

## Guidelines for GaAs MMIC and FET life testing

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INTERNATIONAL  
ELECTROTECHNICAL  
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## Guidelines for GaAs MMIC and FET Life Testing

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## INTERNATIONAL ELECTROTECHNICAL COMMISSION

## GUIDELINES FOR GaAs MMIC AND FET LIFE TESTING

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## GUIDELINES FOR GaAs MMIC AND FET LIFE TESTING

(From Council Ballot JCB-92-16, formulated under the cognizance of JC-50.1 Committee on Gallium Arsenide Quality and Reliability.)

### 1. GENERAL

These guidelines apply to monolithic microwave GaAs integrated circuits (MMICs) and their individual component building blocks, such as GaAs field effect transistors (FETs), resistors and capacitors.

The objective of the tests described here is generally to estimate the expected lifetime of the devices at operational temperatures; usually the median lifetime (50% failure) is used for this purpose. The standard method for predicting device lifetime where this value is too large to be measured directly is to run a series of life tests. Generally, only one parameter, usually the device temperature, is varied. A lifetime is obtained at each temperature. These values are then extrapolated to the temperature of interest. In other cases, the objective may be simply to determine the lifetime at a given temperature.

The purpose of this document is to define a standard approach for evaluating the expected life of GaAs MMICs so that results from different life tests can be compared and so that a user of MMICs can predict a lifetime for his application. It is assumed in the wording of this document that the MMIC contains at least one FET, but the use of this document has no such limitation. Furthermore, the wording suggests that the failures occur at the FET; if this is not the case, then the stresses, tests and failure criteria need to be re-evaluated to ensure that they are appropriate to the failing component.

To perform the life tests, a sample of devices is selected from the lot and is subjected to a stress in excess of normal use conditions to decrease the lifetime. The devices used can be MMICs. Alternatively, the lifetime of MMICs can be determined by determining the failure rate vs time of component structures within the MMIC, e.g., FETs, resistors, capacitors and bond wires, given the structure and temperature profile of a MMIC. This latter calculation is not a straightforward one and a specific procedure is not addressed in this document. If it is assumed that the failure mechanisms are independent, the percentage of MMICs surviving to a given time is the product of the percentages of survival of each component.

Conducting accelerated tests of these devices can be very difficult because of the complexity of determining the channel temperature, the high cost of large sample sizes (especially where radio frequency (RF) stressing is performed) and the need to extrapolate to the temperatures of actual device use. In particular, any difference in the techniques for determining the device thermal resistance that changes the thermal resistance value will have substantial impact on the corresponding predicted failure rate. However, the task of standardizing a method for determining channel temperature is still in progress.

JEDEC STANDARD JESD22-A108-A provides a general description of life testing and serves as a guide, primarily regarding equipment. The provisions of that document are not considered binding here.

### 2. SCOPE

Life tests are run for various purposes. Tests run to detect the level of infant mortality involve short time durations; unless the percentage of devices having infant mortality is extremely high, the sample size specified in this document is not nearly sufficient. Tests to determine device lifetime for a specific application may be conducted by or for a customer; here the stress and test conditions may be specific to the application. Other life tests are run by a manufacturer and are concerned with determining the lifetime of devices under typical or extreme operation.

It is assumed that a given MMIC product is designated either as a power, general purpose, or low-noise (or small-signal) device, based on the intended use of the product. For low-noise devices and passive components, the RF voltage levels are small enough that it may be possible to simulate the stress accurately by imposing only dc stress conditions.

This document applies both to packaged and unpackaged devices. Where the devices are bare die or in packages not suitable for stressing except in sockets, additional failures may occur, due to the packaging, which are not considered part of the product being tested. If this occurs, such failures should be excluded from the population when calculating predicted failure rate.

Since it is not likely that every structure and failure mechanism in an MMIC is known when these guidelines are written, some judgment must be used in applying the principles of this document to the specific tests. Where an unusual circumstance forces exceptions to these guidelines, the exception shall be stated in the life test report.

### 3. SAMPLE SELECTION AND SCREENING

The devices selected for life testing shall be representative of the lot being evaluated. If an application-specific life test is being run, the screen used shall be no more stringent than the screen used before shipment of the production product. For more general application, the test may include an inspection and thermal and reliability screening to eliminate potential infant failures, so that enough devices survive to allow a valid lifetime calculation.

