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SUBJECT: Provides affidavit per 10CFR2.790(b)(1) for consideration by Commission in determining whether encl proprietary Rept FPI 93-427,should be withheld from public disclosure.Rept previously submitted in ref ltr dtd 930730.

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WILLIAM F. CONWAY
EXECUTIVE VICE PRESIDENT
NUCLEAR

102-02679-WFC/RAB/JRP
October 1, 1993

U. S. Nuclear Regulatory Commission
ATTN: Document Control Desk
Mail Station P1-37
Washington, D. C. 20555

Reference: Letter 102-02593, dated July 30, 1993, from W. F. Conway, Executive Vice President, Nuclear, APS, to USNRC

Dear Sirs:

Subject: Palo Verde Nuclear Generating Station (PVNGS)
Units 2
Docket Nos. STN 50-259
Estimation of Crack Growth Rate
File: 93-056-026

The purpose of this letter is to provide an affidavit pursuant to Section 2.790(b)(1) of the regulations of the NRC, for consideration by the Commission in determining whether information sought to be withheld from public disclosure, included in the enclosed Proprietary Report, FPI 93-427, should be withheld. The report was previously submitted to the NRC in the above referenced letter.

Should you have any questions, please contact Richard A. Bernier at (602) 393-5882.

Sincerely,

WFConway

WFC/RAB/JRP/bcf

Enclosures: 1. Affidavit
2. Proprietary Report, FPI 93-427

cc: B. H. Faulkenberry
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ESTIMATION OF CRACK GROWTH RATE, CRACK INITIATION TIME, AND ALLOWABLE OPERATION TIME PALO VERDE NUCLEAR GENERATING STATION UNIT 2

July 14, 1993
FPI International
Proprietary Report FPI 93-427

Prepared by: FPI International Root Cause Analysis Team

Approved By: Chong Chiu, PH.D President

For
ARIZONA PUBLIC SERVICE COMPANY, Phoenix, Arizona

2310130186 3/18

1. PURPOSE

Arizona Public Service Company requested FPI International to investigate the growth rate of the cracks found on the steam generator tubes, to estimate the time when the cracks were initiated, and to determine the allowable operation time before the next tube inspection outage. The study uses the bobbin probe measurements conducted in the End of Cycle (EOC) 3 and EOC 4 refueling outages of the Palo Verde Unit 2. The FPI-CSTAT prediction code, which is a statistical code developed by FPI International for the analysis of the crack propagation and initiation time, is used for the analysis.

2. SUMMARY OF RESULTS

Based on the FPI-CSTAT results, the cracks grow at an average rate of 7.2% (3 mils) through-wall per month. The crack initiation occurred at approximately 18.8 months ± 9.7 months prior to the EOC 4 refueling outage with a 95% probability and a 95% confidence level.

The allowable operation time before the next inspection outage for Steam Generator 22 is 13.8 months for the best estimate conditions, which assume that the Palo Verde specific probability of detectability (POD) for the bobbin probes is applicable, and that after 13.8 months of operation, there is a 95% probability at a 95% confidence level that no crack has gone beyond 65% through wall. For the most conservative estimate assuming that the POD curve for the bobbins is the Palo Verde specific, and that the crack distribution has a 99% of population below 62% through-wall depth at a 99% confidence level, the allowable operation time before the next inspection is about 11.8 months.

As a sensitivity analysis to the above base case conditions,

it is assumed that the bobbin probes have a 5% mis-reading error. The calculated allowable operation time for the best estimate conditions for the Palo Verde Unit 2 is 13.2 months. For the most conservative case, the calculated allowable operation time is 10.8 months. To be absolutely conservative, FPI International recommends a 6 months allowable operation time before the next inspection outage.

3. BASIC ASSUMPTIONS

The assumptions made in this study are as follows:

(1) The true crack growth rate and the measured crack growth rate are identical.

(2) The crack distribution is always a normal distribution. A Chi-square goodness-of-fit test for normal distribution was conducted for the EOC 4 measured data as shown in Table 2.

(3) The mean of the crack distribution at the time of crack initiation can be hypothesized to have a negative value with a 0.01% population above zero crack depth, which is almost a problem free situation.

(4) For the base case, even though there was no measured crack at the BOC 4, there was a 1% chance that the bobbin signature is mis-read. That is, in terms of a normal distribution curve, there is a 1% probability that the measured crack distribution is above zero crack depth.

(5) For the worst case sensitivity analysis, there is a 5% probability that the bobbin signature is mis-read. That is, there is a 5% chance that there is a crack even though the bobbin probe signatures indicate no crack at

the BOC 4.

(6) For the best estimate conditions for the Palo Verde, the calculation was performed on a 95%/95% probability/confidence level. The final true crack depth before the inspection outage is 65% through-wall. The POD curve is Palo Verde specific as shown in Figure 5.

(7) For the most conservative conditions, in addition to Item (5), the calculation was performed on a 99%/99% probability/confidence level. The final crack depth is 62% through-wall. Since a pessimistic POD curve will result in a larger mean value of the measured crack distribution and a longer operation time given a true mean crack depth, the POD curve for the worst case scenarion is also the Palo Verde specific POD curve.

4. <u>MODELING METHOD</u>

The modeling method consists of the following three steps.

(1) <u>Determination of the Bias Distribution</u>

Based on the POD curve, we derive a transfer function, called bias distribution, which relates the measured crack distribution to the true crack distribution as shown in Figure 1. Since th POD curve is highly dependent on the through-wall crack depth, the bias distribution is generated whenever a conversion from the true crack distribution to the measured crack distribution is required.

(2) <u>Determination of the Crack Growth Rate and The Crack Propagation Time</u>

(a) Figure 2 shows the forming and growing of cracks in a

statistical view. Based on the fact that none of the 58 cracked tube was found cracked by bobbins during the EOC 3 refueling outage, the measured crack distribution in the BOC 4 is essentially below zero crack depth. Assume a 1% (or 5% for a sensitivity analysis) chance that cracked tubes were missed, thus, the measured distribution has 1% of tubes above the zero crack depth as shown in Figure 3. The standard deviation is assumed the same as that during the EOC 3 measured crack distribution.

(b) From the BOC 4 and EOC 4 measured crack distributions, we calculate a crack growth rate.

