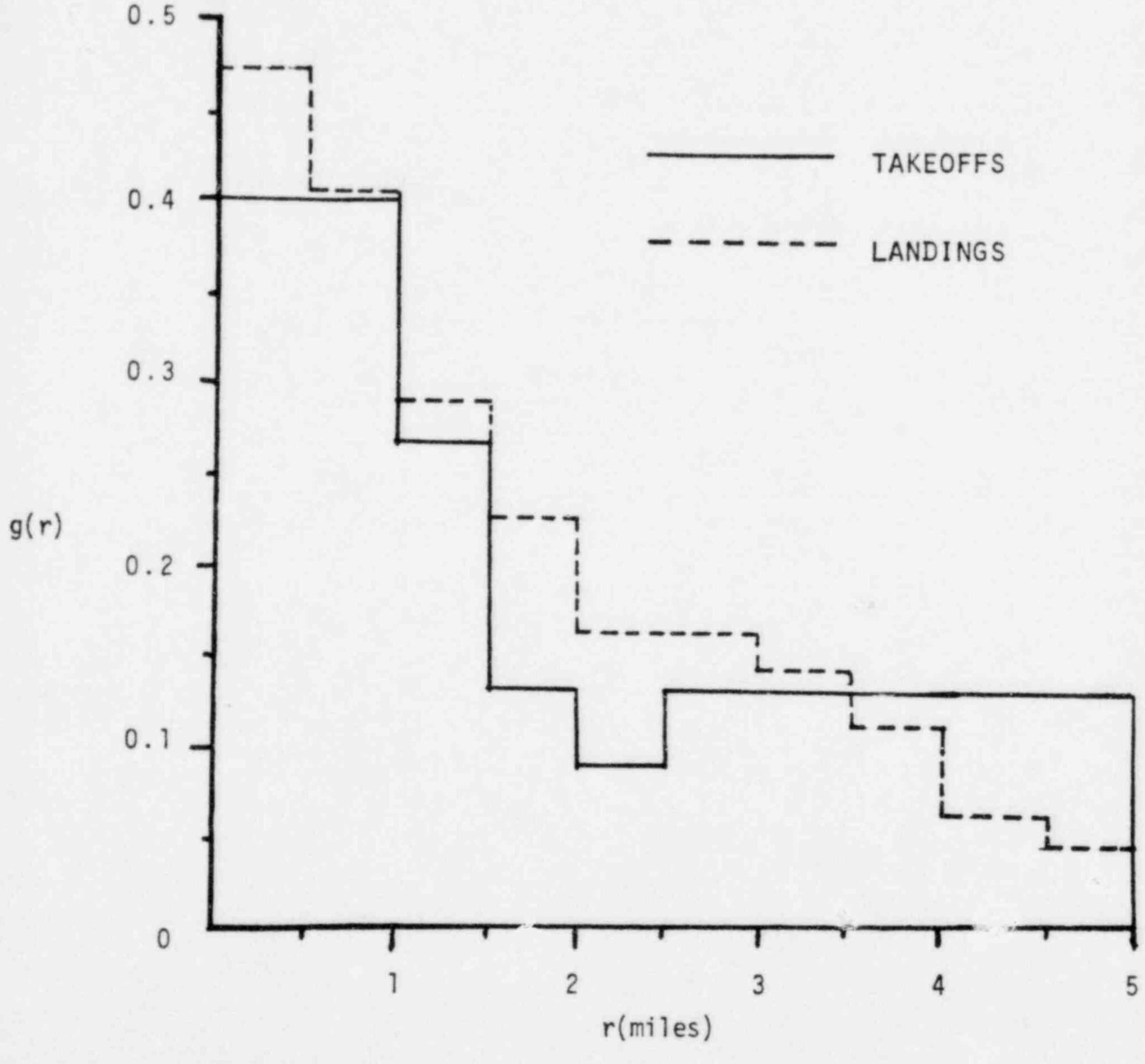

FIGURE 1 (UPDATED). ESTIMATED CRASH DENSITY FOR r (PER MILE)