Screens may include electrical measurements to eliminate devices that do not meet specification, thermal resistance or x-ray techniques to eliminate devices that will operate at atypical channel temperatures, and environmental stress to eliminate infant failures. The screening conditions and limits shall be included in the life test data.

### 4. LIFE TESTS

#### 4.1 Electrical and Thermal Characterization

Each of the devices to be life-tested (plus control samples) shall be electrically characterized in their life test packages. Parameters to be measured will depend on the device function, but shall include every parameter that has a failure criterion, and shall be measured using the same method as during the life test. In some cases, the design of the MMIC will prevent measurement of certain parameters; otherwise,  $I_{dss}$ , drain-gate voltage at a leakage current of 1 mA/mm channel width, and, for the bias used in the stress, operating current, transconductance, and S-parameters should be included. Power and general-purpose devices shall have 1 dB compression point and, if possible, gate current, measured, while low noise devices shall have noise figure data. RF data shall be taken as a function of frequency and include a point in the center plus one point at each end of the band of interest for the device. These measurements will serve as the reference points to compare against subsequent data to determine the level of degradation that has taken place; consequently no change in the test conditions or tuning shall be made. Measurement may be performed at any baseplate temperature at or below 125°C.

Thermal resistance shall be determined using infrared scan or any other test or modeling technique that becomes widely accepted after these guidelines are issued. Experimental data shall be taken on at least 10% of the devices used for the life test to verify consistency. If the standard deviation of these measurements multiplied by the device power dissipation is no greater than 5°C, the average value may be

used for all devices; if not, then the relative thermal resistance of each device must be measured and used to determine the actual difference between case and channel temperature.

If a series of life tests is being run at different temperatures, the device thermal resistance shall be determined at the case temperature of the second highest ( $\pm 25^{\circ}\text{C}$ ) steady state life test temperature. If infrared scan is used, appropriate correction shall be made for infrared emissivity.

For packaged devices, if infrared scan or liquid crystal is used, an electrical method shall be used to adjust the thermal resistance for the effect of the package lid; to do this, measure the device temperature using the electrical method (or other accepted method) before and after the lid is applied, calculate the increase in temperature, and add this to the value determined on the unlidded device.

The rise above ambient of the hottest location on a FET divided by the power dissipated by the device shall be used as the thermal resistance unless failure analysis shows that the predominant failure location is elsewhere. This value averaged over the devices measured may be used for all devices and temperatures in the life test to convert between case and channel temperatures unless thermal resistance has been determined on 100% of the devices. Thermal resistance at a channel temperature of  $140^{\circ}\text{C} \pm 10^{\circ}\text{C}$  shall also be determined on a sample so that results obtained later can be related to a case temperature.

#### 4.2 Step Stress Tests

If there are no data available on similar devices that can be used to determine the stress temperatures to be used, a step stress shall be performed. The step stress should use at least six devices, have the same bias and RF input power to be used in the life test, start at  $150^{\circ}\text{C}$  baseplate temperature, proceed in steps of  $25^{\circ}\text{C}$  of duration of at least 24 hours at each temperature, and with the electrical measurements to be used in the life test made between every step. Similar step stress tests using constant temperature and increasing bias or RF input power may also be used to verify reasonable bias conditions for life testing.

#### 4.3 Choice of Ambient Temperatures and Other Operating Conditions

The highest steady state stress temperature used shall be based on an expected median life of at least 100 hours; if too long an interval is used, the lowest temperature life test may take an unreasonable time or the life test temperatures may be too close together for a reasonable extrapolation. If the step stress test is used, the highest steady state stress baseplate temperature shall be at least  $20^{\circ}\text{C}$  below the step stress baseplate temperature which produces 50% failure in 24 hours. In addition, if it is known that the dominant failure mechanism changes as the device temperature is raised above the temperature of application, the life tests shall be performed at temperatures below that transition temperature.

