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Optimum Test Intervals for Online Testing

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INTRODUCTION

Optimal periodic test intervals are given for standby components, when testing is performed on line and the testing causes the component to be unavailable while the test is performed. The optimal test interval, which is the optimal time between tests, minimizes the average component unavailability. Figures and tables are presented that give the optimal test interval versus component failure rates and test times, which were selected to cover the range of values normally encountered in nuclear power plant applications. When component failure rates and test times are not accurately known, the figures and tables can be used to obtain a range on the optimal test interval.

ASSUMPTIONS

The assumptions used in deriving the optimal component test intervals are:

1. The component is a standby component with a constant failure rate λ per hour.

2. Testing is done periodically and is done on-line, i.e., during the test the component could be called upon to operate.

3. During the time of the test, the component is unavailable and unable to respond if called upon to operate.

4. The testing requires an average time period τ to complete.

5. Other than the test time τ during which the component is unavailable there are no test-caused failures or degradations such as due to human error.

DEVIATIONS FROM THE ASSUMPTIONS

If the test time is variable, then τ should be the statistical average of the probability distribution of the test time. If there is an override device which is capable of taking the component out of the test mode into the operate mode if needed or if the operator has instructions to do so then τ should be replaced by $p\tau$ where p is the probability that the override attempt is unsuccessful. (In all the tables and figures calculate $p\tau$ and use as the τ value).

The optimal test intervals which are presented still apply even if there are additional test-caused failures as long as the probabilities of having these failures are not dependent on the test interval. For violations of assumptions not covered here, the figures and tables in a number of cases may still be used to obtain bounds or ballpark values for the optimal test intervals; the analyst however must decide on the meaningfulness of the optimal test intervals in these other cases.

CALCULATION OF AVERAGE COMPONENT UNAVAILABILITY

Under the above assumptions the average component unavailability is modeled as:

$$q_c = \frac{1}{T+\tau}\left[\int_0^T (1-e^{-\lambda t})\,dt + \tau\right] \qquad (1)$$

where:
- q_c = average component unavailability
- λ = component failure rate
- T = constant time between tests (test interval)
- τ = constant test time (downtime) during which the component is unavailable

As Equation (1) indicates q_c is an average (over time) of the time dependent pointwise unavailability; because of the cyclic nature of the unavailability the average is taken over one cycle (of length $T + \tau$).

For $\tau \ll T$ and $\lambda T \ll 1$, Eq. 1 can be approximated as:

$$q_c = \frac{1}{2} \lambda T + \frac{\tau}{T} \qquad (2)$$

The above approximation is conservative and agrees with the exact value to within 10% relative precision when $\lambda T < .05$ and $\tau/T < .05$. The errors made in using Eq. 2 are generally much less than the uncertainties in data. We shall use Eq. 2 in our evaluations.

Using Equation (2), curves of q_c versus T were plotted for parametric values of λ and τ. These curves are displayed in Figures 1 through 12. Curves of q_c versus T with λ as a parameter are shown for assumed values of τ in Figures 1 through 9; curves of q_c versus T with τ as a parameter are shown for assumed values of λ in Figures 10 through 20.

DERIVATION OF OPTIMUM TEST INTERVALS

The optimum test interval, T_O, is obtained by differentiating equation (2) and solving for time between test:

$$T_O = \sqrt{\frac{2\tau}{\lambda}} \qquad (3)$$

As can be seen from Equation (3), the optimum test interval increases as outage duration, τ, increases, and as the component failure rate, λ, decreases.

Tables 1 through 11 tabulate the optimum values for T for each different value of τ and λ. The optimum (minimum) component unavailability corresponding to the optimum value of T is also given in the tables. Figure 21 plots the optimum test interval (the x-axis) versus test downtime (TAU) for various failure rates λ ("LAMDA"). Figure 22 plots the optimum test interval (x-axis) versus λ for various test times TAU (τ = TAU).

DEVIATIONS FROM OPTIMAL TEST INTERVALS

Tables 12 through 22 tabulate ranges for the test interval for which the unavailability is no greater than a certain percentage above the minimal (optimal) unavailability. The tables give ranges for maximum increases of 10%, 20%, and 30%.

For example, from Table 12 if TAU = 10 hours, the optimal test interval Topt is 447 hours; however, the test interval could be between 287 and 697 hours and the component unavailability would still be no greater than 10% above the minimum unavailability observable at Topt.

Tables 12 through 22 are useful for, among other things, indicating whether test intervals or proposed test interval changes are acceptable and in the right range. For example, if existing test intervals are not in, say, the 30% range, assessments might be done to determine the reasons why. Along this same line of reasoning, a test interval change would be allowed if it caused no greater than 30% increase in the unavailability and if assessments showed no other deleterious effects from the change. In actual application, the percentage value to be used would depend on size of data uncertainties and importance of the component to system availability.

UNCERTAINTIES IN LAMDA (λ) and TAU (τ)

Oftentimes, we do not know the precise value of λ or τ. In these cases, Tables 1-11 or Tables 12-22 can be used to find ranges on the optimal test interval. For example, suppose our best estimates are τ=4 hrs. and $\lambda = 3 \times 10^{-6}$/hr. We know τ fairly precisely based on test data; but, we do not know λ within a factor of 3 of the best estimate, i.e., λ could be between 1×10^{-6}/hr and 1×10^{-5}/hr.

From Table 4, using our best estimates, the optimal test interval is 1633 hours (approximately 2¼ months). Using the lower bound failure rate of 1x10^{-6}/hr we find from Table 5 that the optimal test interval is 2828 hours (about 4 months). Using the upper bound failure rate of 1x10^{-5}/hr, we find the optimal test interval from Table 3 to be 894 hours (about 1¼ months). Thus the range on the optimal test interval, due to the failure rate uncertainty, is from 894 hours to 2828 hours or from about 1¼ months to 2¼ months. Even with the failure rate uncertainty we see that we should be testing about every one or two months and not, say, every year. This degree of precision would be adequate for many decisions. As an alternative, to be conservative and to guard against the possibility of the high failure rate of 1x10^{-5}/hr, we could also use 894 hours (rounded to say 1 month) as the test interval.

As a different approach to handling the uncertainty, we could use the best estimate test interval of 1633 hours and use Tables 12-22 to see how much the unavailability is degraded if we had different failure rates. Referring to Table 14 for λ = 1x10^{-5}/hr we see that 1633 hours lies within the 20% range so that the unavailability is increased by no more than 20% if we used 1633 hours (2¼ months) and λ = 1x10^{-5}/hr. This analysis again shows that the unavailability is relatively insensitive to the exact testing interval we use, as long as, it is in the vicinity of the optimal value.

The above examples deal with uncertainties in the failure rate. However, uncertainties in the test time and uncertainties in both the failure rate and test time can be handled in a similar manner.* As extensions, we can also assign probability distributions to the failure rate and/or test time and obtain the probability distribution for the

---

*For example, for both failure rate and test time uncertainties from Eq. 3, conservative lower bound on the test interval could be computed using the lower bound in the test time and upper bound in the failure rate.

optimal test interval. The probability distribution approach would be useful if failure rate and test time uncertainties were of the same order and if simplistic conservative applications (such as in the fo[illegible]te in the preceding page) gave a large unworkable range. The probability distribution approach would also be useful if decision-theoretic approaches were being used. These extensions, however, are beyond the scope of this report.

TABLE 1

Optimum Test Intervals and Component Unavailability

OUTAGE TIME,HRS	TOPT	QOPT
0.10	45.	0.004472
0.25	71.	0.007071
0.50	100.	0.010000
1.00	141.	0.014142
2.00	200.	0.020000
4.00	283.	0.028284
6.00	346.	0.034641
8.00	400.	0.040000
10.00	447.	0.044721

LAMDA = 1.0E-04

TABLE 2

Optimum Test Intervals and Component Unavailability

OUTAGE TIME, HRS	TOPT	QOPT
0.10	82.	0.002449
0.25	129.	0.003873
0.50	183.	0.005477
1.00	258.	0.007746
2.00	365.	0.010954
4.00	516.	0.015492
6.00	632.	0.018974
8.00	730.	0.021909
10.00	816.	0.024495

LAMDA = 3.0E-05

TABLE 3

Optimum Test Intervals and Component Unavailability

OUTAGE TIME,HRS	TOPT	QOPT
0.10	141.	0.001414
0.25	224.	0.002236
0.50	316.	0.003162
1.00	447.	0.004472
2.00	632.	0.006325
4.00	894.	0.008944
6.00	1095.	0.010954
8.00	1265.	0.012649
10.00	1414.	0.014142

LAMDA = 1.0E-05

TABLE 4

Optimum Test Intervals and Component Unavailability

OUTAGE TIME, HRS	TOPT	QOPT
0.10	258.	0.000775
0.25	408.	0.001225
0.50	577.	0.001732
1.00	816.	0.002449
2.00	1155.	0.003464
4.00	1633.	0.004899
6.00	2000.	0.006000
8.00	2309.	0.006928
10.00	2582.	0.007746

LAMDA = 3.0E-06

TABLE 5

Optimum Test Intervals and Component Unavailability

OUTAGE TIME,HRS	TOPT	QOPT
0,10	447.	0.000447
0,25	707.	0.000707
0,50	1000.	0.001000
1,00	1414.	0.001414
2,00	2000.	0.002000
4,00	2828.	0.002828
6,00	3464.	0.003464
8,00	4000.	0.004000
10,00	4472.	0.004472

LAMDA = 1.0E-06

TABLE 6

Optimum Test Intervals and Component Unavailability

OUTAGE TIME,HRS	TOPT	QOPT
0.10	816.	0.000245
0.25	1291.	0.000387
0.50	1826.	0.000548
1.00	2582.	0.000775
2.00	3651.	0.001095
4.00	5164.	0.001549
6.00	6325.	0.001897
8.00	7303.	0.002191
10.00	8165.	0.002449

LAMDA = 3.0E-07

TABLE 7

Optimum Test Intervals and Component Unavailability

OUTAGE TIME, HRS	TOPT	QOPT
0.10	1414.	0.000141
0.25	2236.	0.000224
0.50	3162.	0.000316
1.00	4472.	0.000447
2.00	6325.	0.000632
4.00	8944.	0.000894
6.00	10954.	0.001095
8.00	12649.	0.001265
10.00	14142.	0.001414

LAMDA = 1.0E-07

TABLE 8

Optimum Test Intervals and Component Unavailability

OUTAGE TIME, HRS	TOPT	QOPT
0.10	2582.	0.000077
0.25	4082.	0.000122
0.50	5774.	0.000173
1.00	8165.	0.000245
2.00	11547.	0.000346
4.00	16330.	0.000490
6.00	20000.	0.000600
8.00	23094.	0.000693
10.00	25820.	0.000775

LAMDA = 3.0E-08

TABLE 9

Optimum Test Intervals and Component Unavailability

OUTAGE TIME,HRS	TOPT	QOPT
0,10	4472.	0.000045
0,25	7071.	0.000071
0,50	10000.	0.000100
1,00	14142.	0.000141
2,00	20000.	0.000200
4,00	28284.	0.000283
6,00	34641.	0.000346
8,00	40000.	0.000400
10,00	44721.	0.000447

LAMDA = 1.0E-08

Table 10

Optimum Test Intervals and Component Unavailability

OUTAGE TIME.HRS	TOPT	QOPT
0.10	8165.	0.000024
0.25	12910.	0.000039
0.50	18257.	0.000055
1.00	25820.	0.000077
2.00	36515.	0.000110
4.00	51640.	0.000155
6.00	63246.	0.000190
8.00	73030.	0.000219
10.00	81650.	0.000245

LANDA = 3.0E-09

TABLE 11

Optimum Test Intervals and Component Unavailability

OUTAGE TIME,HRS	TOPT	QOPT
0,10	14142.	0.000014
0,25	22361.	0.000022
0,50	31623.	0.000032
1,00	44721.	0.000045
2,00	63246.	0.000063
4,00	89443.	0.000089
6,00	109545.	0.000110
8,00	126491.	0.000126
10,00	141421.	0.000141

LAMDA = 1.0E-09

TABLE 12

Optimum Test Intervals; Test Intervals Bounds That Result In 10%, 20% and 30%.
Component Average Unavailability Degradation From Optimum.

OUTAGE TIME,HRS (TAU) 1	TIME BETWEEN OUTAGE,HRS						
	2	10% DEGRADATION 3		20% DEGRADATION 4		30% DEGRADATION 5	
	TOPT	TMIN	TMAX	TMIN	TMAX	TMIN	TMAX
0.10	45.	29.	70.	24.	83.	21.	95.
0.25	71.	45.	110.	38.	132.	33.	151.
0.50	100.	64.	156.	54.	186.	47.	213.
1.00	141.	91.	220.	76.	264.	66.	301.
2.00	200.	128.	312.	107.	373.	94.	426.
4.00	283.	182.	441.	152.	527.	133.	603.
6.00	346.	222.	540.	186.	645.	163.	738.
8.00	400.	257.	623.	215.	745.	188.	852.
10.00	447.	287.	697.	240.	833.	210.	953.

Component Failure Rate

LAMDA = 1.0E-04

TABLE 13

Optimum Test Intervals; Test Intervals Bounds That Result In 10%, 20% and 30%. Component Average Unavailability Degradation From Optimum.

OUTAGE TIME, HRS (TAU) 1	TIME BETWEEN OUTAGE, HRS						
	TOPT 2	10% DEGRADATION 3		20% DEGRADATION 4		30% DEGRADATION 5	
		TMIN	TMAX	TMIN	TMAX	TMIN	TMAX
0.10	82.	52.	127.	44.	152.	38.	174.
0.25	129.	83.	201.	69.	241.	61.	275.
0.50	183.	117.	284.	98.	340.	86.	389.
1.00	258.	166.	402.	139.	481.	121.	550.
2.00	365.	234.	569.	196.	680.	171.	778.
4.00	516.	331.	805.	277.	962.	242.	1100.
6.00	632.	406.	986.	339.	1178.	297.	1348.
8.00	730.	469.	1138.	392.	1361.	343.	1556.
10.00	816.	524.	1272.	438.	1521.	383.	1740.