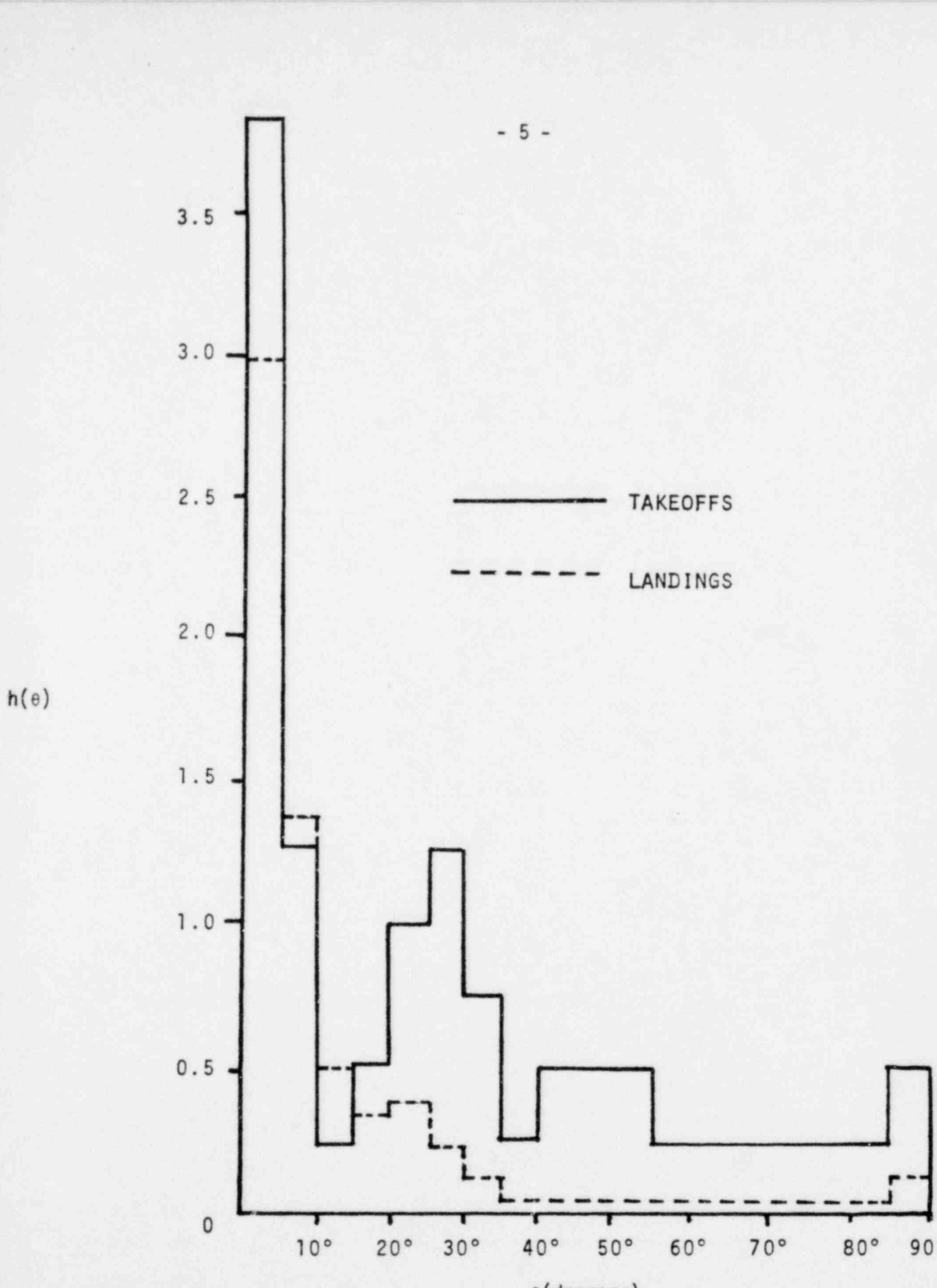

FIGURE 2 (UPDATED). ESTIMATED CRASH DENSITY FOR θ (PER RADIAN)