(c) Based on the EOC 4 measured crack distribution and the bias distribution, we determine the EOC 4 true crack distribution.

(d) Assuming that at the time the crack was formed, there was a 0.01% probability with non-zero crack depth, which is almost a problem free situation, we can determine the mean value of the true crack depth as a function of the standard deviation.

(e) From the crack growth model and the true crack distributions at the time of crack initiation and the EOC 4 outage, we determine the standard deviation of the crack distribution at the crack initiation and the total crack propagation time.

(3) <u>Determination of the Allowable Operation Time</u>

With the crack growth rate determined by Step (2) and the measured crack distribution after all the crack tubes are plugged at the EOC 4 outage (a crack distribution with the

same standard deviation as that measured during EOC 4 outage, but only having a 1% population above zero crack depth), we derive the maximum operation time into which the measured crack distribution will produce a true crack distribution that 95% area is below 65% through-wall crack depth. Figure 4 shows the calculation of the allowable operation time. It illustrates the concept of the initial crack distribution after startup at the EOC 4 outage and the final measured and true crack distributions.

5. ANALYSIS

(1) Crack Growth Rate

The crack growth rate is determined from the bobbin probe measurements conducted during EOC 3 and EOC 4 refueling outages. The crack measurements by bobbin probes during these two periods are shown in Table 1. In EOC 3, there were only three bobbin signatures with indications, while the remainder of the bobbin probes had no indications. Similarly, in EOC 4, there were 58 bobbin probe signatures with indications, but only 34 data have numerical values of the average through-wall crack depth as shown in Table 1. The remaining 3,800 bobbin probe readings showed no indications.

To study the characteristics of crack growth, we select same number of samples (n=34) from the two groups of measurements for comparison. The mean and standard deviation for EOC 3 and EOC 4 are, respectively, (.058, .2) and (.61, .24), where the first number in the parenthesis is the mean, and the second number is the standard deviation.

It should be noted that the three tubes with measured crack indications in the EOC 3 were removed from service, resulting in no measured cracks at the BOC 4. However,

for the purpose of calculating the crack growth rate, we assume that there is a certain probability of the bobbin probe mis-reading error to develop the initial conditions. Further, the sensitivity of the assumed bobbin probe error on the calculation of the crack growth rate is investigated.

The growth rate of the cracks which propagate between the measurements in the EOC 3 and EOC 4 can be expressed as

$$V_2 = V_1 + GT \qquad (1)$$

where V_1, V_2, and G are variables with assumed normal distributions. G is the crack growth rate with X_G and σ_G being its mean and standard deviation. T is the time interval between Cycles 3 and 4, which is 15 months for Palo Verde Unit 2. V_1 and V_2 are the measured crack distributions at the EOC 3 and EOC 4, respectively. The mean and standard deviation of the measured crack distribution in the EOC 4 as discussed above are

$$V_2 = (0.61, 0.24)$$

A. <u>1% Bobbin Probe Error (Base Case)</u>

For the base case to determine the crack distribution after the EOC 3 outage, we assume that after all the cracked tubes were plugged, there was still a 1% chance of the measured crack distribution having above zero crack depth. That is, the mean of the measured crack distribution in Cycle 3 is -2.33σ, where σ is the standard deviation, which is the same as that measured during EOC 3. Therefore, the mean and standard deviation of the measured crack distribution for the BOC 4 are

$$V_1 = (-0.466, 0.2)$$

The mean and standard deviation of the growth rate G for the base case of a 1% probe error are determined according to Equation (1) and the above characteristics of V_1 and V_2 as

$$X_G = 0.0717$$

$$\sigma_G = 0.00884$$

B. <u>5% Bobbin Probe Error</u>

For the sensitivity of the probe error, we assume that a 5% chance that the measured tubes with defects at the BOC 4. That is, the mean of the crack distribution in the BOC 4 is -1.65σ, or -0.33. Thus, the mean and standard deviation of the measured crack distribution in the BOC 4 are

$$V_1 = (-0.33,\ 0.2)$$

The mean and standard deviation of the growth rate for a 5% probe error are determined from Equation (1) as

$$X_G = 0.0627$$

$$\sigma_G = 0.00884$$

(2) <u>Crack Initiation Time</u>

The crack initiation time is the total crack propagation time of the crack from the time of initiation till the Cycle 4 outage based on the growth rate determined in Section 5.(1). We assume at the time of crack initiation that the true crack population has only 0.01% above zero crack depth, which is almost a problem free situation. From a normal distribution curve, the mean of the crack distribution at initiation is -

$3.71\sigma_T$, where σ_T is the standard deviation of the crack population.

A. True Crack Distribution

To determine the crack initiation time, we will convert the measured crack distribution in EOC 4 to the true crack distribution. The measured crack distribution in Cycle 4 includes a bias of bobbin probe inefficiency, and does not reflect the true crack distribution. From the probability of detectability (POD) curve, we can derive a transfer function, called bias distribution, that relates the measured distribution and the true distribution. Based on the measured crack distribution during the Cycle 4 outage, the mean and standard deviation of the bias (ΔV_2) and the true crack distributions (V_{T2}) are

$$V_{T2} = (0.65,\ 0.155)$$

B. Initiation Time with 1% Probe Error

Considering the propagation of crack from the time of initiation till the EOC 4 refueling outage with the growth rate determined above, we can express the true crack population at the time of initiation as

$$V_{T2} = V_{T1} + G\ T_i \qquad (2)$$

where T_i is the total crack propagation time. V_{T1} and V_{T2} are the true crack distributions at the time of initiation and the Cycle 4 outage, respectively. Their mean and standard deviation are

$$V_{T1} = (-3.71\sigma_{T1},\ \sigma_{T1})$$

$$V_{T2} = (0.478,\ 0.278)$$

where the standard deviation σ_{T1} is to be determined. For the 1% bobbin probe error case, the mean and standard deviation of the growth rate were previously determined as

$$G = (0.0717,\ 0.00884)$$

According to Equation (2), the mean and standard deviation of the variables are expressed as

$$-0.371\sigma_{T1} + 0.0717T_i = 0.478 \qquad (3)$$

$$\sigma_{T1}{}^2 + (0.00884T_i)^2 = 0.278^2 \qquad (4)$$

σ_{T1} and T_i can be determined by solving Equations (3) and (4) simultaneously as

$$\sigma_{T1} = .226$$

$$T_o = 18.4$$

The mean and standard deviation of V_{T1} are,

$$V_{T1} = (-0.838,\ 0.226)$$

According to Equation (2), the total crack propagation time T_o can be expressed in terms of a normal distribution as

$$T_o = (V_{T2} - V_{T1})/G$$

$$= [(0.478,0.278)-(-0.838,0.226)]/(0.0717,0.00884)$$

$$= (18.8,\ 5.9\ )$$

where the mean propagation time is 18.8 months with a standard deviation of 5.9 months. For a 95% probability of occurrence, the total propagation time is within the interval of 18.8 ± 9.7 months.