Component Failure Rate

LAMDA = 3.0E-05

TABLE 14

Optimum Test Intervals; Test Intervals Bounds That Result In 10%, 20% and 30%. Component Average Unavailability Degradation From Optimum.

OUTAGE TIME, HRS (TAU) 1	TIME BETWEEN OUTAGE, HRS						
	TOPT 2	10% DEGRADATION 3		20% DEGRADATION 4		30% DEGRADATION 5	
		TMIN	TMAX	TMIN	TMAX	TMIN	TMAX
0.10	141.	91.	220.	76.	264.	66.	301.
0.25	224.	143.	348.	120.	417.	105.	476.
0.50	316.	203.	493.	170.	589.	148.	674.
1.00	447.	287.	697.	240.	833.	210.	953.
2.00	632.	406.	986.	339.	1178.	297.	1348.
4.00	894.	574.	1394.	480.	1667.	420.	1906.
6.00	1095.	703.	1707.	588.	2041.	514.	2334.
8.00	1265.	812.	1971.	679.	2357.	594.	2695.
10.00	1414.	908.	2204.	759.	2635.	664.	3013.

Component Failure Rate

LAMDA = 1.0E-05

TABLE 15

Optimum Test Intervals; Test Intervals Bounds That Result In 10%, 20% and 30%.
Component Average Unavailability Degradation From Optimum.

OUTAGE TIME, HRS (TAU) [1]	TIME BETWEEN OUTAGE, HRS: TOPT [2]	10% DEGRADATION [3]: TMIN	10% DEGRADATION [3]: TMAX	20% DEGRADATION [4]: TMIN	20% DEGRADATION [4]: TMAX	30% DEGRADATION [5]: TMIN	30% DEGRADATION [5]: TMAX
0.10	258.	166.	402.	139.	481.	121.	550.
0.25	408.	262.	636.	219.	761.	192.	870.
0.50	577.	371.	900.	310.	1076.	271.	1230.
1.00	816.	524.	1272.	438.	1521.	383.	1740.
2.00	1155.	741.	1799.	620.	2152.	542.	2460.
4.00	1633.	1048.	2545.	876.	3043.	766.	3479.
6.00	2000.	1283.	3117.	1073.	3727.	939.	4261.
8.00	2309.	1482.	3599.	1239.	4303.	1084.	4921.
10.00	2582.	1657.	4023.	1386.	4811.	1212.	5501.

Component Failure Rate

LAMDA = 3.0E-06

TABLE 16

Optimum Test Intervals; Test Intervals Bounds That Result In 10%, 20% and 30%.
Component Average Unavailability Degradation From Optimum.

OUTAGE TIME, HRS (TAU) 1	TIME BETWEEN OUTAGE, HRS						
	2	10% DEGRADATION 3		20% DEGRADATION 4		30% DEGRADATION 5	
	TOPT	TMIN	TMAX	TMIN	TMAX	TMIN	TMAX
0.10	447.	287.	697.	240.	833.	210.	953.
0.25	707.	454.	1102.	379.	1318.	332.	1507.
0.50	1000.	642.	1558.	537.	1863.	469.	2131.
1.00	1414.	908.	2204.	759.	2635.	664.	3013.
2.00	2000.	1283.	3117.	1073.	3727.	939.	4261.
4.00	2828.	1815.	4407.	1518.	5270.	1327.	6026.
6.00	3464.	2223.	53[illegible]8.	1859.	6455.	1626.	7381.
8.00	4000.	2567.	6233.	2147.	7453.	1877.	8523.
10.00	4472.	2870.	6959.	2400.	8333.	2099.	9529.

<u>Component Failure Rate</u>

LAMDA = 1.0E-06

TABLE 17

Optimum Test Intervals; Test Intervals Bounds That Result In 10%, 20% and 30%. Component Average Unavailability Degradation From Optimum.

OUTAGE TIME, HRS (TAU) 1	TIME BETWEEN OUTAGE, HRS						
	2	10% DEGRADATION 3		20% DEGRADATION 4		30% DEGRADATION 5	
	TOPT	TMIN	TMAX	TMIN	TMAX	TMIN	TMAX
0.10	816.	524.	1272.	438.	1521.	383.	1740.
0.25	1291.	828.	2012.	693.	2406.	606.	2751.
0.50	1826.	1172.	2845.	980.	3402.	857.	3890.
1.00	2582.	1657.	4023.	1386.	4811.	1212.	5501.
2.00	3651.	2343.	5690.	1960.	6804.	1714.	7780.
4.00	5164.	3314.	8047.	2771.	9622.	2424.	11003.
6.00	6325.	4059.	9855.	3394.	11785.	2968.	13475.
8.00	7303.	4687.	11380.	3919.	13606.	3428.	15560.
10.00	8165.	5240.	12723.	4382.	15214.	3832.	17397.

Component Failure Rate

LAMDA = 3.0E-07

TABLE 18

Optimum Test Intervals; Test Intervals Bounds That Result In 10%, 20% and 30%.
Component Average Unavailability Degradation From Optimum.

OUTAGE TIME, HRS (TAU) 1	TIME BETWEEN OUTAGE, HRS						
	TOPT 2	10% DEGRADATION TMIN	10% DEGRADATION TMAX 3	20% DEGRADATION TMIN	20% DEGRADATION TMAX 4	30% DEGRADATION TMIN	30% DEGRADATION TMAX 5
0.10	1414.	908.	2204.	759.	2635.	664.	3013.
0.25	2236.	1435.	3484.	1200.	4167.	1049.	4764.
0.50	3162.	2029.	4928.	1697.	5892.	1484.	6738.
1.00	4472.	2870.	6969.	2400.	8333.	2099.	9529.
2.00	6325.	4059.	9855.	3394.	11785.	2968.	13475.
4.00	8944.	5740.	13937.	4800.	16666.	4198.	19057.
6.00	10954.	7030.	17070.	5879.	20412.	5141.	23340.
8.00	12649.	8117.	19711.	6788.	23569.	5937.	26951.
10.00	14142.	9076.	22037.	7590.	26351.	6637.	30132.

Component Failure Rate

LAMDA = 1.0E-07

TABLE 19

Optimum Test Intervals; Test Intervals Bounds That Result In 10%, 20% and 30%.
Component Average Unavailability Degradation From Optimum.

OUTAGE TIME, HRS	TIME BETWEEN OUTAGE, HRS						
1	2	10% DEGRADATION 3		20% DEGRADATION 4		30% DEGRADATION 5	
(TAU)	TOPT	TMIN	TMAX	TMIN	TMAX	TMIN	TMAX
0.10	2582.	1657.	4023.	1386.	4811.	1212.	5501.
0.25	4082.	2620.	6362.	2191.	7607.	1916.	8698.
0.50	5774.	3705.	8997.	3098.	10758.	2710.	12301.
1.00	8165.	5240.	12723.	4382.	15214.	3832.	17397.
2.00	11547.	7410.	17993.	6197.	21516.	5419.	24603.
4.00	16330.	10480.	25446.	8764.	30428.	7664.	34794.
6.00	20000.	12835.	31165.	10734.	37266.	9387.	42613.
8.00	23094.	14320.	35986.	12394.	43032.	10839.	49206.
10.00	25820.	16570.	40234.	13857.	48111.	12118.	55013.

Component Failure Rate

LAMDA = 3.0E-08

TABLE 20

Optimum Test Intervals; Test Intervals Bounds That Result In 10%, 20% and 30%.
Component Average Unavailability Degradation From Optimum.

OUTAGE TIME, HRS (TAU) 1	TIME BETWEEN OUTAGE, HRS						
	TOPT 2	10% DEGRADATION 3		20% DEGRADATION 4		30% DEGRADATION 5	
		TMIN	TMAX	TMIN	TMAX	TMIN	TMAX
0.10	4472.	2870.	6969.	2400.	8333.	2099.	9529.
0.25	7071.	4536.	11019.	3795.	13176.	3319.	15066.
0.50	10000.	6417.	15583.	5367.	18633.	4693.	21307.
1.00	14142.	9076.	22037.	7590.	26351.	6637.	30132.
2.00	20000.	12835.	31165.	10734.	37266.	9387.	42613.
4.00	28284.	18151.	44074.	15179.	52703.	13275.	60264.
6.00	34641.	22231.	53980.	18591.	64547.	16258.	73808.
8.00	40000.	25670.	62330.	21467.	74533.	18774.	85226.
10.00	44721.	28700.	69687.	24001.	83330.	20989.	95286.

Component Failure Rate

LAMDA = 1.0E-08

TABLE 21

Optimum Test Intervals; Test Intervals Bounds That Result In 10%, 20% and 30%. Component Average Unavailability Degradation From Optimum.

OUTAGE TIME, HRS	TIME BETWEEN OUTAGE, HRS						
	1	2		3		4	
		10% DEGRADATION		20% DEGRADATION		30% DEGRADATION	
(TAU)	TOPT	TMIN	TMAX	TMIN	TMAX	TMIN	TMAX
0.10	8165.	5240.	12723.	4382.	15214.	3832.	17397.
0.25	12910.	8285.	20117.	6928.	24055.	6059.	27507.
0.50	18257.	11717.	28450.	9798.	34020.	8569.	38900.
1.00	25820.	16570.	40234.	13857.	48111.	12118.	55013.
2.00	36515.	23433.	56900.	19597.	68039.	17138.	77801.
4.00	51640.	33139.	80468.	27714.	96222.	24236.	110027.
6.00	63246.	40587.	98553.	33942.	117847.	29684.	134755.
8.00	73030.	46666.	113799.	39193.	136078.	34276.	155602.
10.00	81650.	52398.	127231.	43819.	152140.	38321.	173968.

Component Failure Rate

LAMDA = 3.0E-09

TABLE 22

Optimum Test Intervals; Test Intervals Bounds That Result In 10%, 20% and 30%.
Component Average Unavailability Degradation From Optimum.

OUTAGE TIME,HRS (TAU) 1	TIME BETWEEN OUTAGE,HRS TOPT 2	10% DEGRADATION 3 TMIN	10% DEGRADATION 3 TMAX	20% DEGRADATION 4 TMIN	20% DEGRADATION 4 TMAX	30% DEGRADATION 5 TMIN	30% DEGRADATION 5 TMAX
0.10	14142.	9076.	22037.	7590.	26351.	6637.	30132.
0.25	22361.	14350.	34844.	12000.	41665.	10495.	47643.
0.50	31623.	20294.	49276.	16971.	58924.	14842.	67377.
1.00	44721.	28700.	69687.	24001.	83330.	20989.	95286.
2.00	63246.	40587.	98553.	33942.	117847.	29684.	134755.
4.00	89443.	57399.	139375.	48002.	166661.	41979.	190572.
6.00	109545.	70299.	170699.	58790.	204117.	51413.	233402.
8.00	126491.	81175.	197106.	67885.	235694.	59367.	269510.
10.00	141421.	90756.	220371.	75897.	263514.	66374.	301321.

Component Failure Rate

LAMDA = 1.0E-09

FIGURE 1

AVERAGE COMPONENT UNAVAILABILITY VERSUS TIME BETWEEN TESTS
PARAMETRIC WITH COMPONENT FAILURE RATE, λ (FAILURES/HR)

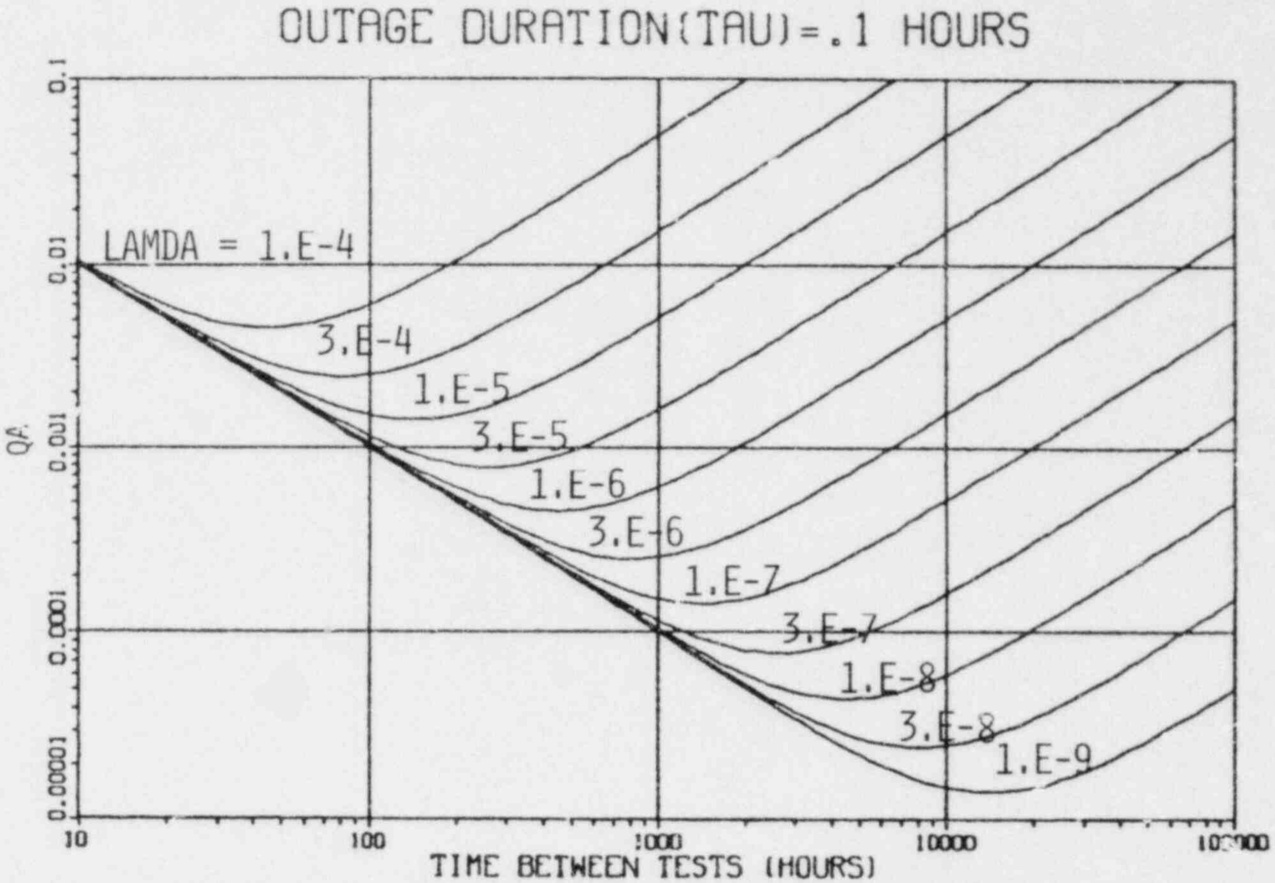


FIGURE 2

AVERAGE COMPONENT UNAVAILABILITY VERSUS TIME BETWEEN TESTS
PARAMETRIC WITH COMPONENT FAILURE RATE, λ (FAILURES/HR)