ATTACHMENT 2

SUPPLEMENTAL TESTIMONY OF R. MOORE AND

L. ABRAMSON IN RESPONSE TO ALAB-525

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UNITED STATES OF AMERICA
NUCLEAR REGULATORY COMMISSION

BEFORE THE ATOMIC SAFETY AND LICENSING APPEAL BOARD

In the Matter of	)	
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METROPOLITAN EDISON COMPANY, ET AL.	)	Docket No. 50-320
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(Three Mile Island Nuclear Station, Unit 2)	)	

SUPPLEMENTAL TESTIMONY OF

R. MOORE AND L. ABRAMSON

IN RESPONSE TO ALAB-525

APPLIED STATISTICS BRANCH
OFFICE OF MANAGEMENT AND PROGRAM ANALYSIS
U.S. NUCLEAR REGULATORY COMMISSION

March 16, 1979

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In ALAB-525 (February 1, 1979), the Board made several comments on the methodology of estimating the areal crash density at TMI-2 as presented in our testimony submitted at the December 12 hearing session in this proceeding (prefiled testimony following Tr. 378). The purpose of this addition is to respond to the Board comments.

Before responding to the specific comments, however, we feel that a short discussion of the rationale for our methodology would be helpful. Our choice of approach was motivated by the requirement to analyze the uncertainty associated with the point estimates. There are two sources of uncertainty - model uncertainty and statistical uncertainty. Model uncertainty stems from the particular choice of assumptions made about the underlying relations among the problem parameters and variables and the possibility that the assumptions might be in error. Statistical uncertainty stems from the random nature of the observations and the possibility that the observations might not be representative of the assumed model.

One way to handle model uncertainty is to choose the model assumptions such that any plausible departure from them would be in a conservative direction. This is the approach we adopted. Before adopting our particular model assumptions, we reviewed the applicant's approach involving the choice of a specific functional form for the conditional crash densities. This can be a useful approach, provided that the assumed functional form is correct, since it makes use of all the data to estimate the unknown parameters. However, if the assumed functional form is incorrect, then using it can lead to significant estimation errors. Instead of trying to use data distant from TMI-2 to estimate the probability of a hit at TMI-2, we based our estimates only on data in the vicinity of TMI-2. (By the assumption of model independence between r and θ, justified on pages 3-4 of our testimony, we treat r and θ separately.) Our estimates are then based on the mild assumption that the conditional crash densities for r and θ are approximately constant in the vicinity of TMI-2. If the conditional crash densities are not approximately constant, then it is plausible to assume that they would be concave decreasing (see Tables 9A and 9B, revised 12/8/78), so that a chord joining any two points on the curve would lie wholly above the curve. (The exponential form assumed by the applicant has this property.) In such a case, an estimate made with our methodology would be conservatively biased, i.e., it would tend to overestimate the density.

In addition to minimizing the model uncertainty, our methodology was also designed to estimate the statistical uncertainty in a straightforward manner. This we did by the method of confidence intervals, which require no extra assumptions in addition to those already made for the point estimate. In contrast, the applicant assumed a prior distribution and a likelihood function in order to apply a Bayesian analysis to estimate the uncertainty. Thus, our methodology requires fewer and weaker (i.e., assuming less) assumptions than does the applicant's methodology, both for the point estimates and the uncertainty analysis.

On page 12 of ALAB-525, the Board referred to the "very irregular angular probability distribution" produced by the staff's methodology and claimed that it fails to decrease regularly as the angle θ (measured from the runway center-line) increases. In addition, the Board noted that the staff model "appears to yield a zero probability for a crash within large segments of angle within the 0-5 mile range."

Our testimony was focused on the preselected location of TMI-2. For this use we felt that our methodology represented a conservative yet reasonable treatment of available data. Although our methodology was not specifically designed to apply to an arbitrary point in the (r, θ) plane it is certainly possible to do so,with modifications for "edge effects" and zero-valued estimates, as follows. To be consistent with the data available, we confine our attention to that portion of the (r, θ) plane defined by $0 \leq r \leq 5$ and $0 \leq \theta \leq 90°$. We omit consideration of angles greater than 90° because the data indicates that the density appears to be increasing in this region, and our methodology is designed for a decreasing density. Because of the apparent special situation for angles greater than 90°, it is our judgment that this case deserves special study before an appropriate estimator can be devised.