There shall be at least three temperatures of steady state stress. The second shall be at least  $15^{\circ}\text{C}$  below the highest, and the third shall be at least  $15^{\circ}\text{C}$  below the second. In addition, if the lowest of the three baseplate temperatures is greater than  $200^{\circ}\text{C}$ , a fourth sample of devices shall be run at a baseplate temperature  $50^{\circ}\text{C}$  above the device maximum operating temperature (or, if this is not specified, at a baseplate temperature of  $150^{\circ}\text{C}$ ) for a minimum of 2000 hours to verify the validity of the extrapolation to the operation range. At this temperature, few failures are expected, and the analysis method of 4.9 could only state with high certainty that the median life is greater than 2000 hours. (A 2000 hour life at a channel temperature of  $200^{\circ}\text{C}$  corresponds to 1 year at a device maximum operating temperature of  $150^{\circ}\text{C}$  if the failure activation energy is 0.5 eV or 32 years if the failure activation energy is 2 eV.)

Stresses other than temperature can also be performed for the purpose of determining acceleration factors. While they can not be expressed as activation energies, the dependence of device life on voltage, current, and other variables relevant to the device can be determined; the devices can be stressed above normal

operating conditions to accelerate the test. Analysis of the data is similar to temperature dependence except that the functional dependence on each variable may be different. When using electrical overstress, the device temperature may change enough to impact device lifetime, and the ambient temperature of each electrical overstress group may have to be different to keep the FET channel temperatures equal.

#### 4.4 Electrical Stress

During the step stress and life tests, the devices shall be operated under recommended dc operational electrical stress. If no recommended conditions exist, the bias conditions used shall be stated in the life test report. Unless special circumstances prevail, low-noise and passive devices may be stressed with dc only. General purpose and power devices and MMICs not containing FETs shall be stressed with continuous wave RF. It is desirable that the RF stress level drive the device into at least 1 dB compression at the stress temperature; the values of the RF input power, degree of compression, and frequency shall be stated in the life test report. If the life test is being run by or for a specific user, the operational dc and RF stress for the application shall be used.

During the life tests, the devices shall be monitored periodically to detect the occurrence of catastrophic failure and to adjust the equipment so that the applied stresses (temperature, current, voltage, etc.) are unchanged within tight tolerance except as described in the remainder of this section. Since the ideal life test is performed at constant temperature and with constant electrical stresses, any drift in device performance prevents the ideal from being met. Engineering judgment shall be used to determine the best compromise in keeping the electrical stresses and the channel temperature of the devices on the baseplate constant, and gate voltage during stress shall be periodically adjusted as required to implement this compromise. This compromise shall be described in the life test report, in order that the reader understands the life test conditions, and as a precedent for others facing the same problem in subsequent life tests.

To facilitate failure analysis, the device stress circuitry should be designed to quickly remove voltage from the device once it has failed; this practice will minimize subsequent damage due to a runaway condition such as a shorted FET.

#### 4.5 Sample Size

A minimum sample size of 50 devices is recommended. This represents the sum of all temperature groups which are taken to at least 70% failure. A larger sample size will provide more precise results in that the calculated confidence intervals will be smaller.

Allocation of the devices to the various stress temperatures is optimized by the technique of ref. 3 (pp. 320 - 327). Since the lowest stress temperature (assumed greater than the operating temperature of interest) has the greatest impact in the extrapolation to the temperature of interest, more devices should be stressed at the lowest temperature than at the others.

#### 4.6 Failure Criteria

The failure criteria shall be expressed as a parametric change and shall be stated if different from those listed here. Unless stated otherwise, drain and gate voltages used in measurement shall be kept constant, allowing currents under measurement conditions to vary. Measurement temperature shall be consistent with 4.1.

Changes defining failure:

Current (operating or  $I_{dss}$ )

+/- 20%

Gate bias current	as specified by manufacturer
Transconductance	+/- 20%
RF small signal gain	+/- 1 dB
Power added efficiency	+/- 20% of initial value (amplifiers only)
Output power at 1 dB gain compression	- 1 dB (power devices only)
Noise figure	+/- 0.5 dB (low-noise devices only)
Isolation -	3 dB change and less than 20 dB final isolation (switches only)
Switching time	+ 100% (switches only)
Insertion loss	+ 1 dB (switches only)
Phase error	+/- 11°C (phase shifters only)
Other	as specified by manufacturer.

Operating current is defined as the current when the device is biased as it was at the start of the life test.

Control devices shall be used to verify calibration of the measurement equipment.