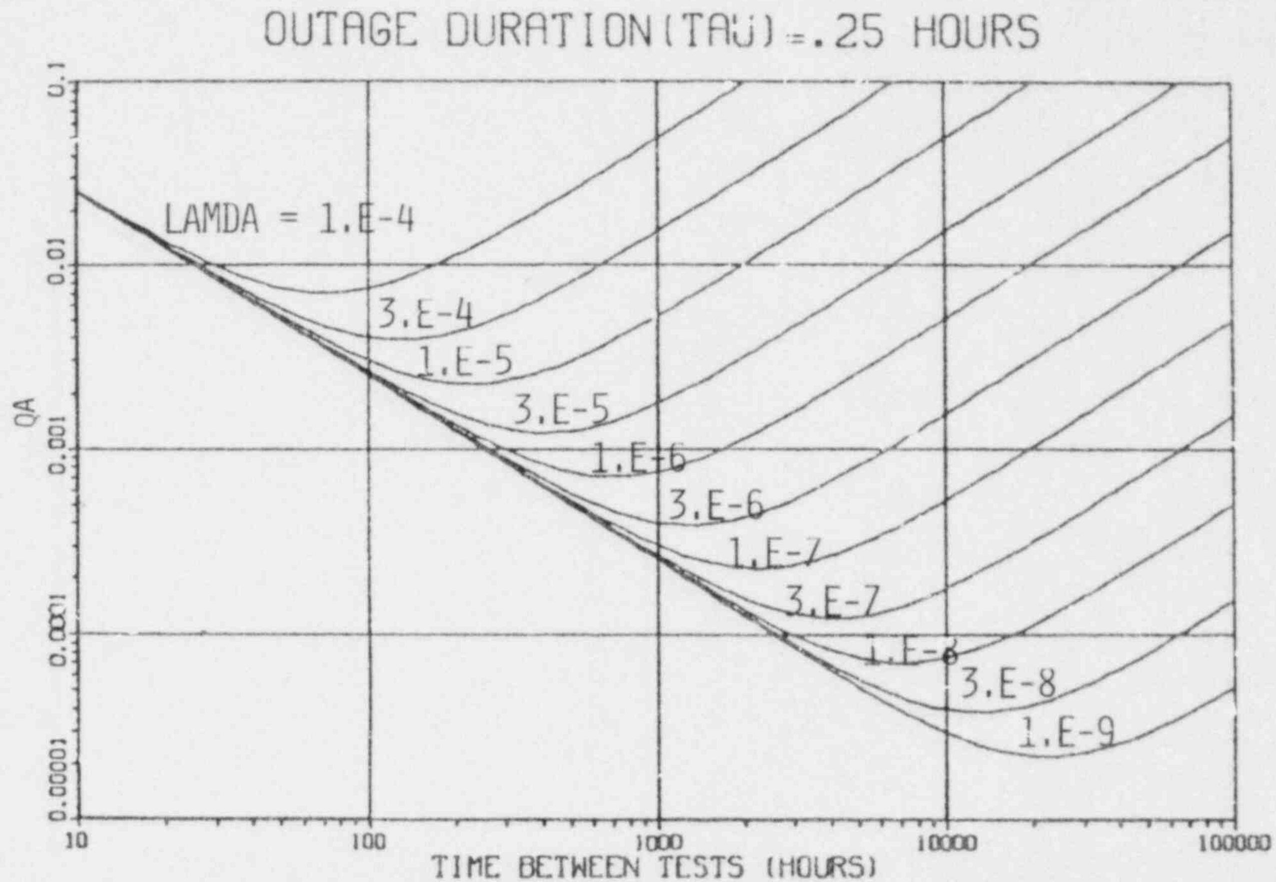


FIGURE 3

AVERAGE COMPONENT UNAVAILABILITY VERSUS TIME BETWEEN TESTS
PARAMETRIC WITH COMPONENT FAILURE RATE, λ (FAILURES/HR)

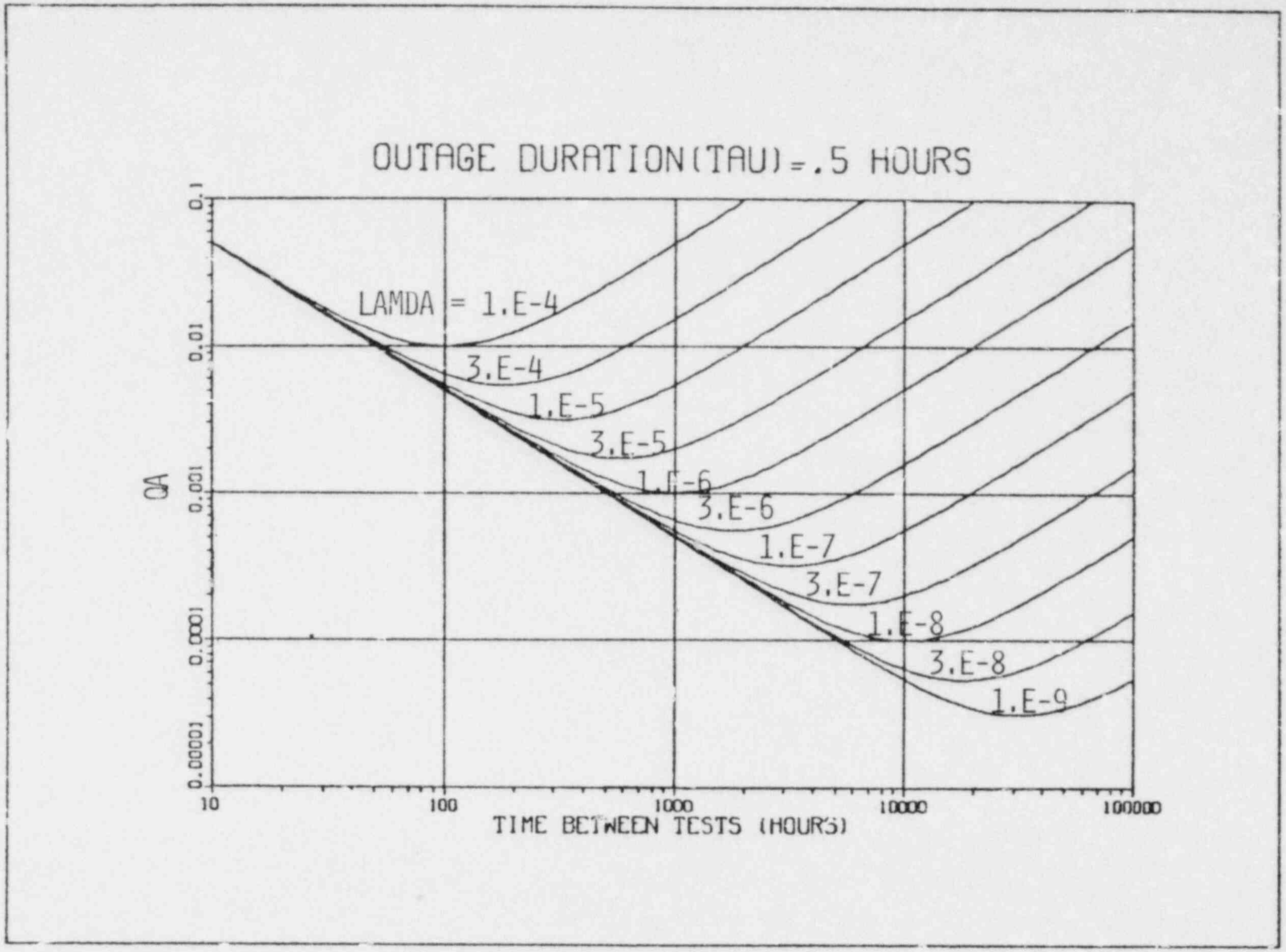


FIGURE 4

AVERAGE COMPONENT UNAVAILABILITY VERSUS TIME BETWEEN TESTS
PARAMETRIC WITH COMPONENT FAILURE RATE, λ (FAILURES/HR)

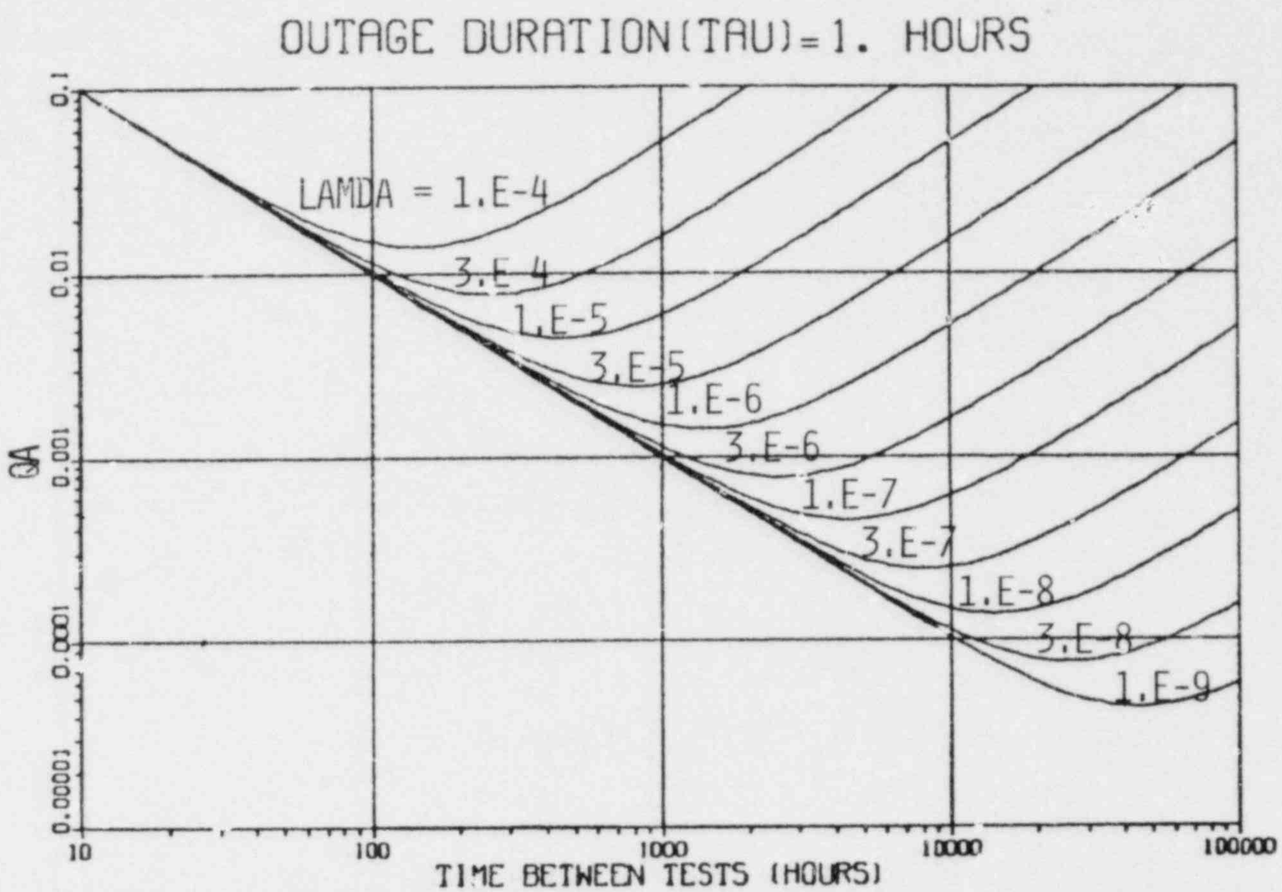


FIGURE 5

AVERAGE COMPONENT UNAVAILABILITY VERSUS TIME BETWEEN TESTS
PARAMETRIC WITH COMPONENT FAILURE RATE, λ (FAILURES/HR)