The approach described in our testimony was to base our estimates of the crash densities for r and θ at a point (r_0, θ_0) on the observed number of hits in an interval of width 1.5 miles roughly centered at r_0 and an interval of width 15° roughly centered at θ_0. This approach can be applied throughout the region of interest except where r_0 or θ_0 is near the edge of the region. Accordingly, the edge effect modification to our methodology is to base our estimates on the number of hits in the half-mile wide intervals [0, 0.5] for $0 < r_0 < 0.5$ and [4.5, 5.0] for $4.5 \leq r_0 \leq 5.0$, respectively, and on the 5° wide interval [0, 5°] for $0 < \theta_0 < 5°$. (Note that the 15° wide interval [80°, 95°] is used if $85° \leq \theta_0 \leq 90°$. Even though we do not estimate the density for $\theta_0 > 90°$, using the observed hits for $\theta_0 > 90°$ still leads to a conservative estimate of density for $85° \leq \theta_0 \leq 90°$.)

The second modification to our methodology is designed to obtain a non-zero estimate for the crash density at all points. There are several ways to do this. The one we use is to assume one additional hit at r_o or θ_o for those points for which the modified methodology described above would yield an estimate of zero for the crash density of either r or θ. The addition of this pseudo-hit raises both the numerator and denominator by one and yields a conservative non-zero estimate of the crash density.

The results of applying this modified methodology to the data in Tables 9A and 9B are shown in Figs. 1 and 2. Of the four estimated crash densities, three are essentially monotonically decreasing and the fourth (the crash density of θ for takeoffs) is somewhat irregular.[1/] For TMI-2, r_o = 2.7 miles and θ_o = 34°. From Figs. 1 and 2, $g_T(r_o)$ = .133, $g_L(r_o)$ = .133, $h_T(\theta_o)$ = .764, $h_L(\theta_o)$ = .143. Since the modifications discussed above were not needed at the TMI-2 location, these estimates are identical to those on page 7 of our testimony.

It is worth noting that the areas under the four estimated densities in Figs. 1 and 2 are all slightly greater than one. This is a reflection of the conservatisms introduced by the modifications for edge effects and zero-valued estimates. This phenomenon is not a matter for concern, since the purpose of our modified methodology is to obtain <u>point</u> estimates rather than estimates of the densities as a whole. If the latter were required, then an adjustment could be made so that the areas would be equal to one.

1/ Due mainly to the absence of observed takeoff hits between 5° and 20°. This does not imply that the "true" density is zero between 5° and 20°. Because of the small total number of hits (15), a considerable degree of irregularity is to be expected in the estimated density.