#### 4.7 Data Taking

Section 4.6 (or an alternate definition) states the criteria for failure. Measurement of all these parameters shall be taken at intervals suggested by the step stress results. Devices may be, but do not have to be, removed from the life test fixture for parametric testing. Data used for fitting a line shall start after 10% of the sample has failed. Measurements shall be taken at enough time intervals to provide at least five time intervals which contain new failures after 10% and before 90% of the total population has failed. The purpose is to interpolate the time where half the sample has failed.

If the life test is to be performed with a minimal number of interruptions for parametric tests, note that, in a normal distribution of lifetime, the interval between tests (in a lognormal distribution, the interval between the logs of the time) should be decreased as the devices approach the expected median life. If more data points are taken, the risk of not achieving five points as described above and the random error in fitting a curve in 4.9 are both decreased.

The median life of a sample should always be estimated using step stress or comparison to similar devices to provide the best judgment that the baseplate temperature chosen is reasonable. Once the estimated median life is determined, a set of measurement intervals can be chosen; it can be revised if the devices are failing more or less rapidly than expected. A possible set of measuring intervals as a multiple of expected median life is: .277, .43, .59, .78, 1, 1.28, 1.69, 2.3, 3.6. These numbers correspond to the increments of 10% failure for a lognormal distribution with sigma = 1; if the life test followed this distribution perfectly, there would be nine measurement times fitting the requirement of this section, and the final measurement would have 90% cumulative failure.

The time at which parametric failure occurred for a given device can be obtained by interpolation of parametric data. If so desired, this time may be used in the graphing in 4.9. (This is not done in Appendix B.) This approach creates a slight bias to the data, as described by the concept of median ranks. One formula for removing this bias is to define cumulative failure fraction as

$$(i - 0.3) / (N + 0.4)$$

where:  $i$  = number of failures and  
 $N$  = starting population (ref. 1, pp. 112-114).

#### 4.8 Failure Analysis

Examination using a microscope shall be performed on every device failure to determine the failure site. Full failure analysis shall be performed on representative samples to determine the failure mechanism. Failure mechanisms which are incidental to the test, e.g., test fixtures, and broken bond wires on devices to be sold unpackaged, shall be reported, but may be ignored in subsequent calculations if it is determined that the failure was not caused by the device. A sample of parametric failures (but not all of them, to avoid their destruction by a catastrophic failure mode) should be placed back on life test to allow determinations of lifetime using a looser failure criterion and whether the parametric failure leads to catastrophic failure.

#### 4.9 Data Analysis

Analysis shall be performed and reported separately for each failure mode. The five or more points described in 4.7 will be used to create a curve of cumulative failure percentage vs elapsed time. The data shall be analyzed to determine a statistical distribution that fits the data. To do this, it is recommended that the data be plotted on paper having axes that make the curve a straight line, for example lognormal paper. From the line, the parameters of the curve, e.g., median life and sigma for lognormal, may be determined. If the curve is not linear, one possibility is that the wrong plotting scales were chosen.

An alternative is to transform the data. For example, to fit data to a lognormal distribution, use the standard normal variate ( $z$ ) using a normal distribution table corresponding to the value of phi that equals the cumulative failure fraction. For the time axis, use the logarithm of the time.

The range of these parameters with 60% confidence shall be stated for each channel temperature. Statistical methods are described in Appendix A.

It is not necessary to know when during the interval between parametric tests the devices failed so long as there are enough intervals (data points) to produce a smooth curve with little error in interpolation; the number of devices that have failed is being plotted as a function of elapsed time.

Lifetimes at other than 50% cumulative failure, e.g., 1% failure, may be determined from the cumulative failure curve. Unless a very large sample size is used, there will be few device failures contributing to the 1% cumulative value, so that the confidence interval will be much larger than for the median life. An alternative approach is to assume a given failure distribution, use the parameters for the distribution, e.g.,  $t_{50}$  (median life) and sigma (shape factor) for lognormal, and calculate the time to 1% failure based on this distribution; this approach is acceptable so long as it is stated and the cumulative failure curves are provided.