C. <u>Initiation Time with 5% Probe Error</u>

For the case of 5% bobbin probe error, the mean and standard deviation of the growth rate were previously determined as

$$G = (0.0627,\ 0.00884)$$

The mean and standard deviation of the true crack distributions, V_{T1} and V_{T2} are defined previously as,

$$V_{T1} = (-3.71\sigma_{T1},\ \sigma_{T1})$$

$$V_{T2} = (0.478,\ 0.278)$$

According to Equation (2), two equations for the mean and the standard deviation, respectively, are developed as

$$-0.371\sigma_{T1} + 0.0627T_i = 0.478 \qquad (5)$$

$$\sigma_{T1}^2 + (0.00884T_i)^2 = 0.278^2 \qquad (6)$$

σ_{T1} and T_i are determined by solving Equations (5) and (6) as

$$\sigma_{T1} = 0.213$$

$$T_o = 20.2$$

The mean and the standard deviation of the initial true crack distribution V_{T1} are,

$$V_{T1} = (-0.79,\ 0.213)$$

According to Equation (2), the total crack propagation time T_i can be expressed in terms of a normal distribution as

$$T_i = (V_{T2} - V_{T1})/G$$

$$= [(0.478,0.278)-(-0.79,0.0213)]/(0.0627,0.00884)$$

$$= (20.8,\ 6.8)$$

Therefore, the mean propagation time is 20.8 months with a standard deviation of 6.8 months. For a 95% probability of occurrence, the total propagation time is within the interval of 20.8 ± 11.2 months.

(3) Maximum Operation Time

After the EOC 4 outage, all the cracked tubes are plugged, resulting in no cracks in the measured population. The maximum operation time is, thus, the time for the new crack distribution to propagate to one at which a high probability of the true crack population is still less than the allowable crack depth. We will investigate two scenarios for the maximum operation time. One is the base case which represents the best estimate conditions for the Palo Verde, while the other is the worst case which represents the most conservative estimates of conditions.

A. Base Case

For the base case scenario, we hypothesize that at the next inspection, the true crack distribution will have a 95% probability that the crack depth is less than 65% through-wall at a 95% confidence level. The POD curve for the crack

inspection in the base case is the Palo Verde specific as shown in Figure 5. It is assumed that there will be about 35 samples having bobbin signatures in the next inspection. Based on a normal distribution curve, the sample mean X_{T2} of the true crack distribution which will satisfy these requirements is

$$X_{T2} = 0.65-1.364\sigma_{T2} \quad (7)$$

where σ_{T2} is the standard deviation of the allowable true crack distribution.

(a) <u>Allowable Measured Crack Distribution</u>

The allowable measured crack distribution (V_{M2}) is related to the true crack distribution (V_{T2}) by a statistical trasfer function of the bias distribution (ΔV) as follows

$$V_{M2} = V_{T2} + \Delta V \quad (8)$$

If the characteristics of the true crack population (X_{T2}, σ_{T2}) at the time of next inspection are known , the mean and standard deviation of the measured crack distribution (X_{M2}, σ_{M2}) can be determined from the POD curve of the bobbin probes.

(b) <u>Operation Time with 1% Probe Error</u>

Since the cracked tubes are plugged and removed from service during the EOC 4 outage, there is no measured cracks after the startup of BOC 5. The standard deviation of the crack population is still the same as that measured during the EOC 4 outage. However, we assume that there is a 1% of measured tubes being defects due to bobbins mis-reading error. The initial measured crack distribution will, therefore, have the

mean (X_{M1}) and standard deviation (σ_{M1}) as

$$X_{M1} = -2.33\sigma_{M1} = -0.559$$

$$\sigma_{M1} = 0.24$$

Let X_{M2} and σ_{M2} be the mean and the standard deviation of the maximum measured crack distribution (V_{M2}) for which the true crack distribution will satisfy the requirements discussed above. The means and standard deviations of the true crack distribution (V_{T2}) and the bias distribution (ΔV) are (X_{T2}, σ_{T2}) and ($X_{\Delta v}$, $\sigma_{\Delta v}$), respectively.

The crack propagation from the initial condition (V_{M1}) after Cycle 4 startup to the maximum measured distribution at the next inspection (V_{M2}) is expressed as follows:

$$V_{M1} + GT_o = V_{M2} \quad (9)$$

where G is the crack growth rate as determined in Section 5.(1), and T_o is the allowable operation time from the BOC 5 until the next inspection outage.

According to Equation (9), we can formulate the relationships for the means and the standard deviations of the variables as

$$-0.559 + 0.0717T_o = X_{M2} \quad (10)$$

$$0.24^2 + (0.00884T_o)^2 = \sigma_{M2}^2 \quad (11)$$

The unknown parameters T_o, σ_{T2}, X_{T2}, and σ_{M2} and X_{M2} can be determined from Equations (10), (11), and the bias distribution from the POD curve. The results are summarized as follows:

$T_o = 13.8$

$\sigma_{T2} = 0.263$

$X_{T2} = 0.291$

$\sigma_{M2} = 0.269$

$X_{M2} = 0.43$

The maximum operation time until next inspection with a 1% probe error is 13.8 months.