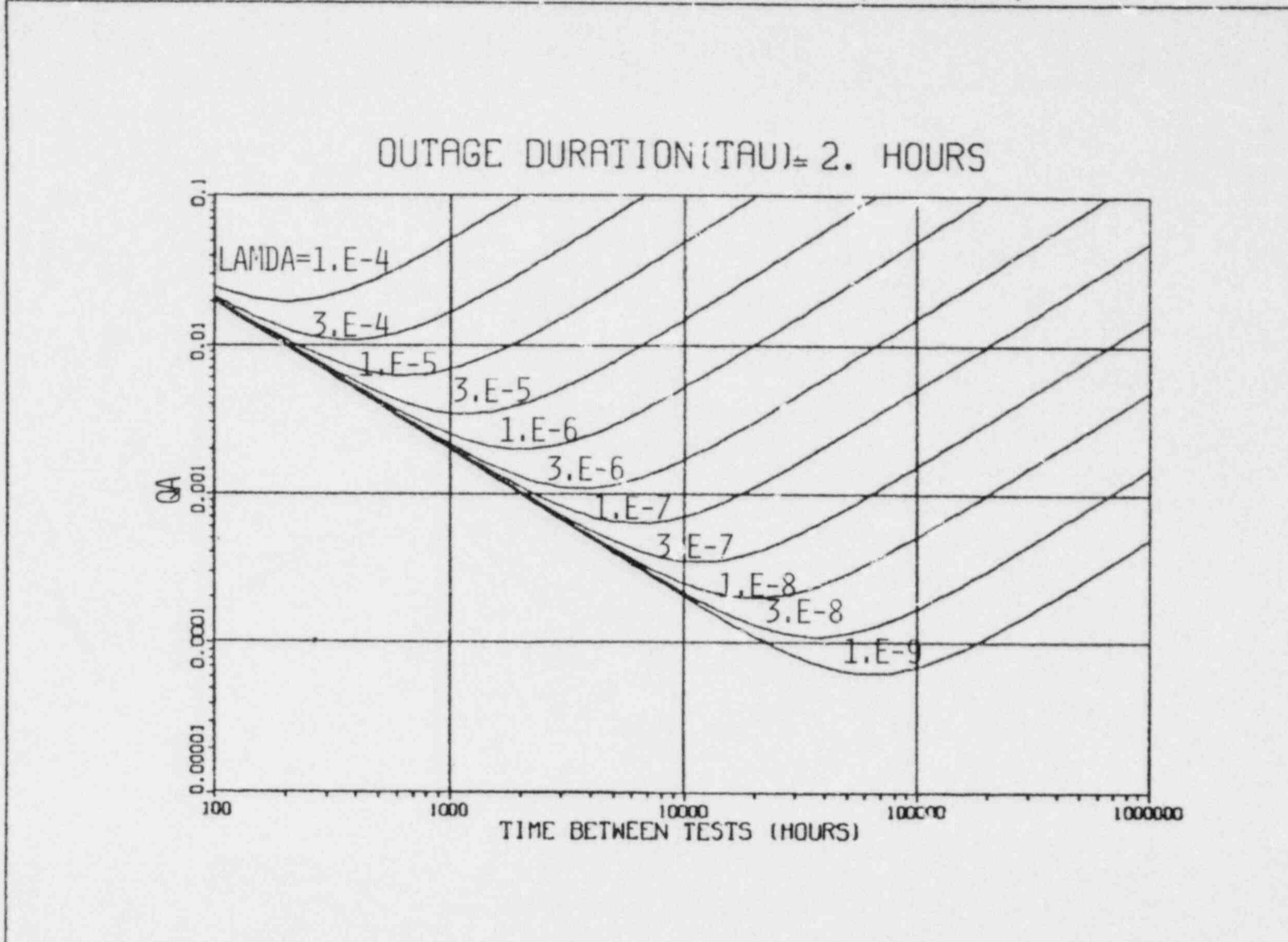


FIGURE 6

AVERAGE COMPONENT UNAVAILABILITY VERSUS TIME BETWEEN TESTS
PARAMETRIC WITH COMPONENT FAILURE RATE, λ (FAILURES/HR)

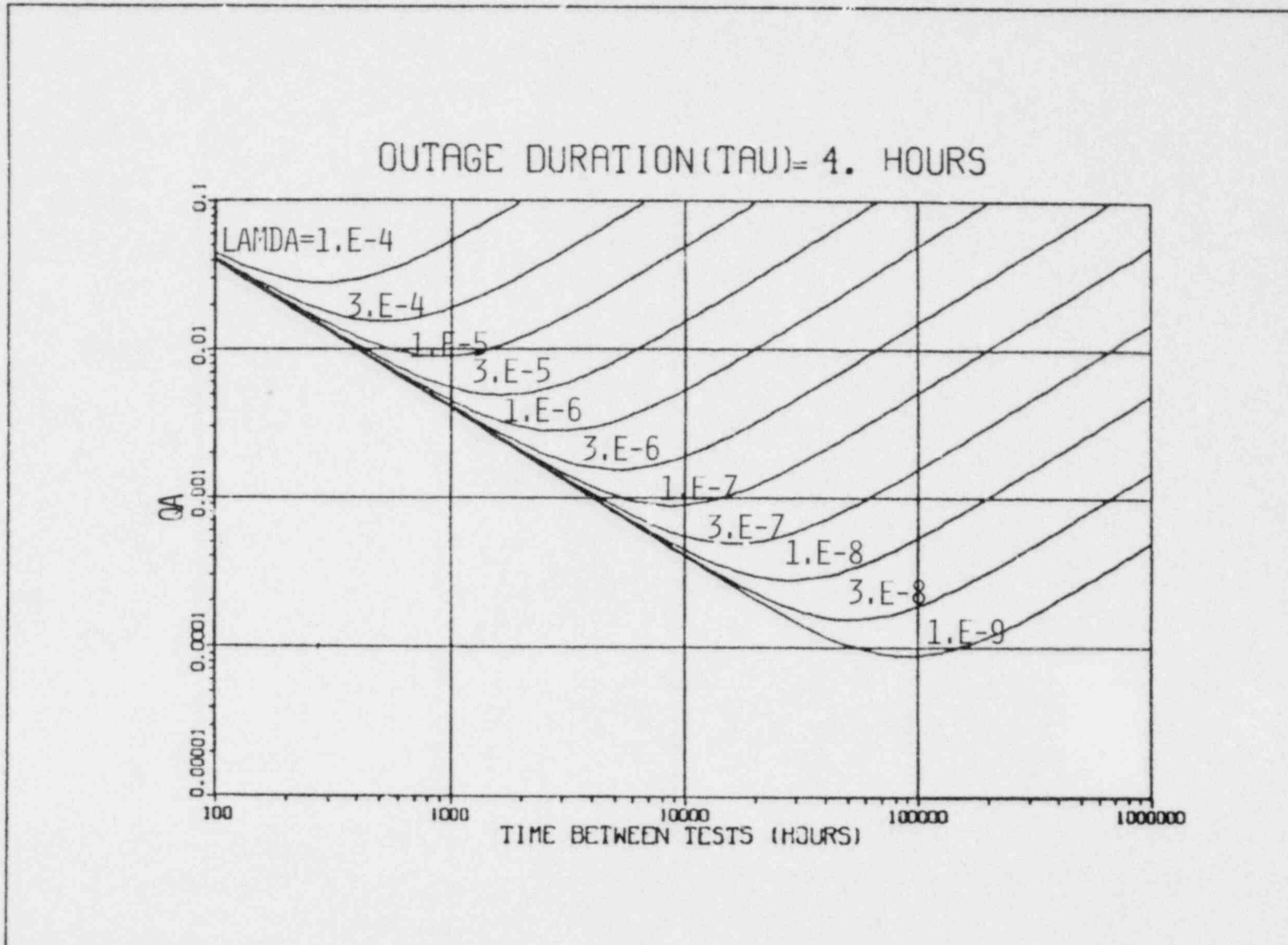


FIGURE 7

AVERAGE COMPONENT UNAVAILABILITY VERSUS TIME BETWEEN TESTS
PARAMETRIC WITH COMPONENT FAILURE RATE, λ (FAILURES/HR)

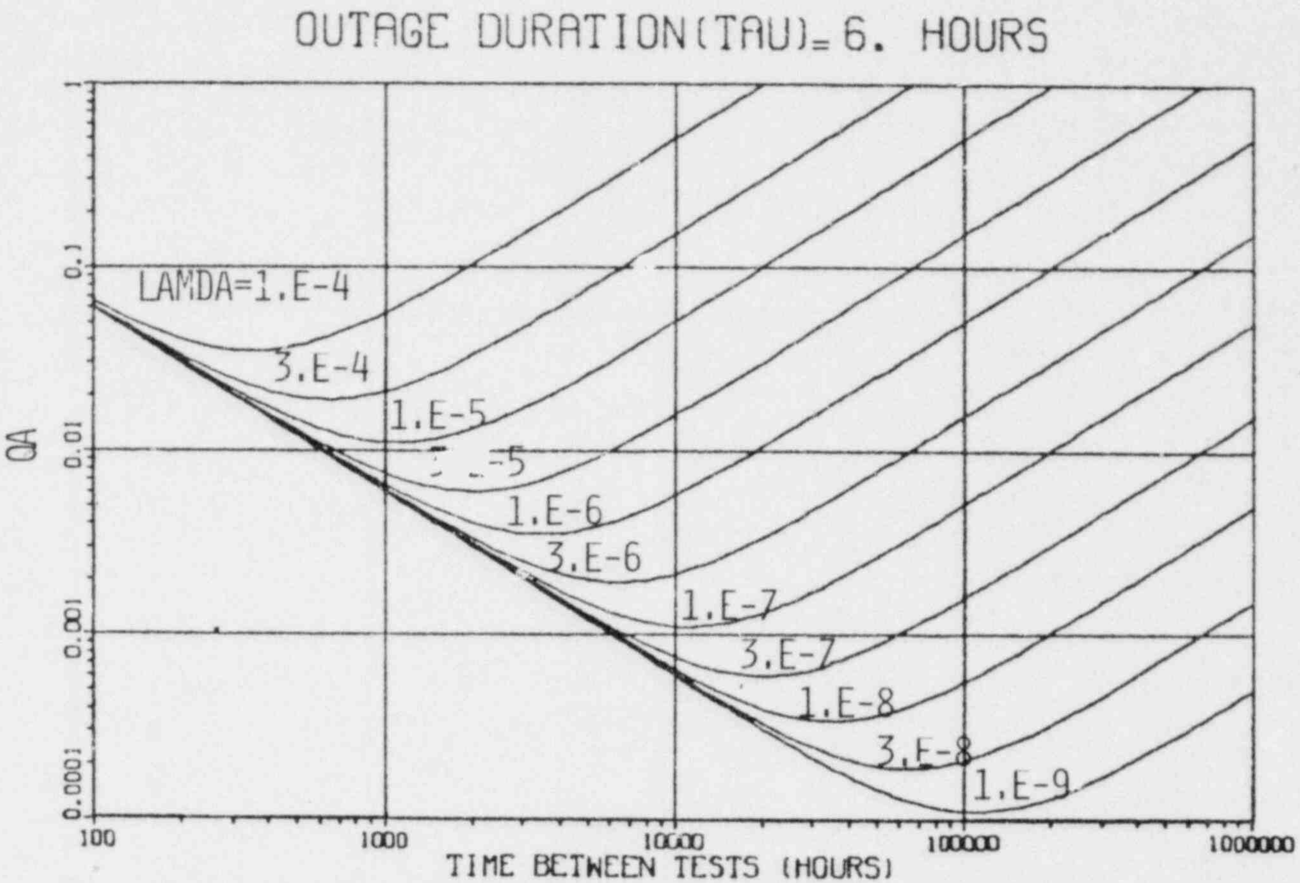


FIGURE 8

AVERAGE COMPONENT UNAVAILABILITY VERSUS TIME BETWEEN TESTS
PARAMETRIC WITH COMPONENT FAILURE RATE, λ (FAILURES/HR)

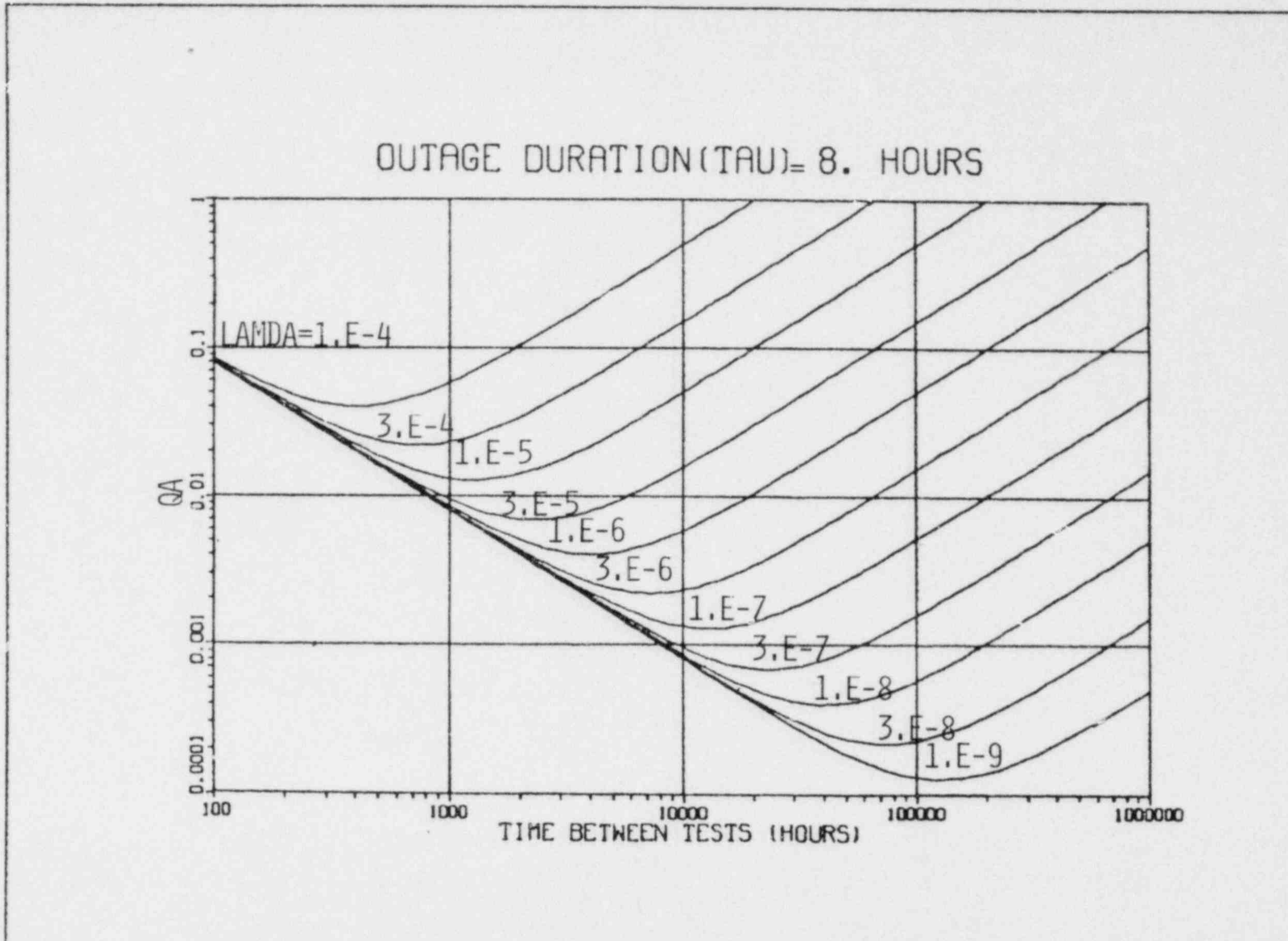


FIGURE 9

AVERAGE COMPONENT UNAVAILABILITY VERSUS TIME BETWEEN TESTS
PARAMETRIC WITH COMPONENT FAILURE RATE, λ (FAILURES/HR)