Mean time to failure (MTTF) may be determined by assuming a failure distribution which fits the data well, and using the proper formula for MTTF. For a lognormal distribution,

$$MTTF = t_{50} * \exp[(\sigma^2)/2].$$

For a Weibull distribution with shape parameter  $m$  and characteristic life parameter  $c$ ,

$$MTTF = c * \gamma[1 + (1/m)],$$

where  $\gamma[ ]$  is the gamma function. It is important to distinguish among median life, MTTF and MTBF. The life test report shall state that since failure rate is generally not a constant, the reader of the

report needs to use this calculated MTTF with care and not to use it for mean time between failures (MTBF).

When life test and failure analysis data indicate that more than one failure mechanism is present in the sample, the calculation of failure rate shall be conducted separately for each mechanism. Sometimes, part of the sample will fail by one mode, e.g., broken bond wires, then subsequent failures will fail by a different mode, e.g. shorted FET; in this case, the sample may best be treated as two separate populations. These failure rates can be added to determine the total failure rate, as described in the next paragraph. It should be noted that failure rates are not generally constant with time during a life test.

If the data analyst observes that the cumulative failure plot has a nearly horizontal section, the test may contain two populations, one with an infant failure mode and one without it. The life test will likely cause all devices having the infant failure mode to fail. Once failure analysis is performed, and if there are enough data points, the analyst will be able to determine the identity of each subpopulation and calculate the median life of each. In this case, the 10% to 90% cumulative failure percentage described in 4.7 applies to each population separately.

If devices are removed from the life test without failing or being on the borderline of failing (from the failure mode of interest) and the life test is continued, the subsequent results are biased. One way to handle this problem is to use a hazard plot; see ref. 3 (p. 140) for a description of this technique.

#### 4.10 Activation Energy and Extrapolated Lifetime

The logarithm of the median life (neglecting confidence interval) shall be plotted vs the reciprocal of the channel temperature to obtain the activation energy ( $E_a$ ) and extrapolated median life at infinite temperature ( $t_{\infty}$ ) according to the Arrhenius relation

$$t_{50} = t_{\infty} \exp(E_a/kT)$$

These values, their 60% confidence interval, and the device thermal resistance shall be used to calculate the median life and its 60% confidence interval at a channel temperature of 140°C. Statistical techniques are described in Appendix A.

The activation energy may also be calculated using failure percentages other than 50%, but generally there will be a larger statistical uncertainty. This calculated activation energy should not vary with the choice of percent failure. If certain parameters, e.g., sigma for a lognormal distribution, determined in 4.8 vary with temperature, there are two alternatives: a real variation due to different failure mechanisms, and variation due to statistics of dealing with small sample sizes. In the first case, the analysis is complicated considerably, and life tests may have to be run at additional temperatures. In the second case, a weighted average (weighted by the reciprocal of the square of the confidence interval) should be used as a constant value.

## 5. REPORTABLE DATA

The following data are required to adequately define the results of a life test.

### 5.1 Devices

Manufacturer's device number, electronic function, and whether it is low-noise, general purpose or power;

Package description, and whether packaging failures are included as failures;

Screening methods and criteria;

Average thermal resistance at the two temperatures and method.

### 5.2 Stresses

Case temperatures;

Number of devices for each temperature;

Electrical stress: bias conditions, RF input or output power and comparison to 1 dB compression point;

Definition of failure.

### 5.3 Analysis

Principle failure mode and mechanism;

Plot indicating median life for each temperature 60% confidence limits.

Assumed lifetime distribution, if any;

Plot indicating extrapolation to reference temperature, 60% confidence limits.

## 6. REFERENCES

1. Tobias and Trindade, Applied Reliability, Van Nostrand Reinhold, New York, 1986.
2. Nelson, Applied Life Analysis, Wiley, New York, 1982.
3. Nelson, Accelerated Testing: Statistical Models, Test Plans and Data Analysis, Wiley, New York, 1990.

General: Basic References in Quality Control: Statistical Techniques, ASQC Press, 1985.

## APPENDIX A: STATISTICAL METHODS

(In Appendix A, the notation T50 is used rather than t50 to distinguish from the t-statistic.

### UNCERTAINTY OF A NUMBER OF FAILURES

When a small number of failures (or a small number still good) have occurred, the statistical uncertainty is large. This makes the data at the ends of the cumulative failure curve less certain than the data at the center. This effect is magnified by the probability scale normally found on graph paper used for cumulative failure curves; including such points and giving them equal weight as the points near 50% gives them too much importance. This is the motivation in 4.7 for restricting the range of percentage failure to the 10-90% interval in fitting a line to the cumulative failure curve.