(c) Operation Time with 5% Probe Error

If we assume that the measured crack distribution after plugging the cracked tubes at the EOC 4 outage has a 5% of tubes with above-zero crack depth, then, the mean (X_{M1}) and the standard deviation (σ_{M1}) of the initial measured crack distribution are

$$X_{M1} = -1.65\sigma_{M1} = -0.396$$

$$\sigma_{M1} = 0.24$$

According to the same procedures discussed above for the 1% probe error case, we can develop the means and the standard deviations of the propagated measured crack distribution as follows:

$$-0.396 + 0.0627T_o = X_{M2} \quad (12)$$

$$0.24^2 + (0.00884T_o)^2 = \sigma_{M2}^2 \quad (13)$$

Similarly, T_o, σ_{T2}, X_{T2}, σ_{M2} and X_{M2} can be determined from

Equations(12), (13), and the Palo Verde specific POD curve. They are summarized as follows:

$$T_o = 13.2$$

$$\sigma_{T2} = 0.261$$

$$X_{T2} = 0.294$$

$$\sigma_{M2} = 0.267$$

$$X_{M2} = 0.432$$

The maximum operation time with a 5% probe error is 13.2 months.

B. Worst Case

The above analysis for the maximum operation time is based on the best estimate conditions for the Palo Verde Unit 2. For the sensitivity analysis using the most pessimistic conditions, we hypothesize that the true crack population at the time of next inspection will have a 99% population below 62% crack depth at a 99% confidence level. Since a pessimistic POD curve will result in a larger mean value of the measured crack distribution and, thus, a longer operation time, the POD curve for the worst case scenario is also the Palo Verde specific POD curve.

Based on the normal distribution, the sample mean and standard deviation of the true crack population which will satisfy the requirements of 99% probability and confidence level, is

$$V_{T2} = (0.62-1.917\sigma_{T2},\ \sigma_{T2}) \qquad (14)$$

where σ_{T2} is the standard deviation of the true crack distribution.

(a) Allowable Measured Crack Distribution

Similar to the base case discussed in Section 3.A.(a), the allowable measured crack distribution (V_{M2}) is related to the true crack distribution (V_{T2}) by a trasfer fuction of the bias distribution (ΔV) as described in Equation (8). However, the mean of the true crack distribution for the worst case scenario is expressed in Equation (14).

(b) Operation Time with 1% Probe Error

After the cracked tubes are plugged at the Cycle 4 outage, there is no measured crack in the population. However, similar to the base case discussed in Section 3.A.(b), the initial measured crack distribution with 1% population above zero crack depth due to bobbin mis-reading error will have the mean and standard deviation as follows:

$$X_{M1} = -2.33\sigma_{M1} = -0.559$$

$$\sigma_{M1} = 0.24$$

Using the above initial measured distribution and the maximum crack distribution in Equation (14), we can develop the relationships for the mean and the standard deviation as follows:

$$-0.559 + 0.0717T_o = X_{M2} \qquad (15)$$

$$0.24^2 + (0.00884T_o)^2 = \sigma_{M2} \qquad (16)$$

The unknown parameters T_o, σ_{T2}, X_{T2}, σ_{M2}, X_{M2} can be determined

from Equations (15), (16), and the POD curve used for the worst case scenario. The results are summarized as follows:

$$T_o = 11.8$$

$$\sigma_{T2} = 0.23$$

$$X_{T2} = 0.179$$

$$\sigma_{M2} = 0.262$$

$$X_{M2} = 0.28$$

The maximum operation time for the worst case scenario with a 1% probe error is 11.8 months.

(c) Operation Time with 5% Probe Error

If we assume that the measured crack distribution after EOC 4 outage has a 5% chance being above zero crack depth, then, the initial measured crack distribution have the mean (X_{M1}) and the standard deviation (σ_{M1}) as

$$X_{M1} = -1.65\sigma_{M1} = -0.396$$

$$\sigma_{M1} = 0.24$$

The mean and standard deviation of the propagated measured crack distribution can be expressed as

$$-0.396 + 0.0627T_o = X_{M2} \quad (17)$$

$$0.24^2 + (0.00884T_o)^2 = \sigma_{M2} \quad (18)$$

Similarly, T_o, σ_{M2}, X_{M2}, σ_{T2} and X_{T2} can be determined from Equations(17), (18), and the POD curve used for the worst case scenario. They are summarized as follows:

$$T_o = 10.8$$

$$\sigma_{T2} = 0.226$$

$$X_{T2} = 0.187$$

$$\sigma_{M2} = 0.257$$

$$X_{M2} = 0.284$$

The maximum operation time for the worst case scenario with a 5% probe error is 10.8 months.

TABLE 1 EDDY CURRENT MEASUREMENTS IN SG22

(A) AT CYCLE 4

No	Row #	Col #	Loc	AVG D	D^2
1	22	13	01H	36.00%	0.1296
2	10	23	01H	41.00%	0.1681
3	29	24	01H	72.00%	0.5184
4	112	39	08H	62.00%	0.3844
5	117	42	08H	46.00%	0.2116
6	123	44	08H	71.00%	0.5041
7	118	45	09H	64.00%	0.4096
8	123	46	08H	12.00%	0.0144
9	128	47	08H	82.00%	0.6724
10	129	48	08H	18.00%	0.0324
11	128	49	08H	68.00%	0.4624
12	123	50	09H	54.00%	0.2916
13	129	50	08H	8.00%	0.0064
14	151	90	05H	73.00%	0.5329
15	41	94	TEH	99.00%	0.9801
16	150	115	08H	67.00%	0.4489
17	140	119	09H	59.00%	0.3481
18	137	124	BW1	73.00%	0.5329
19	129	132	09H	75.00%	0.5625
20	128	133	09H	35.00%	0.1225
21	128	135	09H	79.00%	0.6241
22	125	136	09H	56.00%	0.3136
23	128	137	08H	61.00%	0.3721
24	125	138	08H	57.00%	0.3249
25	127	140	08H	76.00%	0.5776
26	128	141	08H	85.00%	0.7225
27	121	142	09H	71.00%	0.5041
28	117	144	08H	100.00%	1.0000
29	118	145	09H	23.00%	0.0529
30	124	145	BW1	83.00%	0.6889
31	110	149	08H	88.00%	0.7744
32	17	152	01H	29.00%	0.0841
33	105	156	08H	87.00%	0.7569
34	104	157	08H	74.00%	0.5476
			SUM =	20.84	14.677
			MEANS=	61.29%	
			DSTDS=	24.02%	
			DSTD =	23.66%	