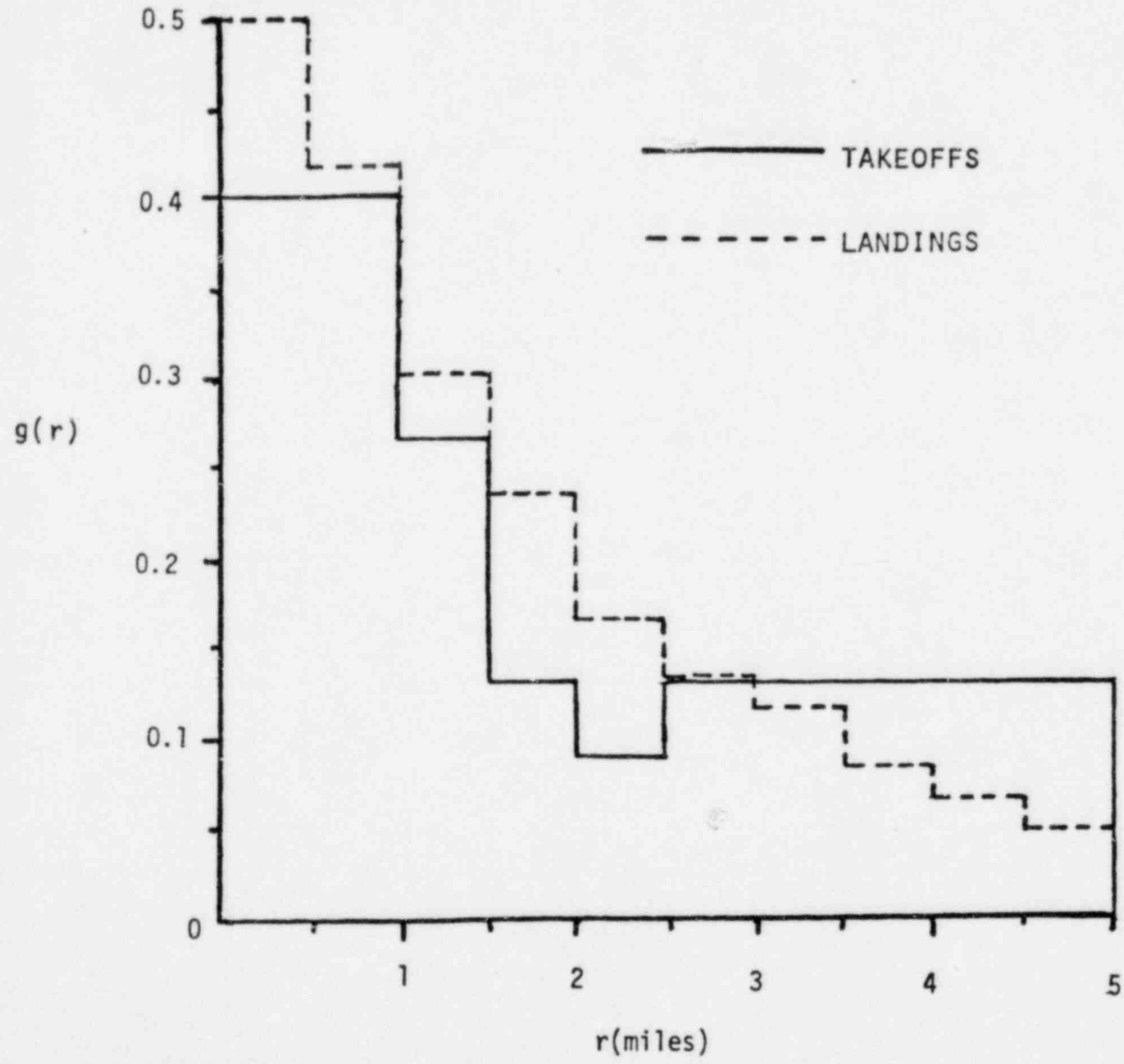

FIGURE 1. ESTIMATED CRASH DENSITY FOR r (PER MILE)