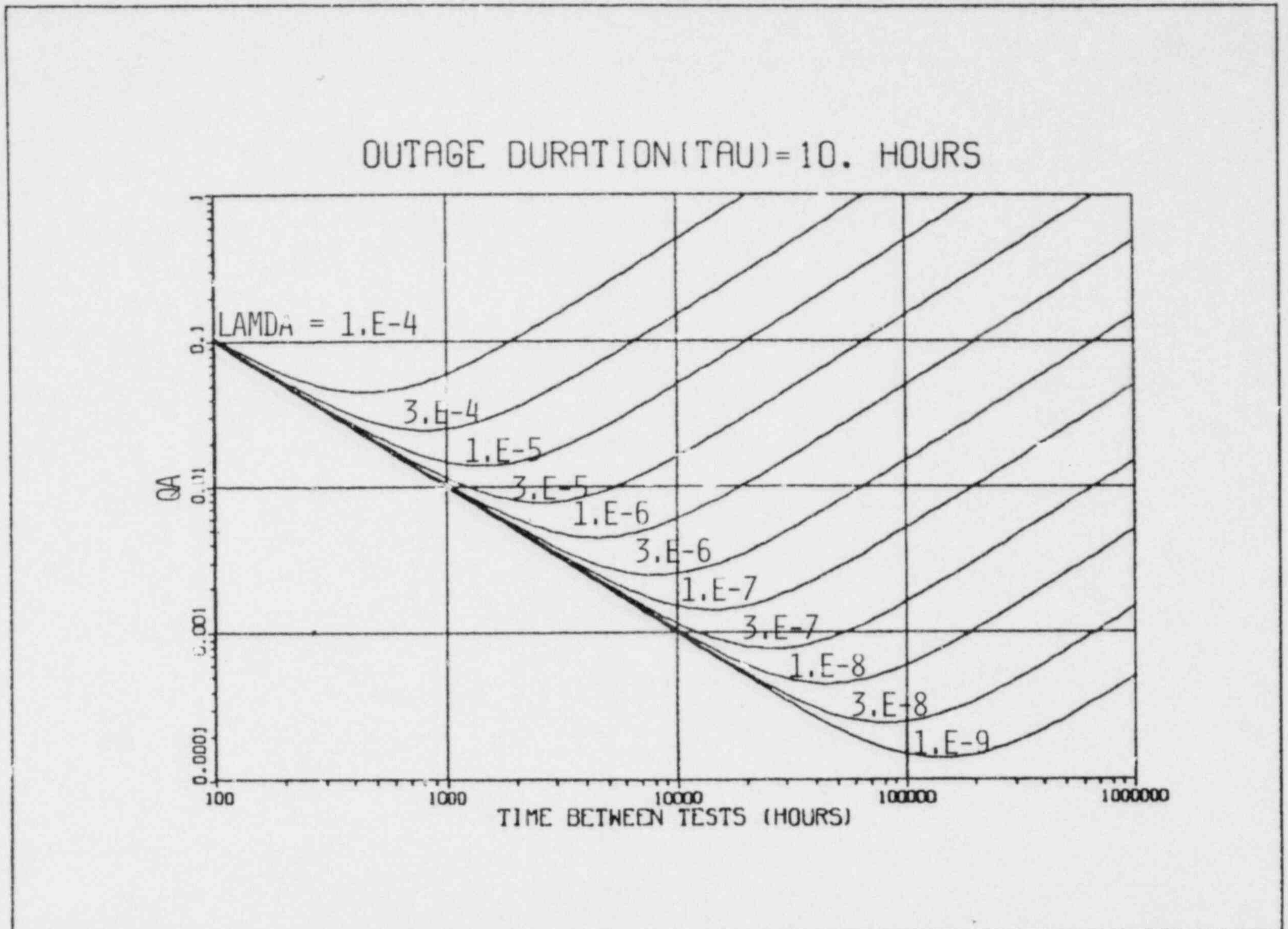


FIGURE 10

AVERAGE COMPONENT UNAVAILABILITY VERSUS TIME BETWEEN TESTS
PARAMETRIC WITH OUTAGE DURATION, τ (HOURS)

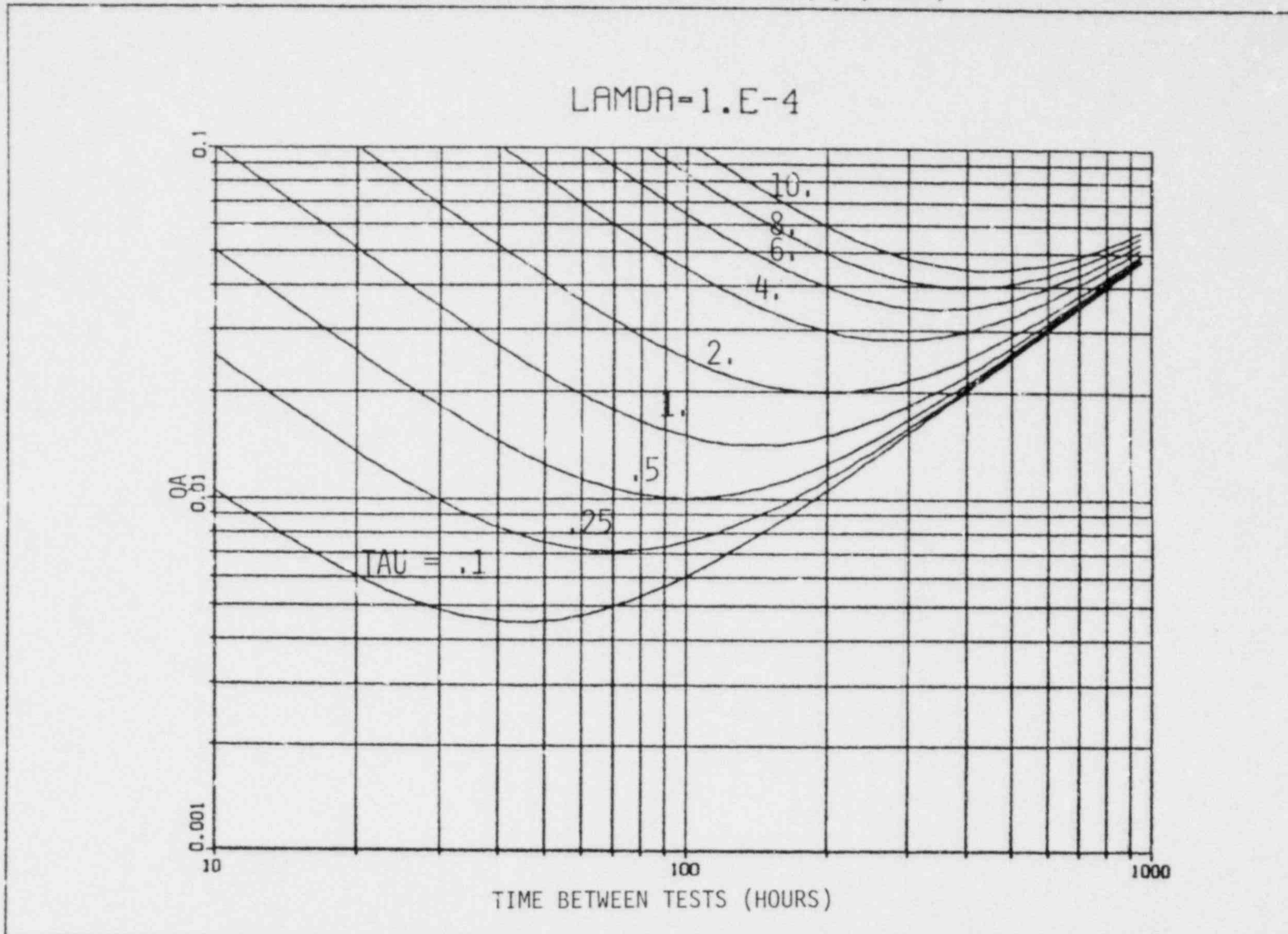


FIGURE 11

AVERAGE COMPONENT UNAVAILABILITY VERSUS TIME BETWEEN TESTS
PARAMETRIC WITH OUTAGE DURATION, - (HOURS)

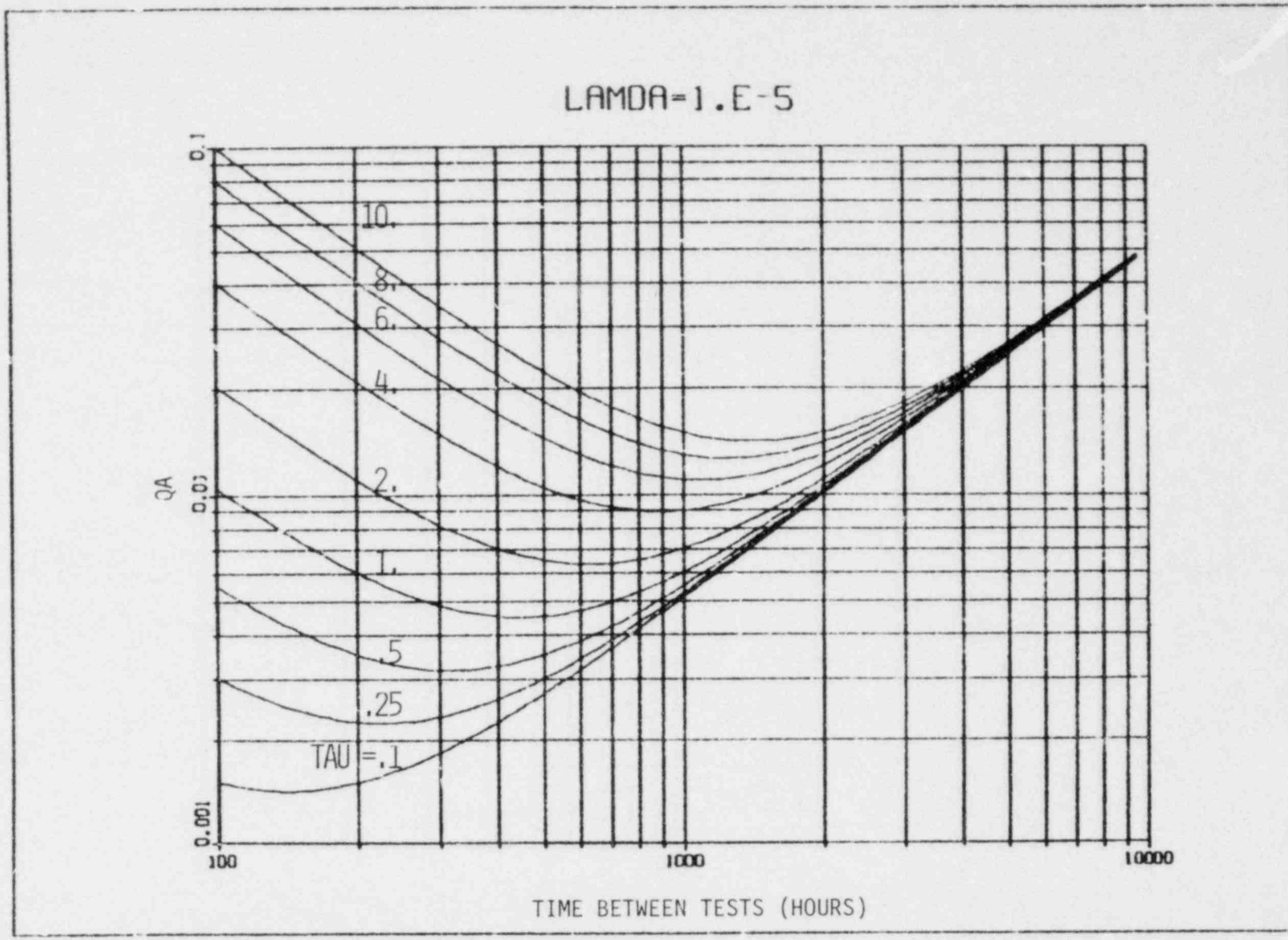


FIGURE 12

AVERAGE COMPONENT UNAVAILABILITY VERSUS TIME BETWEEN TESTS
PARAMETRIC WITH OUTAGE DURATION, τ (HOURS)