(B) AT CYCLE 3

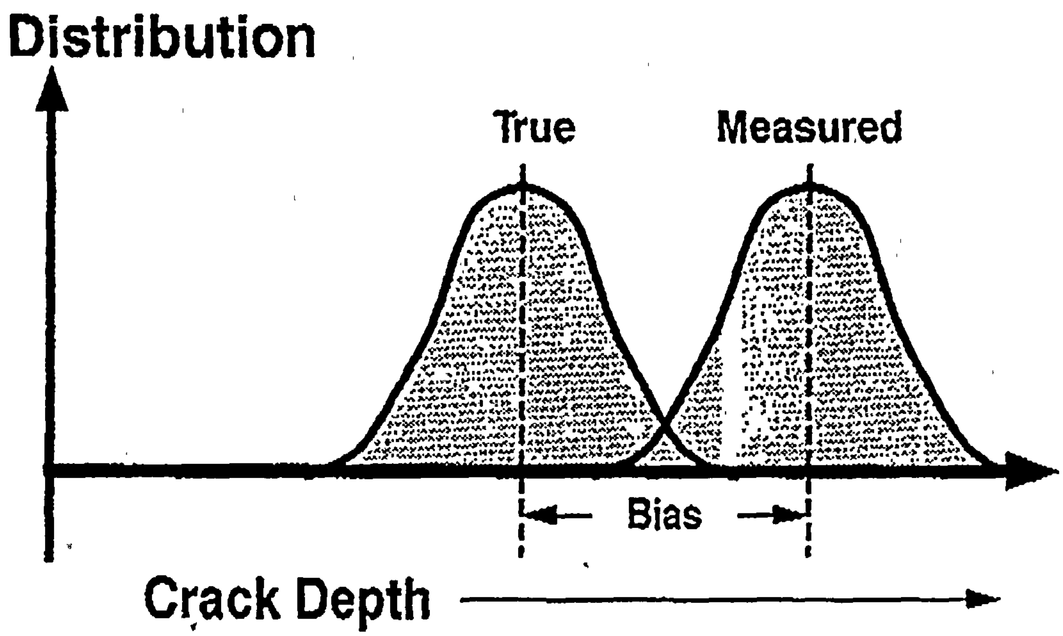
No	Row #	Col #	Loc	AVG D	D^2
1	134	97	BW1	85.00%	0.7225
2	112	151	BW1	36.00%	0.1296
3	117	54	09H	76.00%	0.5776
			SUM =	1.97	1.4297
			MEAN =	5.79%	
			DSTDS=	19.97%	
			DSTD =	19.67%	

TABLE 2 CHI-SQUARE TEST OF NORMALITY ON CYCLE 4 MEASURED DISTRIBUTION

Class Interval From	To	fo	% Occur	x	x-mean	z	Area	dA	f1	fo-f1	(fo-f1)^2	(fo-f1)^2/f1
0.01	0.10	1	0.0294	0.01	-0.602	-2.5083	0.4938	0.0126	0.4284	0.5716	0.3267	0.7627
0.11	0.20	2	0.0588	0.11	-0.502	-2.0917	0.4812	0.0287	0.9758	1.0242	1.0490	1.0750
0.21	0.30	2	0.0588	0.21	-0.402	-1.6750	0.4525	0.0581	1.9754	0.0246	0.0006	0.0003
0.31	0.40	2	0.0588	0.31	-0.302	-1.2583	0.3944	0.0977	3.3218	-1.3218	1.7472	0.5260
0.41	0.50	2	0.0588	0.41	-0.202	-0.8417	0.2967	0.1339	4.5526	-2.5526	6.5158	1.4312
0.51	0.60	4	0.1176	0.51	-0.102	-0.4250	0.1628	0.1598	5.4332	-1.4332	2.0541	0.3781
				0.61	-0.002	-0.0083	0.0030					
0.61	0.70	5	0.1471					0.1470	4.9980	0.0020	0.0000	0.0000
				0.70	0.088	0.3667	0.1440					
0.71	0.80	9	0.2647	0.80	0.188	0.7833	0.2823	0.1383	4.7022	4.2978	18.4711	3.9282
0.81	0.90	5	0.1471	0.90	0.288	1.2000	0.3849	0.1026	3.4884	1.5116	2.2849	0.6550
0.91	1.00	2	0.0588	1.00	0.388	1.6167	0.4474	0.0625	2.1250	-0.1250	0.0156	0.0074
n =		34									Sum =	8.7638

Mean = 0.61
Std = 0.24
DOF = 7
Significance = 0.05
Critical X^2 = 14.07 > 8.76 OK

Measured vs. True Crack Distribution

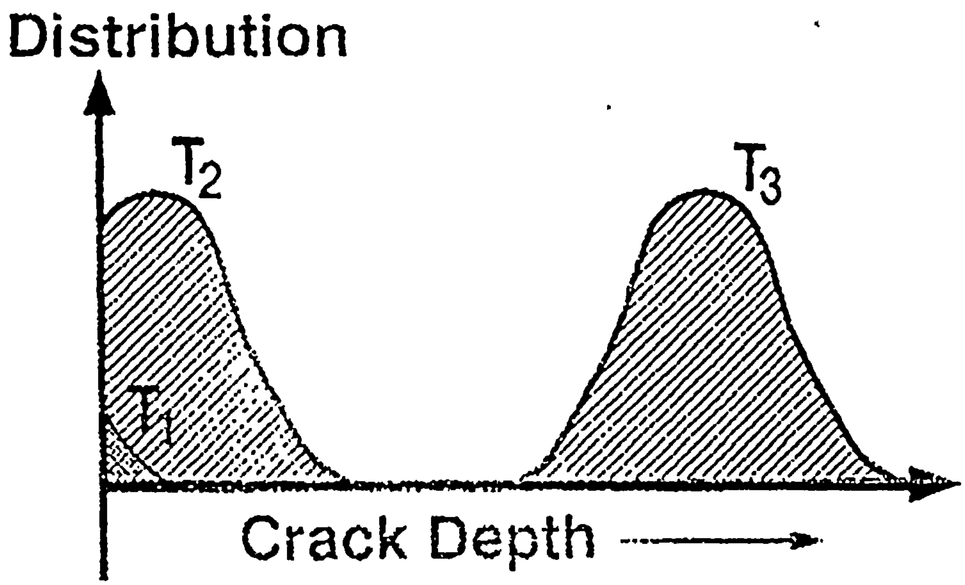


- **The Bias (a statistical transfer function) is derived based on the POD curve.**