Given a population and a percentage failure, the percentage failure in a small sample of the population may be quite different. Inferring data on the population from the sample, there is an uncertainty in the population failure percentage. A Clopper-Pearson plot (ref. 1 pp. 195-7, ref. 2 pp. 590-1) can be used to determine this range for the confidence level specified on the plot; a consequence shown by the plot is that the percentage confidence interval of the time for a given failure percentage is smallest at 50% failure.

### FITTING A LINE TO POINTS ON A CUMULATIVE FAILURE PLOT

An intuitive method to weight the points is described here. Since the standard deviation of the average of a group is proportional to the reciprocal of the square root of the number of individuals in the group, it follows reasonably that the relative weighting of a point should be the reciprocal of the square of the confidence interval. This confidence interval is the interval on the graph paper between the 60% (or other percentage) limits for each point on the cumulative failure plot. Hence the weighting is influenced by the number failing (or the number not failing) directly through the numerical value of the interval and indirectly through the nonlinear scale on the failure fraction axis. For both reasons, points in the region of 50% failure get weighted more heavily than points at the extremes.

There are many computer programs containing linear regression, which will fit a line to a group of data points. Whether or not the method described in the previous paragraph is used, the error in fitting a line to the data will be minimized by having several data points between 10% and 90% cumulative failure.

### CONFIDENCE INTERVAL FOR MEDIAN LIFE

The minimum limit of the confidence interval of a median life for a device following lognormal distribution is given as

$$\ln [T50(B)\min] = \ln[T50] - \sigma * t(N-1,B)/\text{sqrt}(N),$$

where: ln is the natural logarithm

N is the sample size

T50 is the median lifetime as determined by fitting a curve to the cumulative failure plot

t(N-1,B) is the t-statistic for N-1°C of freedom and a confidence level B

sigma is the lognormal shape factor.

For sample sizes typical of life tests, the t-statistic can be approximated by the inverse standard normal cumulative distribution function (ref. 2, p. 577, where "phi" is used as "B" above and "u" is the inverse standard normal cumulative distribution function) with little loss of accuracy.

For the minimum limit at any other failure fraction, substitute the time to reach that failure fraction in place of T50 and the smaller of  $2 \cdot n$  and  $2 \cdot (N - n)$  for "N", where n is the number of devices failing at the failure fraction of interest. For small "n" or small "N-n", the use of the normal in place of the t-statistic may not be justified. The fractional confidence interval will increase as the failure fraction changes from 0.5.

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## APPENDIX B: EXAMPLE OF A LIFE TEST

In this appendix, a life test is performed to serve as an example of the method of determining the lifetime distribution parameters from accelerated test data. The lognormal distribution is used in the example, so the parameters of interest are  $t_{50}$  (median life) and sigma (lognormal shape factor). Similar calculations can be performed using other distributions e.g., Weibull, and should be performed if the cumulative failure curve does not appear as a straight line on lognormal paper.

### STATEMENT OF THE PROBLEM

It is desired to predict the lifetime ( $t_{50}$ ) of an electronic device at the maximum use ambient ( $T_a$ ) of 115°C. Previous versions of this device have had sigma of 0.7, and activation energy ( $E_a$ ) of the failure mechanism has been 1.7 eV. The anticipated lifetime is 1E7 hours at 115°C ambient. The device does not function above 275°C channel temperature. The approach is to develop an accelerated test scheme, then to analyze the data to determine  $t_{50}$  at the test temperature, sigma and  $E_a$ , and finally  $t_{50}$  at the temperature of interest.

### ACCELERATED TEST SCHEME

**Thermal resistance** (4.1) is measured or modeled; the channel temperature is 25°C above ambient in the temperature range of the life tests.

**Choice of test operating conditions** (4.2, 4.3): Since the device being tested is similar to an existing device and there is an estimate of the lifetime, step stress is not necessary. With a 275°C temperature limit and 25°C rise, the upper stress ambient is limited to 250°C. The minimum delta between the stress ambients is 15°C, so temperatures of 220°C, 235°C and 250°C could be used.