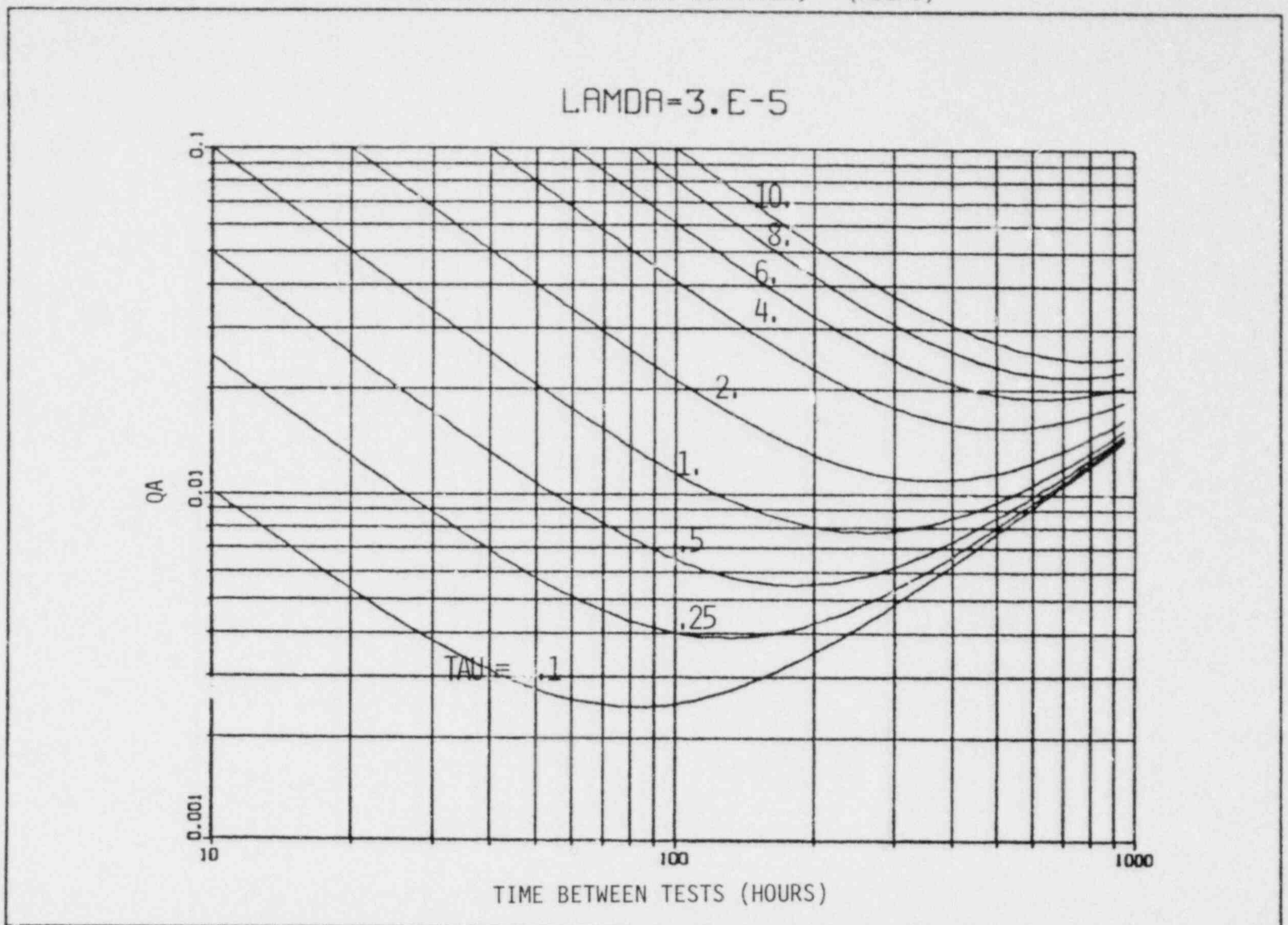


FIGURE 13

AVERAGE COMPONENT UNAVAILABILITY VERSUS TIME BETWEEN TESTS
PARAMETRIC WITH OUTAGE DURATION, τ (HOURS)

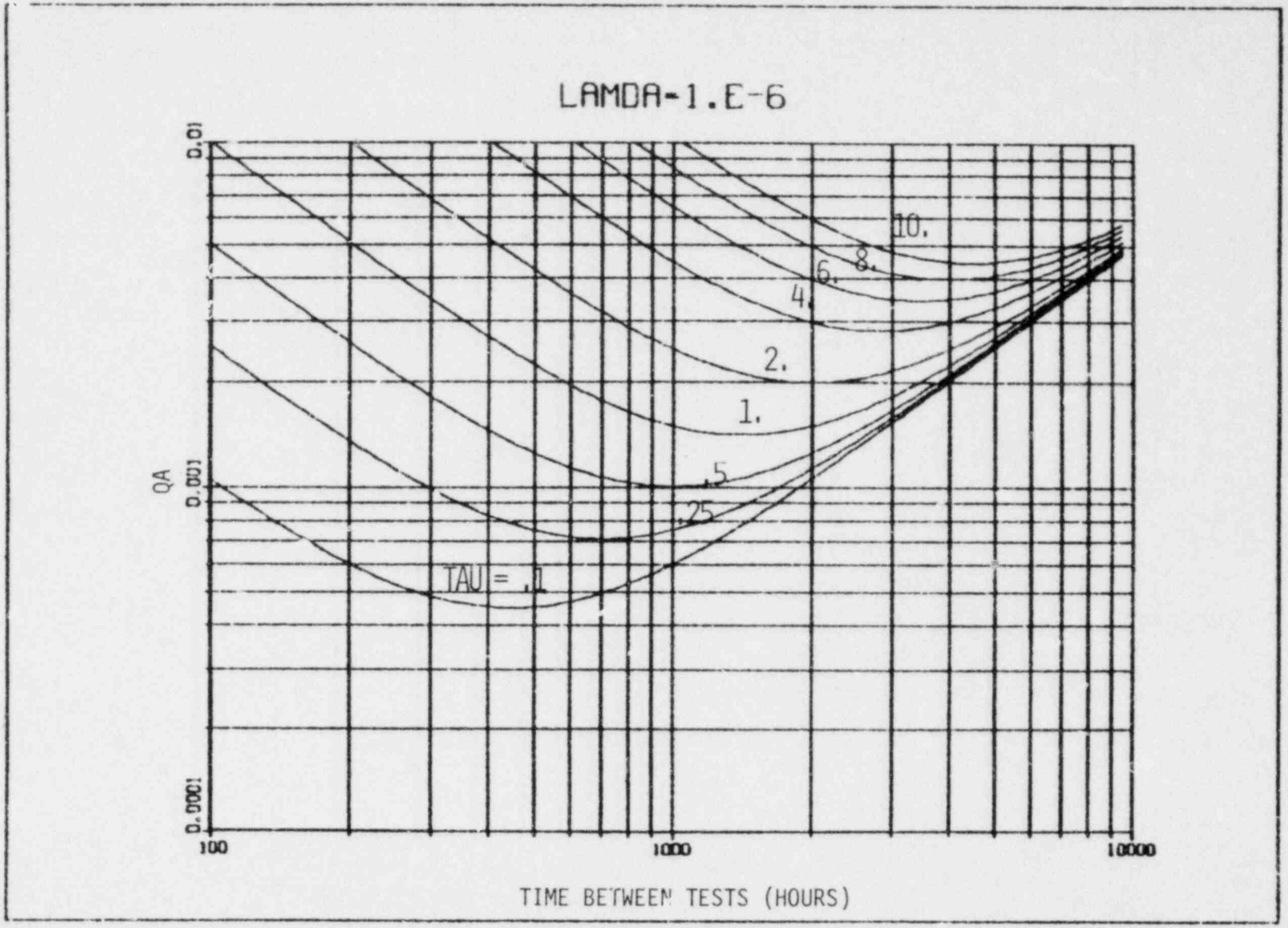


FIGURE 14

AVERAGE COMPONENT UNAVAILABILITY VERSUS TIME BETWEEN TESTS
PARAMETRIC WITH OUTAGE DURATION, τ (HOURS)

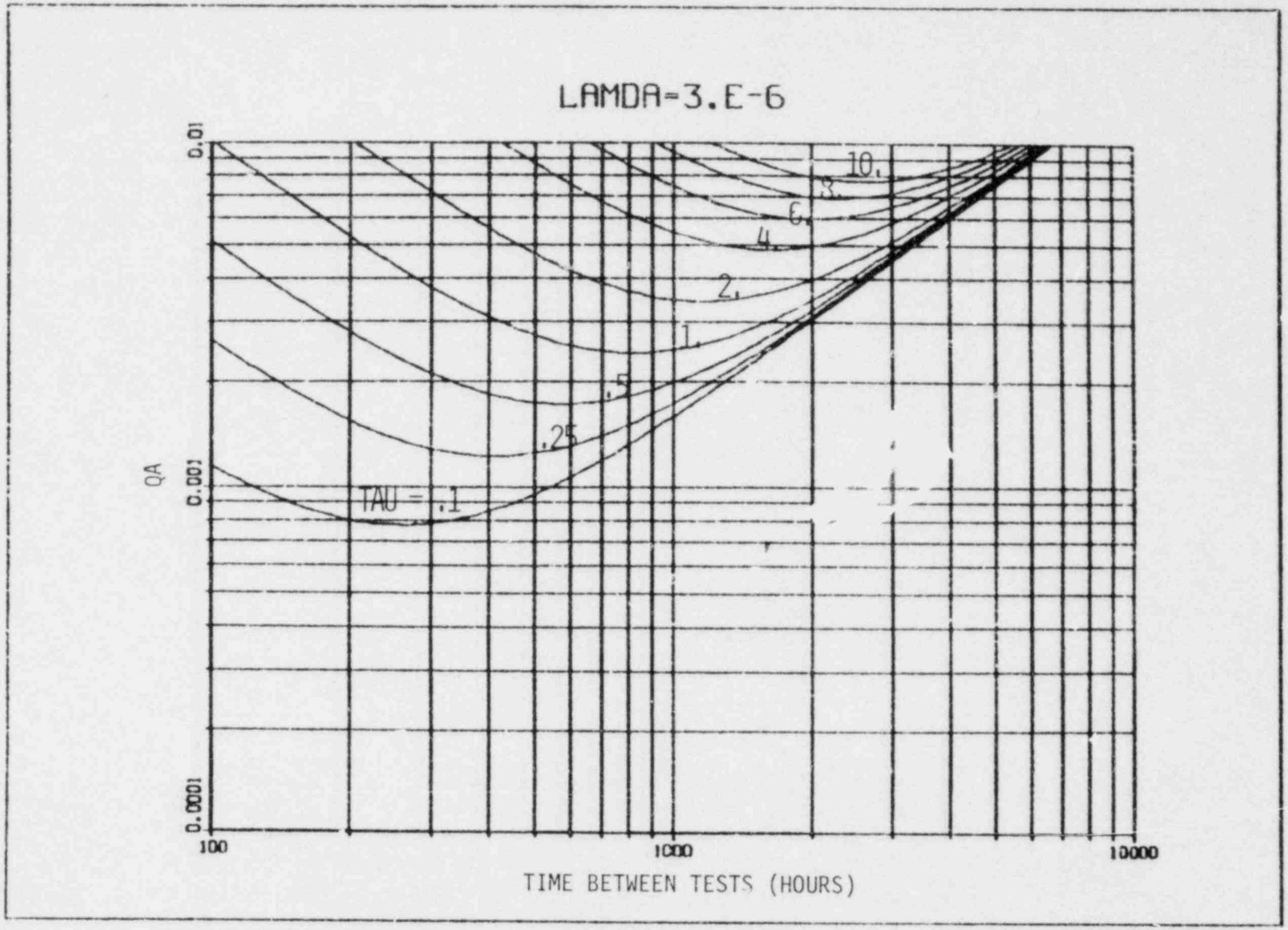


FIGURE 15

AVERAGE COMPONENT UNAVAILABILITY VERSUS TIME BETWEEN TESTS
PARAMETRIC WITH OUTAGE DURATION, τ (HOURS)

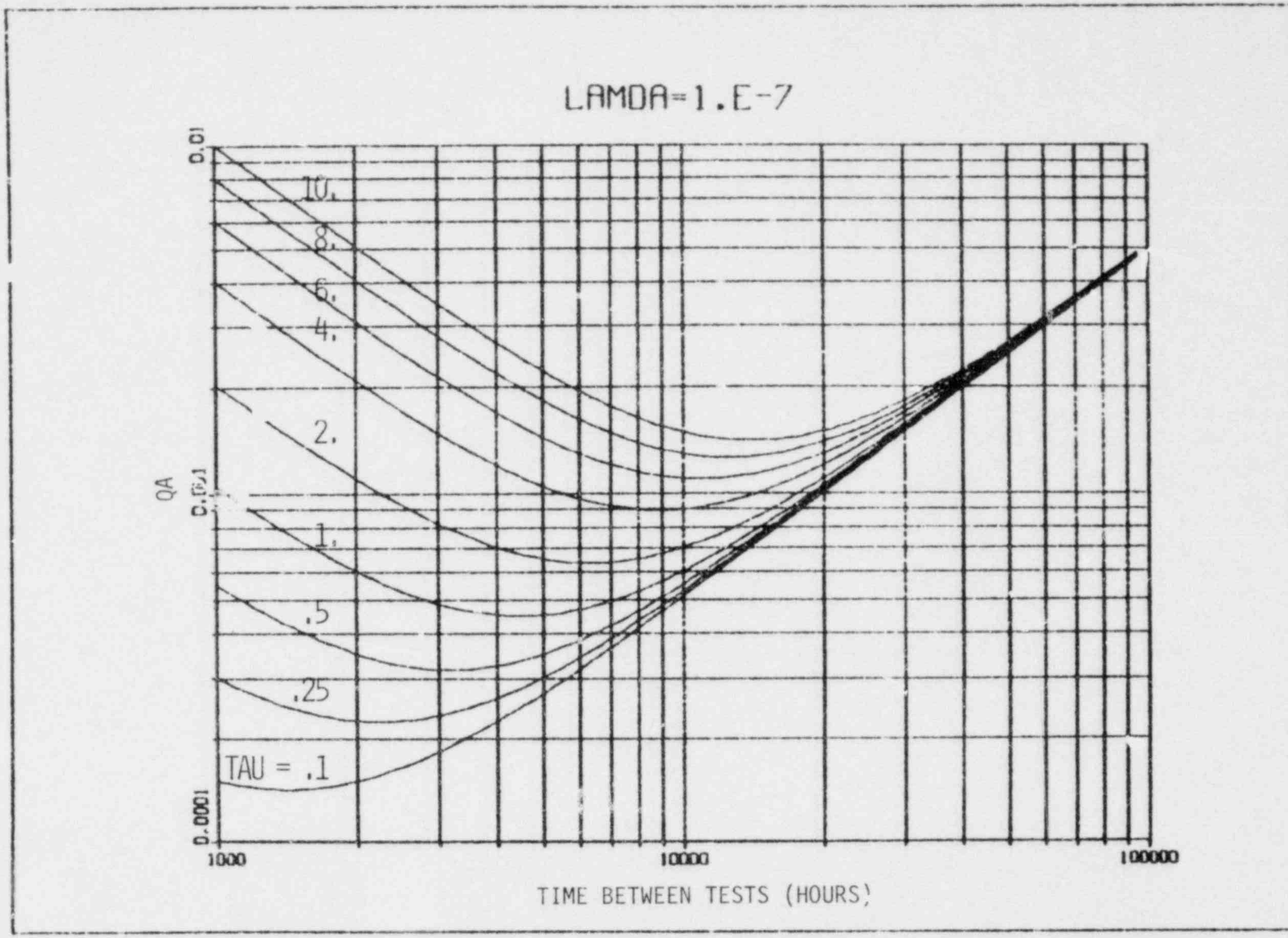


FIGURE 16

AVERAGE COMPONENT UNAVAILABILITY VERSUS TIME BETWEEN TESTS
PARAMETRIC WITH OUTAGE DURATION, τ (HOURS)