FIGURE 1

7-13-93
GROWTH-2

True Crack Growth vs. Time
(A Statistical View)



$T_3 > T_2 > T_1$

- At T_1, *crack is forming*
- At T_2, *crack is forming and growing*
- At T_3, *crack is growing*

FIGURE 2

Growth Rate Determination

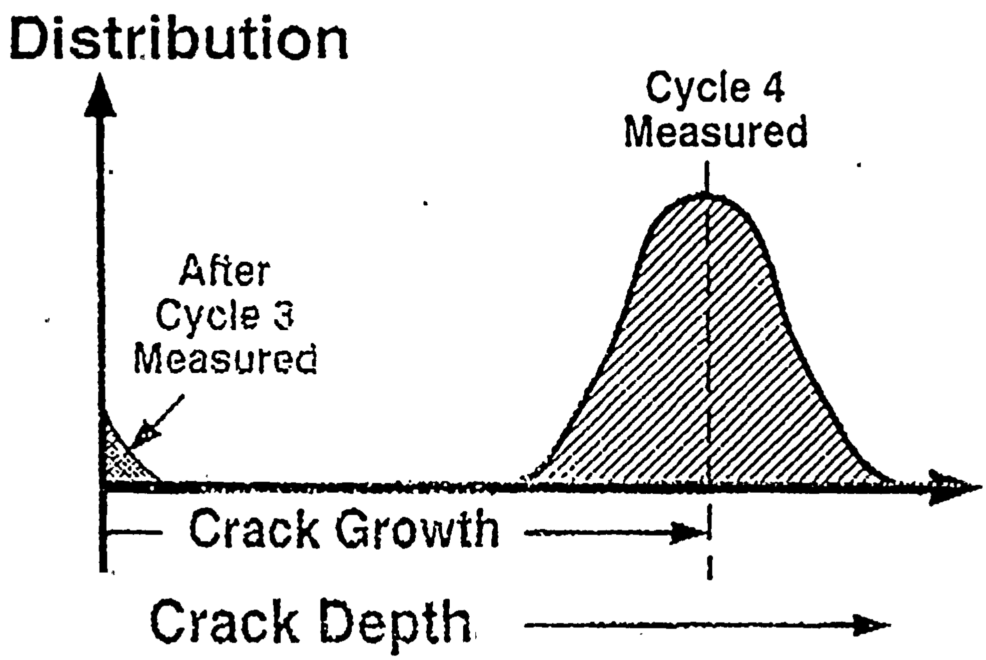


FIGURE 3

Allowable Operation Time

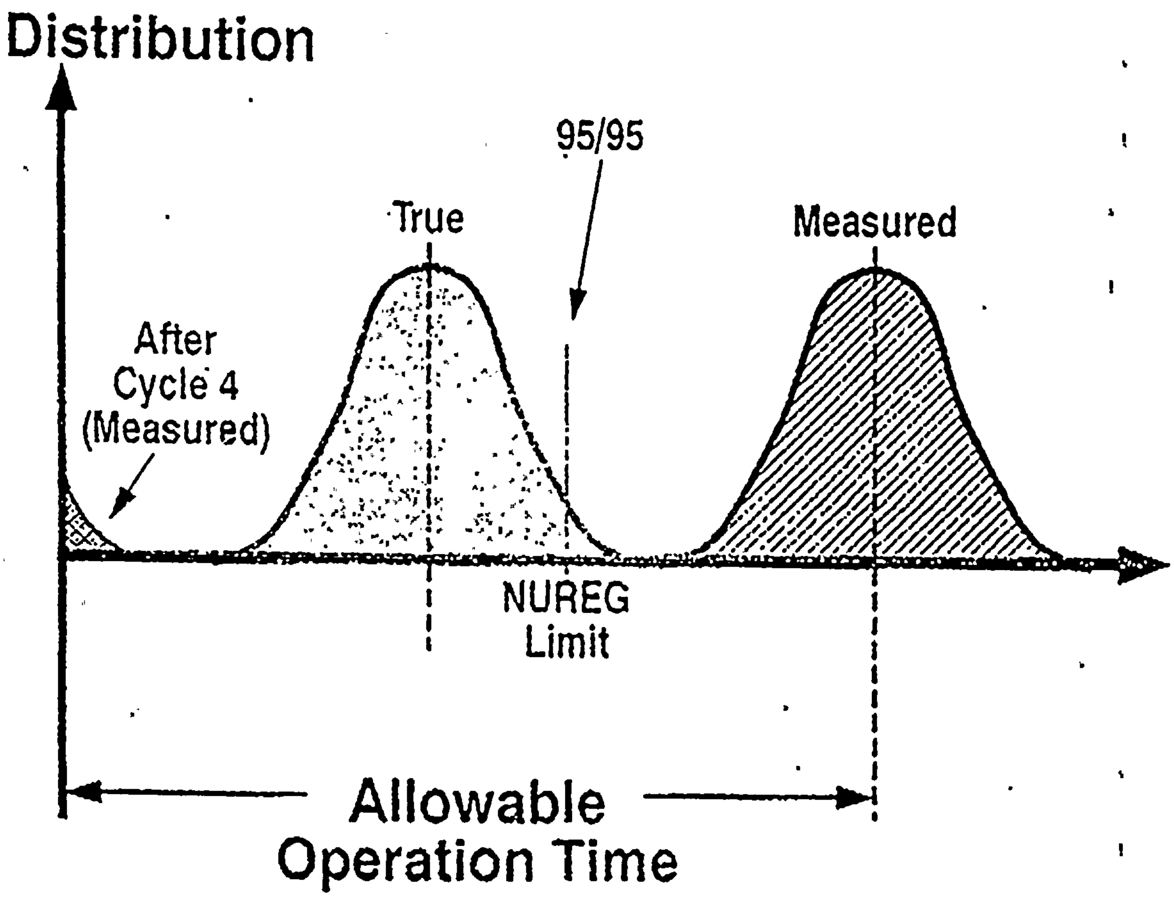


FIGURE 4

Eddy Current Detectability

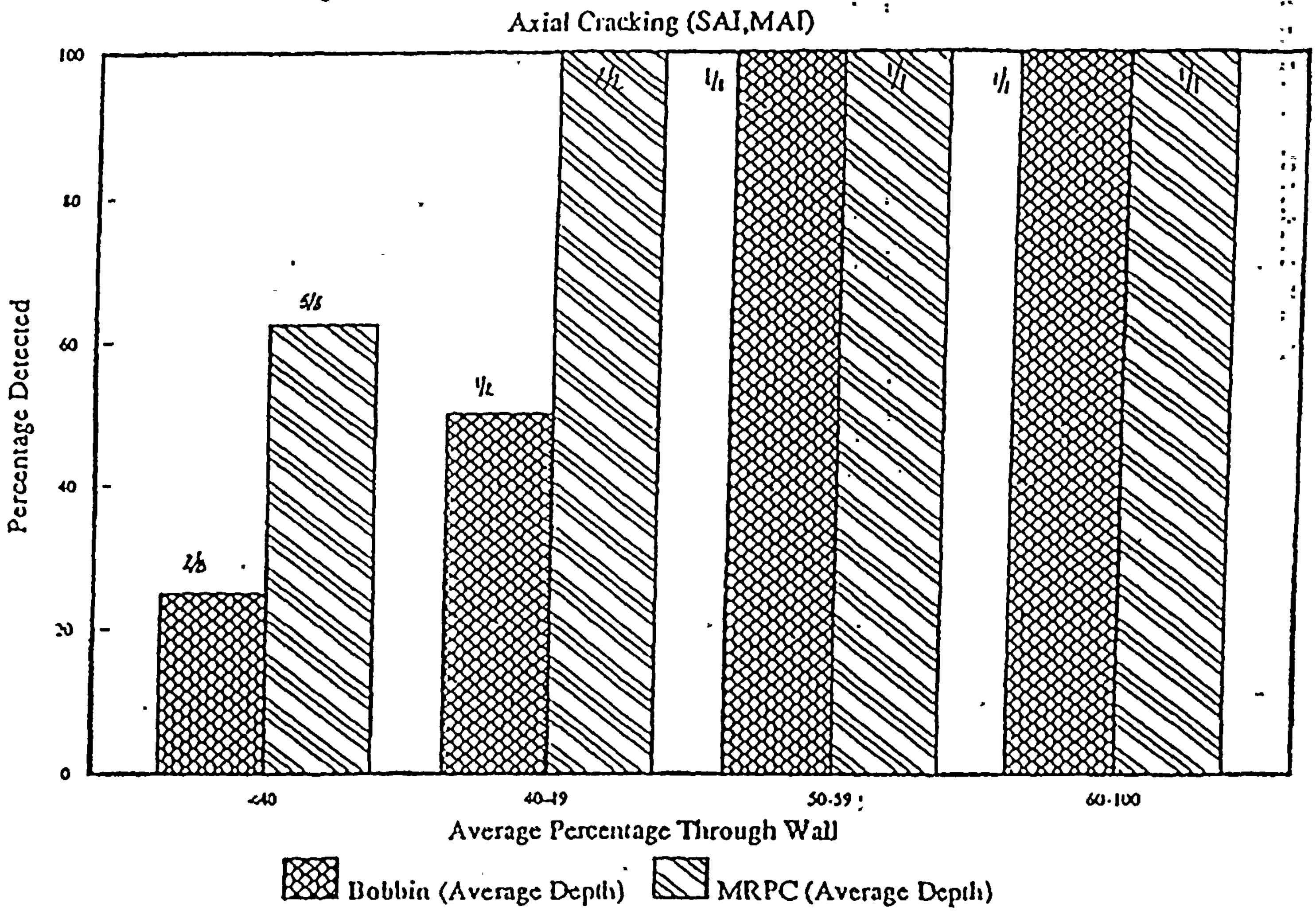


FIGURE 5

APPENDIX A

LIST OF OUTPUT FROM FPI-CSTAT

FPI-CSTAT STATISTICAL ANALYSIS OF CRACK PROPAGATION Ver 1.0

FPI INTERNATIONAL 07-18-1993 17:19:25

CLIENT: ARIZONA PUBLIC SERVICE COMPANY
PROJECT: STEAM GENERATOR 22
CASE: CASE 1: BASE CASE WITH 1% ERROR IN READING PROBE SIGNATURE

***** INPUT DATA *****

DESCRIPTION	VALUE
Std of Measured Crack Distribution After Startup of Last Outage	0.2000
Bobbin Signature Reading Error	0.0100
Mean of Measured Crack Distribution in Current Outage	0.6100
Std of Measured Crack Distribution in Current Outage	0.2400
Time Interval Between Current and Last Outages	15.0
Mean of True Crack Distribution at Current Outage	0.4780
Std of True Crack Distribution at Current Outage	0.2780
Allowable Crack Depth at Next Outage	0.6500