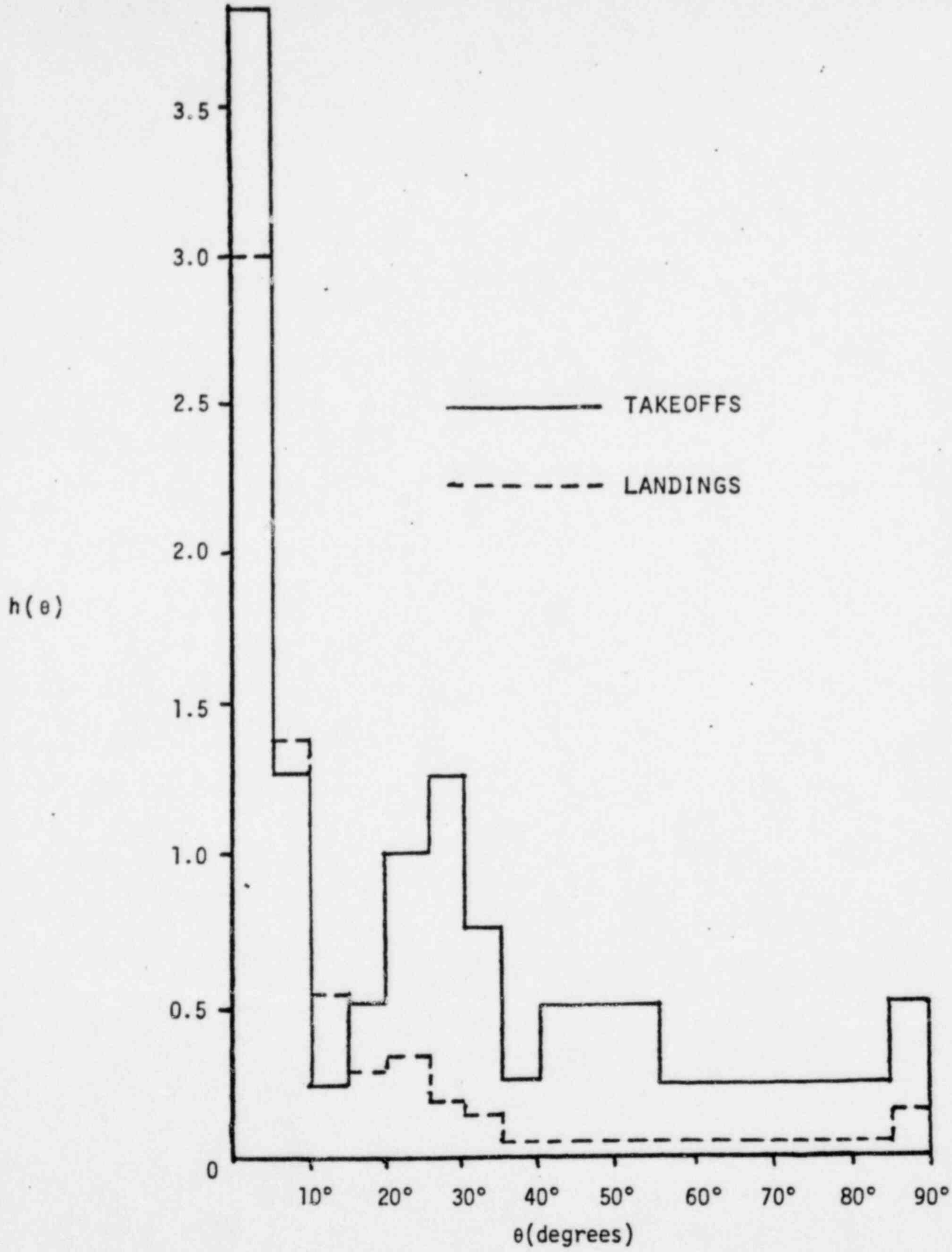

FIGURE 2. ESTIMATED CRASH DENSITY FOR θ (PER RADIAN)

ALAB-525 also discussed[2/] our calculation of confidence limits for the areal crash densities and adduced reasons why our confidence limits might be overly conservative. While the observations made by ALAB-525 are well-taken, the approach we used appeared to us as the only feasible one at the time we developed our testimony. While, in principle, exact confidence limits can be determined from the model assumptions and the observed data, this would involve very extensive computations for the case at hand. As an alternative, we used the Bonferroni method of calculating bounds for the exact confidence limits. Since this method is a very general one, it yields bounds which might be overly conservative for any particular case.[3/] Furthermore, the Bonferroni method yields only upper bounds on the exact confidence limits, so that no estimate of the degree of conservatism is possible. Despite these drawbacks, we were unaware of any other feasible approach, and so we used the conservative Bonferroni bounds as presented in Table IV of our testimony.

Upon reviewing our testimony, both written and oral, we have subsequently discovered that it is possible to calculate less conservative upper bounds on the exact confidence limits. Furthermore, it is possible to also calculate a lower bound for the exact 90% confidence limits. Since the upper and lower bounds for the 90% confidence limits generally differ by a factor of two, it

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[2/] The description of confidence level given by footnote 9 on page 12 of ALAB-525 is misleading. An upper confidence limit L is the endpoint of a random interval (0, L). The confidence level is the probability that the interval (0, L) will cover the unknown parameter. Since the parameter is fixed, no probability is associated with it.