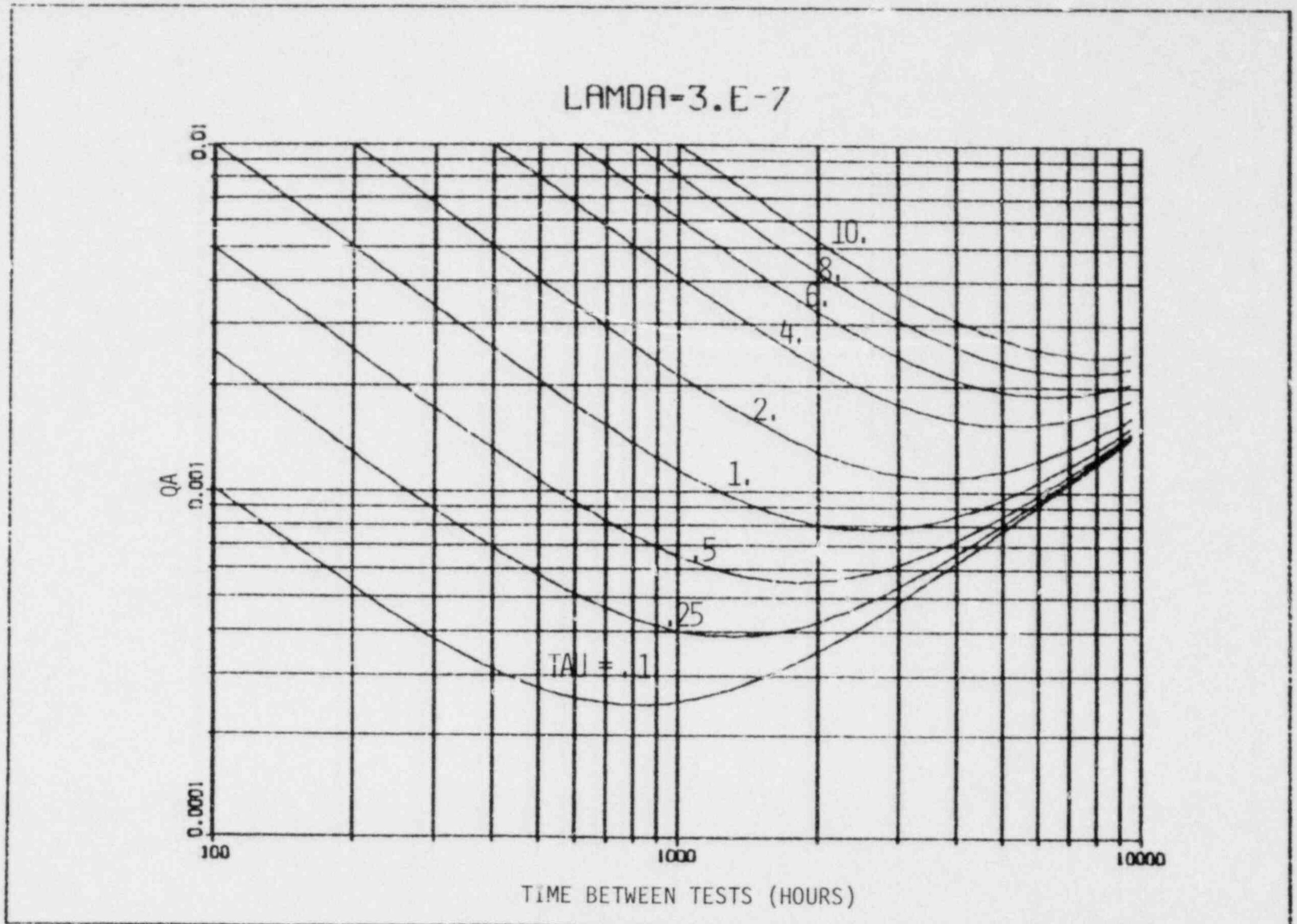


FIGURE 17

AVERAGE COMPONENT UNAVAILABILITY VERSUS TIME BETWEEN TESTS
PARAMETRIC WITH OUTAGE DURATION, τ (HOURS)

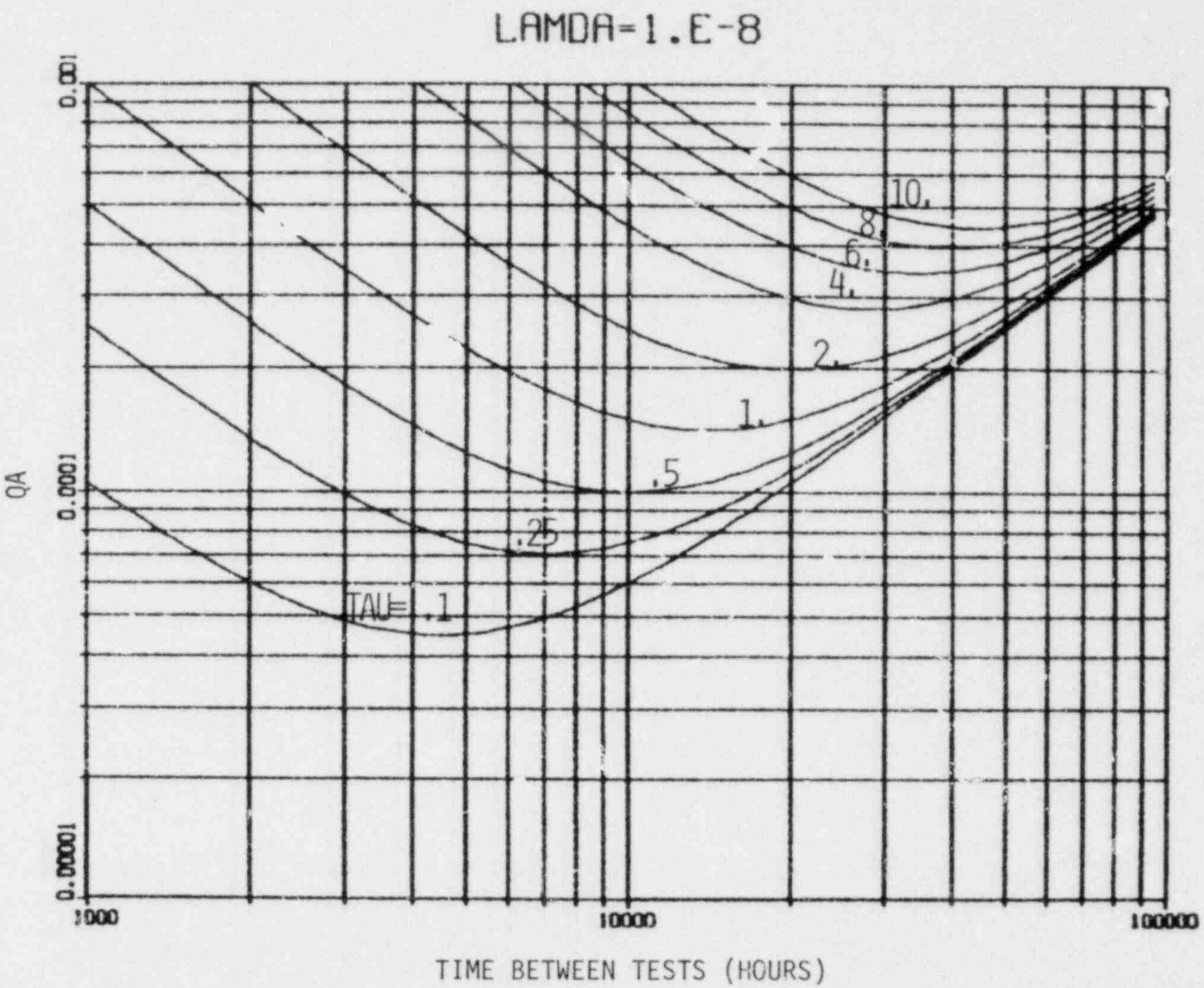


FIGURE 18

AVERAGE COMPONENT UNAVAILABILITY VERSUS TIME BETWEEN TESTS PARAMETRIC WITH OUTAGE DURATION, τ (HOURS)

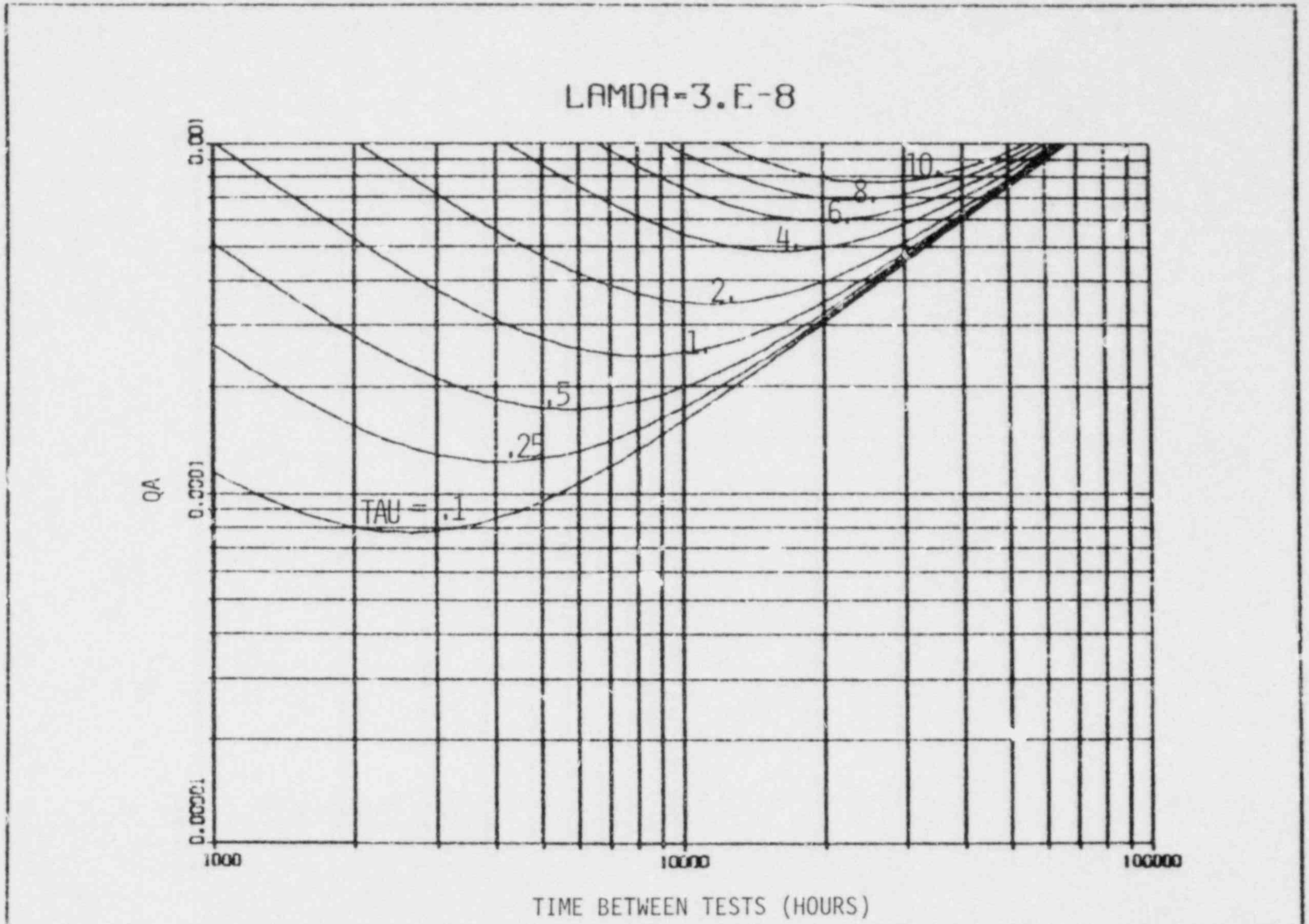


FIGURE 19

AVERAGE COMPONENT UNAVAILABILITY VERSUS TIME BETWEEN TESTS
PARAMETRIC WITH OUTAGE DURATION, τ (HOURS)

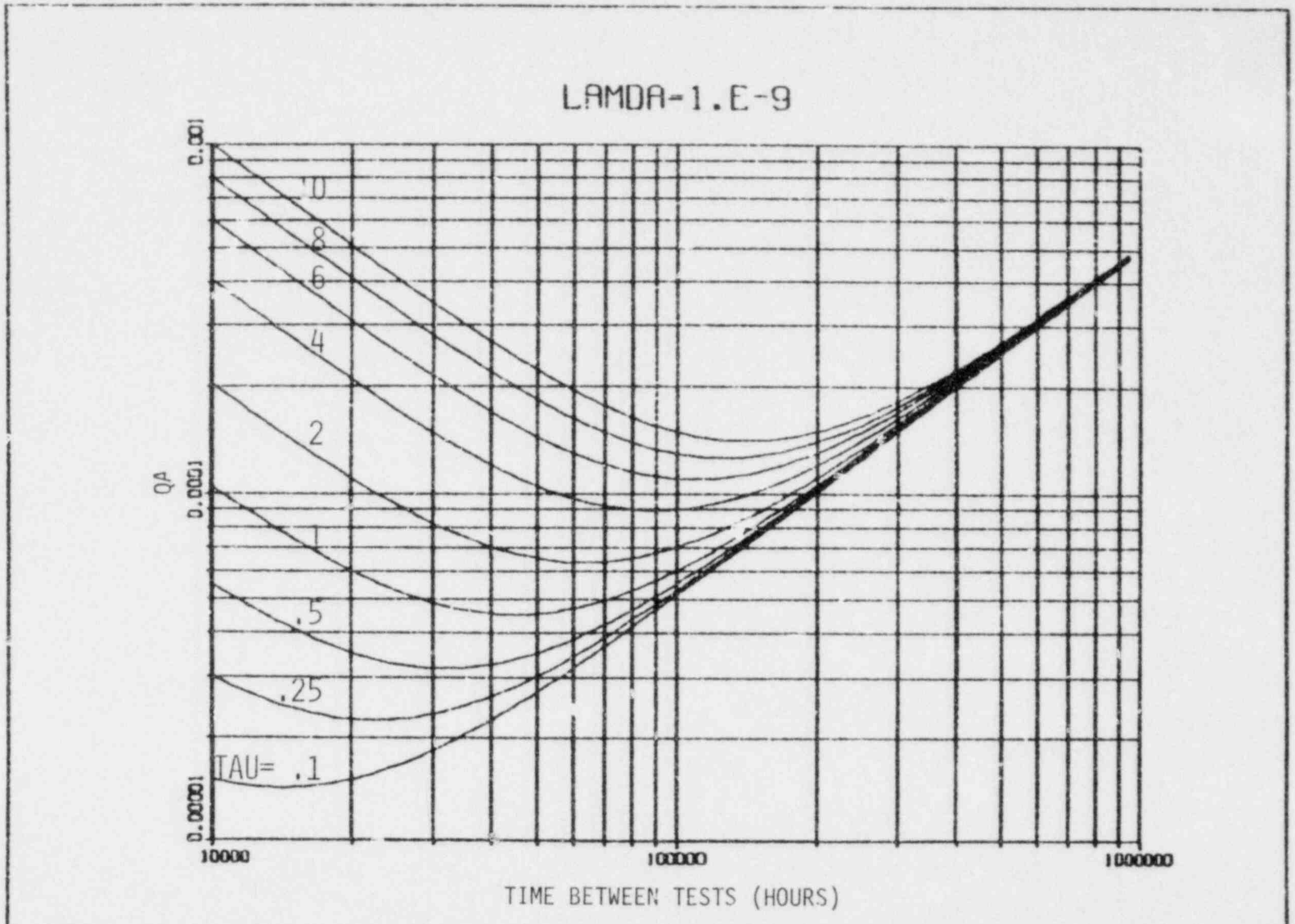


FIGURE 20

AVERAGE COMPONENT UNAVAILABILITY VERSUS TIME BETWEEN TESTS
PARAMETRIC WITH OUTAGE DURATION, τ (HOURS)