Probability and Confidence Level	0.9500
POD Curve, 1=Best Estimate, 2=Conservative Estimate	1

***** SUMMARY OF RESULTS *****

Mean of Crack Growth Rate	0.0717
Std of Crack Growth Rate	0.0088
Mean of Total Propagation Time from Crack Initiation till now	18.7612
Std of Total Propagation Time	5.8505
Allowable Operation Time until Next Inspection Outage	13.8629

FPI-CSTAT STATISTICAL ANALYSIS OF CRACK PROPAGATION Ver 1.0

FPI INTERNATIONAL 07-18-1993 17:22:19

CLIENT: ARIZONA PUBLIC SERVICE COMPANY
PROJECT: STEAM GENERATOR 22
CASE: CASE 2: CONSERVATIVE CASE WITH 1% ERROR IN READING PROBE SIGNATURE

***** I N P U T D A T A *****

DESCRIPTION	VALUE
Std of Measured Crack Distribution After Startup of Last Outage	0.2000
Bobbin Signature Reading Error	0.0100
Mean of Measured Crack Distribution in Current Outage	0.6100
Std of Measured Crack Distribution in Current Outage	0.2400
Time Interval Between Current and Last Outages	15.0
Mean of True Crack Distribution at Current Outage	0.4300
Std of True Crack Distribution at Current Outage	0.2690
Allowable Crack Depth at Next Outage	0.6200
Probability and Confidence Level	0.9900
POD Curve, 1=Best Estimate, 2=Conservative Estimate	1