[3/] Our bounds were obtained by multiplying three confidence limits, each with confidence (1 - g), and calling the product a bound on a confidence limit with confidence level (1 - 3g). As was pointed out by ALAB-525, there is an intrinsic conservatism in this calculation, regardless of the degree of independence or dependence among the three factors.

is our judgment that our revised procedure for calculating bounds on the exact confidence limits yields values which are not overly conservative and therefore no further refinements are felt to be worthwhile.

The revised bounds on the exact confidence limits are presented in Table IV (revised) for 80% and 90% confidence levels, together with the corresponding values from Table IV of our testimony. Because the Bonferroni method is applied to only two factors in our revised approach while it was applied to three factors in our original testimony, the 80% and 90% confidence level bounds in Table IV (revised) correspond to the 70% and 85% confidence level bounds in Table IV, respectively. (There are no revised bounds in Table IV (revised) corresponding to the 97% bounds in Table IV because there were no corresponding tables in the source paper we used for our revised approach.)

As compared with the bounds in Table IV, the revised bounds in Table IV (revised) show a double improvement. First, the confidence levels are increased and second, the upper bounds on the exact confidence limits are decreased. Furthermore, except for the relatively unimportant case of nonscheduled takeoffs[4/], the upper and lower bounds for the 90% level differ by about a factor of two.

[4/] From page 15 of the testimony of Darrell G. Eisenhut, nonscheduled takeoffs contribute less than 10% to P_{total}, the probability of a "heavy" aircraft impacting TMI-2.

BOUNDS ON EXACT CONFIDENCE LIMITS(x 10^{-9})

SCHEDULED	ESTIMATED RATE	70% Upper Bound (Table IV)	80% Upper Bound (revised)	85% Upper Bound (Table IV)	90% Lower Bound	90% Upper Bound (revised)
TAKEOFFS	4.9×10^{-9}	36	23	53	15.4	32.3
LANDINGS	2.0×10^{-9}	10	7	13	5.3	9.0
NONSCHEDULED						
TAKEOFFS	32×10^{-9}	420	273	670	103	409
LANDINGS	39×10^{-9}	210	148	290	101	196

Table IV (revised). Estimated values and bounds on exact confidence limits for areal crash densities at TMI-2 for a U. S. carrier aircraft engaged in a relevant operation (probability per square mile)

The source of this revision was the discovery that the estimates of the crash densities $g(r)$ and $h(\theta)$ (see page 7 of our testimony) are statistically independent for both takeoffs and landings. This fact allows us to calculate approximate[5/] 90% and 95% confidence limits for the conditional crash densities $D_T(r_o, \theta_o)$ and $D_L(r_o, \theta_o)$. (See "Confidence Intervals for the Product of Two Binomial Parameters", by Robert J. Buehler, Journal of the American Statistical Association, December 1957, 482-493.) The approximate confidence limits are then multiplied by the

[5/] Based on the Poisson approximation to the binomial. As discussed on page 5 of the appendix to our testimony, this approximation yields conservative confidence limits.

approximate confidence limits for the off-runway crash rates to get conservative confidence limits for the areal crash densities using the Bonferroni method discussed on page 5 of the appendix. The lower bound for the 90% confidence limit is obtained by multiplying the approximate 90% confidence limits for the conditional crash densities by the estimated off-runway crash probabilities from Table I on page 2 of our testimony. If the values from Table I were equal to the true crash rates, this procedure would yield approximate 90% confidence limits for the areal crash densities, but since the values in Table I are only estimates of the true crash rates, this procedure yields lower bounds.

It should be noted that it is not all obvious that the estimated crash densities for r and θ are statistically independent. From Table 9A for takeoffs, the three hits in $2 \leq \theta < 3.5$ and the three hits in $25° \leq \theta < 40°$ have one hit in common and we believed that this common hit would induce a positive correlation between the estimates of the crash densities as calculated on page 7 of our testimony. The relevant data is summarized in the following table of takeoff hits.