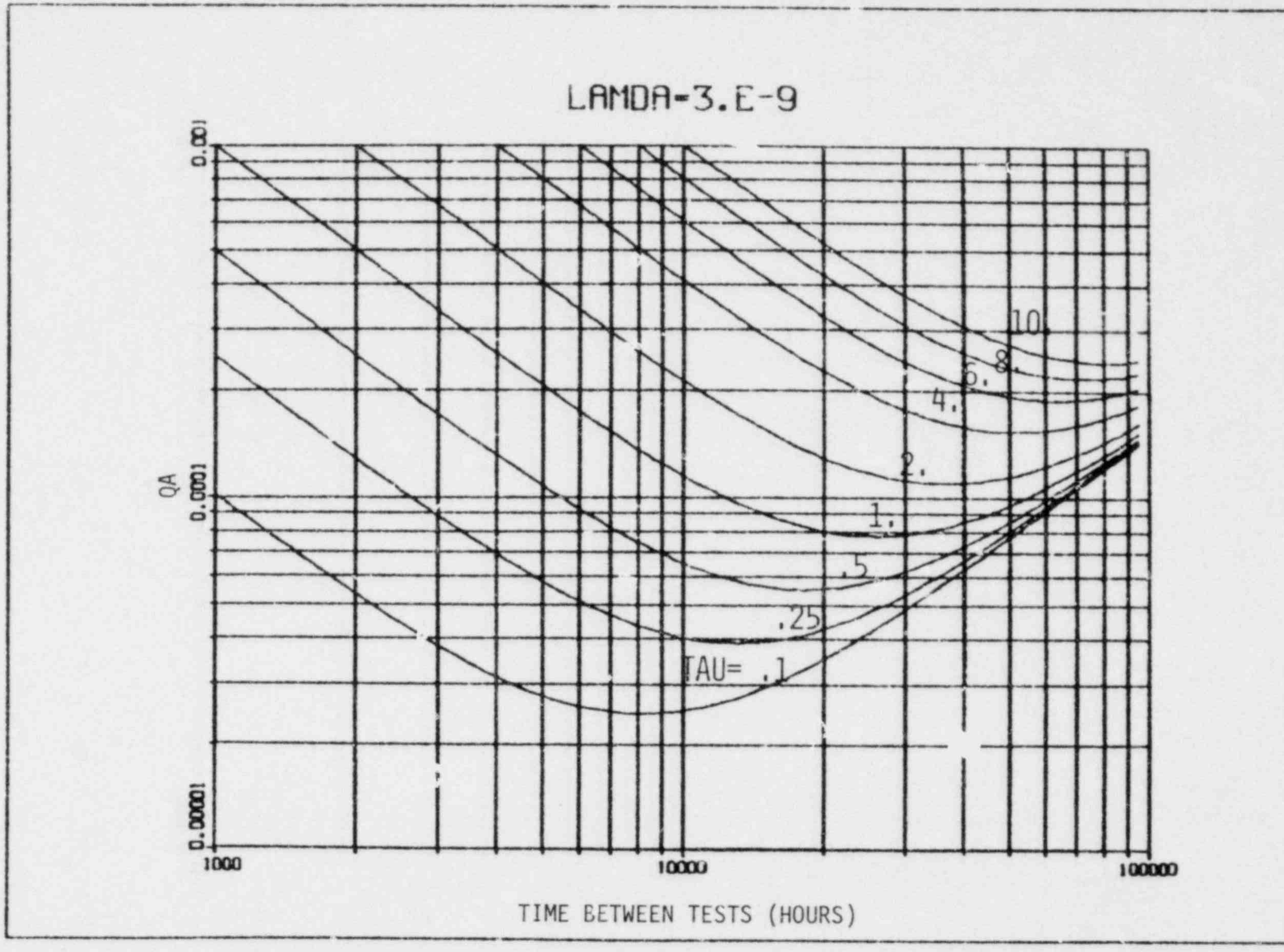


FIGURE 21

AVERAGE COMPONENT UNAVAILABILITY VERSUS TIME BETWEEN TESTS
PARAMETRIC WITH OUTAGE DURATION, λ (HOURS)

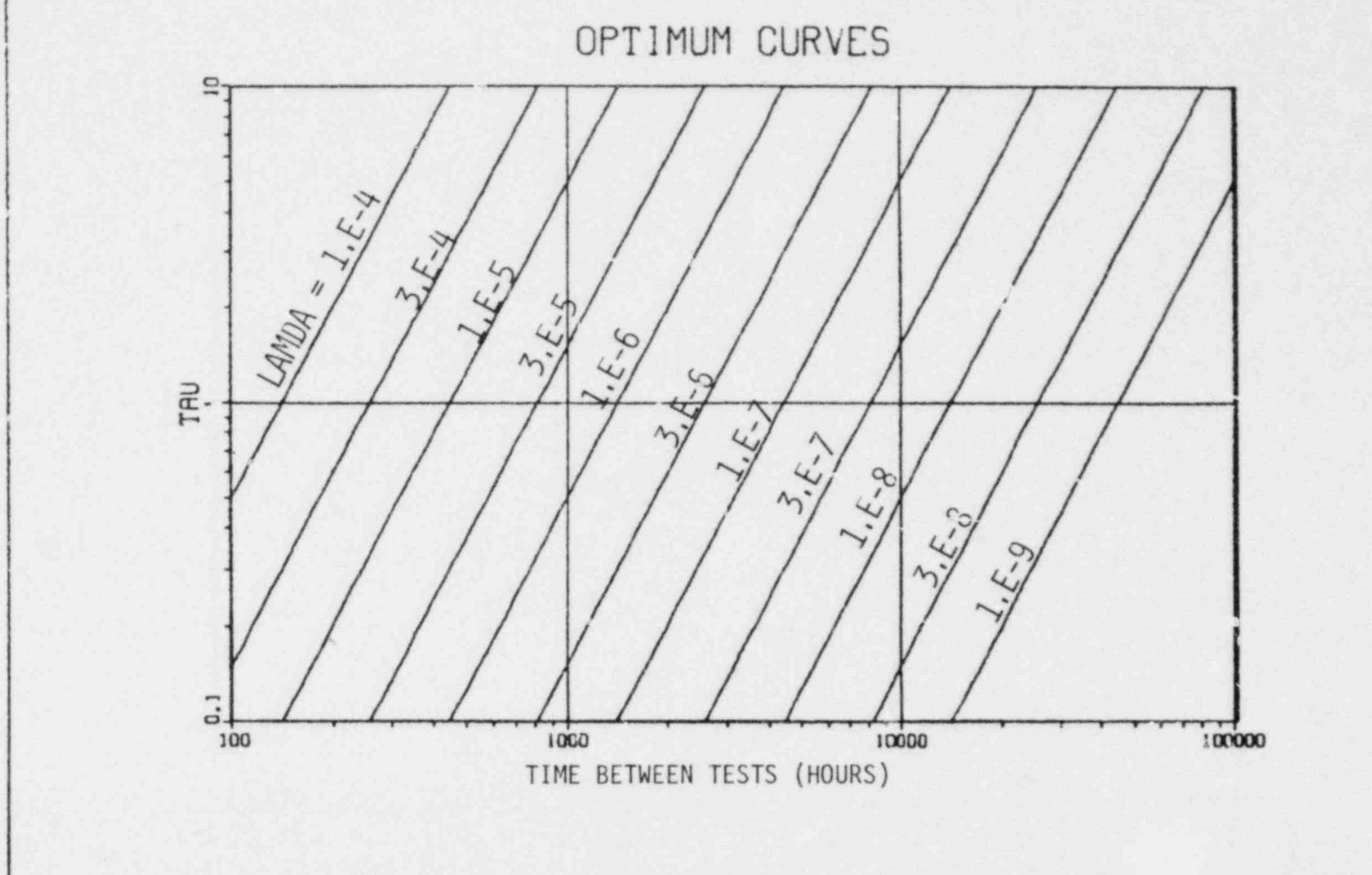
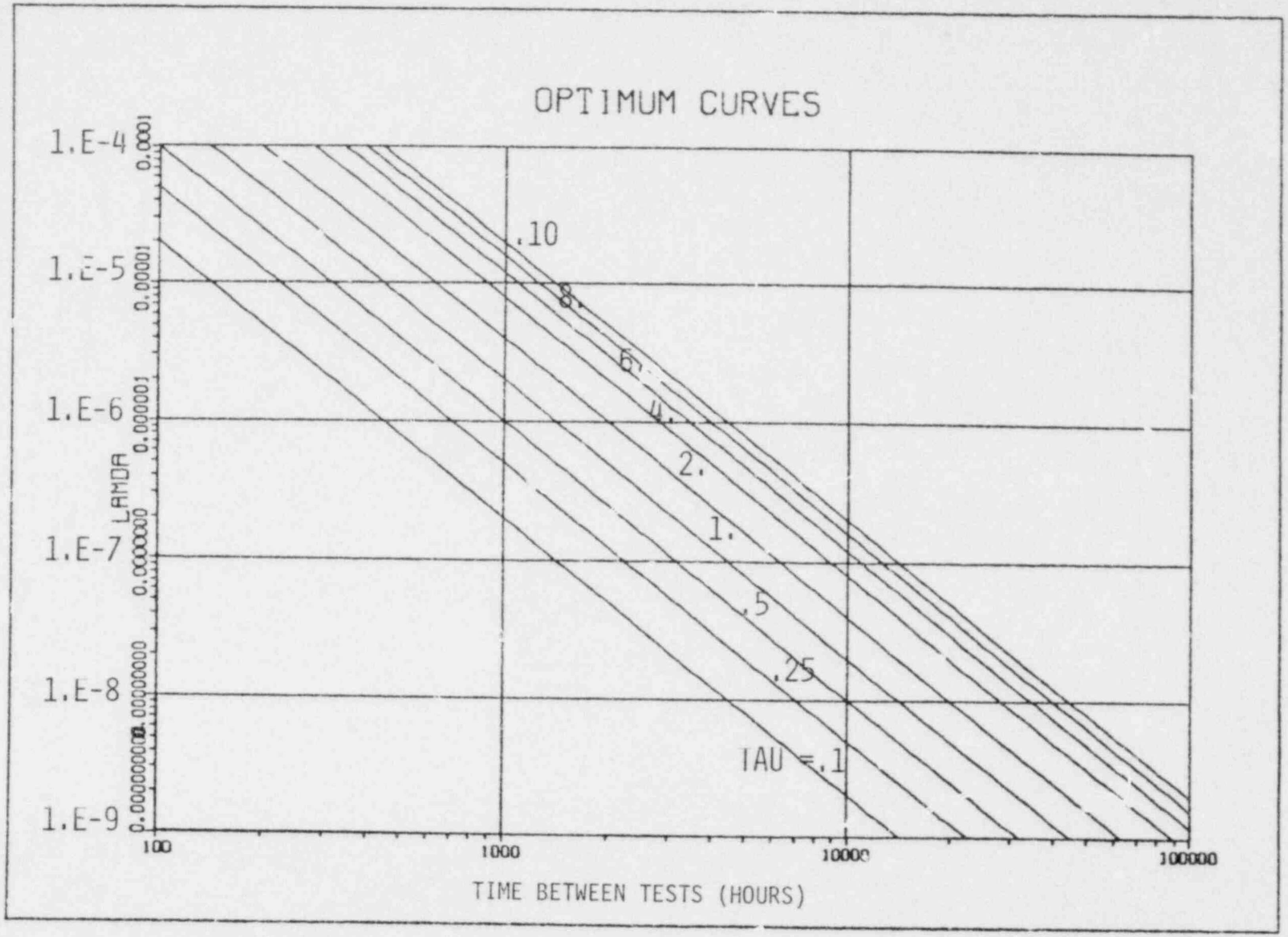


FIGURE 22

AVERAGE COMPONENT UNAVAILABILITY VERSUS TIME BETWEEN TESTS
PARAMETRIC WITH OUTAGE DURATION (HOURS)



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16. ABSTRACT (200 words or less)

Optimal periodic test intervals are given for standby components, when testing is performed on line and the testing causes the component to be unavailable while the test is performed. The optimal test interval, which is the optimal time between tests, minimizes the average component unavailability. Figures and tables are presented which give the optimal test interval versus component failure rates and test times, which were selected to cover the range of values normally encountered in nuclear power plant applications. When component failure rates and test times are not accurately known then the figures and tables can be used to obtain a range on the optimal test interval.

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