***** S U M M A R Y O F R E S U L T S *****

Mean of Crack Growth Rate	0.0717
Std of Crack Growth Rate	0.0088
Mean of Total Propagation Time from Crack Initiation till now	17.8052
Std of Total Propagation Time	5.6579
Allowable Operation Time until Next Inspection Outage	11.6521

FPI-CSTAT STATISTICAL ANALYSIS OF CRACK PROPAGATION Ver 1.0

FPI INTERNATIONAL 07-18-1993 17:25:09

CLIENT: ARIZONA PUBLIC SERVICE COMPANY
PROJECT: STEAM GENERATOR 22
CASE: CASE 3: BASE CASE WITH 5% ERROR IN READING PROBE SIGNATURE

***** I N P U T D A T A *****

DESCRIPTION	VALUE
Std of Measured Crack Distribution After Startup of Last Outage	0.2000
Bobbin Signature Reading Error	0.0500
Mean of Measured Crack Distribution in Current Outage	0.6100
Std of Measured Crack Distribution in Current Outage	0.2400
Time Interval Between Current and Last Outages	15.0
Mean of True Crack Distribution at Current Outage	0.4780
Std of True Crack Distribution at Current Outage	0.2780
Allowable Crack Depth at Next Outage	0.6500
Probability and Confidence Level	0.9500
POD Curve, 1=Best Estimate, 2=Conservative Estimate	1

***** S U M M A R Y O F R E S U L T S *****

Mean of Crack Growth Rate	0.0627
Std of Crack Growth Rate	0.0088
Mean of Total Propagation Time from Crack Initiation till now	20.8143
Std of Total Propagation Time	6.8088
Allowable Operation Time until Next Inspection Outage	13.2988

FPI-CSTAT STATISTICAL ANALYSIS OF CRACK PROPAGATION Ver 1.0

FPI INTERNATIONAL 07-18-1993 17:25:58

CLIENT: ARIZONA PUBLIC SERVICE COMPANY
PROJECT: STEAM GENERATOR 22
CASE: CASE 4: CONSERVATIVE CASE WITH 5% ERROR IN READING PROBE SIGNATURE

***** I N P U T D A T A *****

DESCRIPTION	VALUE
Std of Measured Crack Distribution After Startup of Last Outage	0.2000
Bobbin Signature Reading Error	0.0500
Mean of Measured Crack Distribution in Current Outage	0.6100
Std of Measured Crack Distribution in Current Outage	0.2400
Time Interval Between Current and Last Outages	15.0
Mean of True Crack Distribution at Current Outage	0.4300
Std of True Crack Distribution at Current Outage	0.2780
Allowable Crack Depth at Next Outage	0.6200
Probability and Confidence Level	0.9900
POD Curve, 1=Best Estimate, 2=Conservative Estimate	1

***** S U M M A R Y O F R E S U L T S *****

Mean of Crack Growth Rate	0.0627
Std of Crack Growth Rate	0.0088
Mean of Total Propagation Time from Crack Initiation till now	20.2662
Std of Total Propagation Time	6.8018
Allowable Operation Time until Next Inspection Outage	10.9142

ENCLOSURE 1

AFFIDAVIT

to determine when and whether to hold certain types of information in confidence.

4. The information is being transmitted to the Commission in confidence under the provisions of 10 CFR 2.790 with the understanding that it is to be received in confidence by the Commission.

5. The information, to the best of my knowledge and belief, is not available in public sources, and any disclosure to third parties has been made pursuant to regulatory provisions or proprietary agreements which provide for maintenance of the information in confidence.

6. Public disclosure of the information is likely to cause substantial harm to the competitive position of FPI International because:

   a. A similar product is sold by other major competitors of FPI International.
   b. Development of this information by FPI International required a lot of research and development manhours. To the best of my knowledge and belief, a competitor would have to undergo similar expense in generating equivalent information.
   c. In order to acquire such information, a competitor would also require considerable time and inconvenience

utilized by FPI International in designating information as a trade secret, privileged or as confidential commercial or financial information.

Pursuant to the provisions of paragraph (b) (4) of Section 2.790 of the Commission's regulations, the following is furnished for consideration by the Commission in determining whether the information sought to be withheld from public disclosure, included in the above referenced document, should be withheld.

1. The information sought to be withheld from public disclosure, which is owned and has been held in confidence by FPI International, is the crack growth, crack initiation time, and allowable operation time analysis and modeling techniques.

2. The information consists of detailed modeling techniques or other similar methods concerning a process, method or component, the application of which results in substantial competitive advantage to FPI International.

3. The information is of a type customarily held in confidence by FPI International and not customarily disclosed to the public. FPI International has a rational basis for determining the types of information customarily held in confidence by it and, in that connection, utilizes a system

to determine the cracking growth rate, crack initiation time, allowable operation time modeling and analysis techniques.

d. The information required significant effort and expense to obtain the licensing approvals necessary for application of the information. Avoidance of this expense would decrease a competitor's cost in applying the information and marketing the product to which the information is applicable.

e. Use of the information by competitors in the international marketplace would increase their ability to market competitive services by reducing the costs associated with their technology development.

Chong Chiu

C. Chiu

President

Sworn to before me

this 4th day of August, 1993

Barbara A. DeLeone

Notary Public

My commission expires : 2-28-97

BARBARA A. DE LEONE
NOTARY PUBLIC-CALIFORNIA
COMMISSION # 986014
ORANGE COUNTY
My Comm. Exp. Feb. 28, 1997

ENCLOSURE 2

PROPRIETARY REPORT, FPI 93-427

AFFIDAVIT PURSUANT

TO 10 CFR 2.790

FPI International	)	
State of California	)	
County of Orange County	)	SS.:

C. Chiu, depose and say that I am the President, of FPI International, duly authorized to make this affidavit, and have reviewed or caused to have reviewed the information which is identified as proprietary and referenced in the paragraph immediately below. I am submitting this affidavit in conjunction with the application of Arizona Public Service Company in Conformance with the provisions of 10 CFR 2.790 of the Commission's regulations for withholding this information.

The information for which proprietary treatment is sought is contained in the following document:

"Estimation of Crack Growth Rate, Crack Initiation Time, and Allowable Operation Time, Palo Verde Nuclear Generating Station Unit 2", July 30, 1993, FPI International Proprietary Report, FPI-93-427.

This document has been appropriately designated as proprietary.

I have personal knowledge of the criteria and procedures