Choice of these temperatures will result in the minimum test time. However, there are reasons to consider alternatives. First, as temperature spacing decreases, the need for temperature extrapolation increases, since all test temperatures are high (here, the lowest temperature is 110°C above the ambient of interest). Second, errors in regression slope increase as stress temperature spacing decreases. Both these problems are reduced by using wider spacing in stress temperatures. Using temperatures with wider spacing is practicable where the activation energy is small, but for an expected 1.7 eV activation energy, the test time at the lowest temperature will become excessive.

Operating at a temperature very close to spontaneous failure involves considerable risk. Accordingly, for this series of life tests, the ambient temperatures were reduced by 20°C, and were chosen as 200°C, 215°C, and 230°C. Since the lowest temperature used is not greater than 200°C, a fourth temperature (4.3) is not needed.

**Sample size** (4.5): For this example a total of 70 devices (plus standards) is available.

**Data taking** (4.7): Timing for measurements is calculated from the procedure in 4.7, using the information from the problem statement and the similar device. First, we estimate  $t_{50}$  at each test condition using the estimates of  $E_a$  and  $t_{50}$  at the temperature of interest, and the Arrhenius relation

$$L_2 = L_1 * \exp[E_a/k * (1/T_2 - 1/T_1)]. \quad (1)$$

where:  $T_i$  = channel temperature in K  
 $L_i$  ( $i = 1$  or  $2$ ) is  $t_{50}$  for temperature  $T_i$   
 $k$  = Boltzmann's constant (8.62E-5 eV/deg).

Substituting these estimates, the predicted t50 at 200°C ambient is

$$L_{200} = 1E7 * \exp[1.7/8.62E-5 * (1/(273+200+25) - (1/(273+115+25)))] = 2886 \text{ hours}$$

Similarly, the predicted t50 at 215°C ambient is 907 hours and at 230°C is 304 hours.

Second, we calculate the test intervals in terms of t50 calculated above. Since we have an estimate of sigma of 0.7, we adjust each interval in 4.7 by raising it to the 0.7 power. For example, the first interval is

$$t_{50} * 0.25^{0.7} = t_{50} * 0.379.$$

So our intervals are 0.41, 0.55, 0.69, 0.84, 1, 1.19, 1.44, 1.81 and 2.45, each multiplied by t50. The test intervals as shown in Table 1 are these values adjusted slightly for convenience. Table 1 serves as a data sheet.

Table 1  
Data Sheet

200°C		215°C		230°C	
Time	#fail	Time	#fail	Time	#Fail
1094		0344		115	
1521		0478		160	
1948		0612		205	
2338		0735		246	
2886		0907		304	
3469		1090		365	
4185		1315		441	
5169		1624		544	
6797		2136		716	

Third, we decide how many devices to use at each temperature. It is hoped that enough test intervals having additional failures occur on the lowest temperature test to allow the test to be discontinued before 90% failure. With this in mind, 30 devices were run at 200°C, 20 at 215°C and 20 at 230°C. An alternative would be to use the technique described in 4.5.

### LIFETIME PREDICTION

**Data Analysis (4.9):** The life tests are run providing the data shown in Table 2. The transformed values ln(time) and the inverse normal (z) of the cumulative failure fraction (F) are also shown.

**TABLE 2**  
Life Test Data and Lognormal Transformation

200°C					
					sample size: 30
Time (hours)	ln(time)	# of failures	cumulative failures	cumulative % failures	z
1094	6.998	3	3	10.0	- 1.282
1521	7.327	2	5	16.7	- 0.967
1948	7.575	4	9	30.0	- 0.525
2338	7.757	2	11	36.7	- 0.430
2886	7.968	5	16	53.3	0.168
3469	8.152	2	18	60.0	0.253
4185	8.339	3	21	70.0	0.525
5169	8.550				
6797	8.824				
215°C					
					sample size: 20
Time (hours)	ln(time)	# of failures	cumulative failures	cumulative % failures	z
344	5.841	2	2	10.0	- 1.282
478	6.170	1	3	15.0	- 1.037
612	6.417	3	4	30.0	- 0.525
735	6.600	2	8	40.0	- 0.253
907	6.810	3	11	55.0	0.127
1090	6.994	1	12	60.0	0.253
1315	7.182	1	13	65.0	0.385
1624	7.393	3	16	80.0	0.842
2136	7.667	1	17		1.037