Radial Distance	Angular Distribution			
(miles)	[0°, 25°)	[25°, 40°)	[40°, 100°]	
[0, 2.0)	5	1	3	9
[2.0, 3.5)	0	1	2	3
[3.5, 5.0]	2	1	0	3
	7	3	5	15

Our model assumes that each of the 15 takeoff hits impacts in one of the nine boxes of the table according to the following joint distribution, where p_i and q_j are probabilities such that $p_1 + p_2 + p_3 = q_1 + q_2 + q_3 = 1$.

Radial Distance (miles)	Angular Distribution [0°, 25)	[25°, 40°)	[40°, 100°]	
[0, 2.0)	p_1q_1	p_1q_2	p_1q_3	p_1
[2.0, 3.5)	p_2q_1	p_2q_2	p_2q_3	p_2
[3.5, 5.0]	p_3q_1	p_3q_2	p_3q_3	p_3
	q_1	q_2	q_3	1

The assumption that the probability of a hit in any box is the product of the marginal probabilities is equivalent to the assumption on page 4 of our testimony that "r and θ for off-runway hits are distributed independently".

For the case at hand, the problem is to estimate p_2q_2, the probability that an off-runway crash will impact in the box including TMI-2[6/]. There are two ways to do the estimation. The first is to use the the ratio of the observed number of hits in the box including TMI-2 to the total number of off-runway hits. For this case, the estimate would be 1/15 = .067. The

[6/] The conditional crash density $D(r_0, \theta_0)$ estimated in our testimony differs from p_2q_2 by a normalization factor which yields the probability of impact per square mile. This normalization factor is an exact quantity and it is omitted in this discussion for convenience and to allow us to focus most directly on the statistical issues. Its omission does not affect any of these statistical issues.

second method is to estimate p_2 and q_2 separately and then multiply. For this case, the estimate would be $\frac{3}{15} \cdot \frac{3}{15} = .04$. We use the second method because it has smaller variance than the first.

To consider the issue of independence, denote the estimates of p_2 and q_2 by $\hat{p}_2$ and $\hat{q}_2$, respectively. Even though we have model independence as expressed in the joint distribution table above, this does not necessarily imply that $\hat{p}_2$ and $\hat{q}_2$ are statistically independent. For this case

$$\hat{p}_2 = \frac{0 + 1 + 2}{15}$$

$$\hat{q}_2 = \frac{1 + 1 + 1}{15} ,$$

where we have decomposed $\hat{p}_2$ and $\hat{q}_2$ according to the observed data. In general,

$$\hat{p}_2 = \frac{n_{21} + n_{22} + n_{23}}{N}$$

$$\hat{q}_2 = \frac{n_{12} + n_{22} + n_{32}}{N} ,$$

where n_{ij} is the observed number of hits in row i and column j of the 3 x 3 data table and N is the total number of hits. It is the presence of n_{22} in both $\hat{p}_2$ and $\hat{q}_2$ that led us to believe that $\hat{p}_2$ and $\hat{q}_2$ are not statistically independent and, in fact, are positively correlated. However, because the total number of hits is fixed, n_{22} is negatively correlated with all of the other n_{ij} and, in particular, n_{22} is negatively correlated with

$(n_{21} + n_{23})$ and with $(n_{12} + n_{32})$. It turns out that this negative correlation exactly balances the positive correlation induced by the presence of n_{22} so that $\hat{p}_2$ and $\hat{q}_2$ are, in fact, statistically independent.

Since the estimated conditional crash density $D(r_0, \theta_0)$ is the product of two statistically independent quantities $\frac{g(r)}{r}$ and $h(\theta)$, we can use Buehler's tables to calculate approximate confidence limits for the conditional crash densities for takeoffs and landings. However, the estimated conditional crash densities are not independent of the estimated accident rate, since both depend on the same set of accidents and there is no mechanism to cancel out this dependence. (Numerical calculation indicates that the confidence limits for the accident rate and the conditional crash density are negatively correlated.) It is for this reason that we use the Bonferroni method to calculate bounds on the exact confidence limits for the areal crash densities.