**[Accelerated Life Testing]**

Q\_1: What is accelerated life testing?

A\_1: Accelerated life testing is a method used to test how long a product will last (its lifespan) within a shorter time frame. It involves subjecting the product to more severe conditions to induce failures more quickly, which helps in predicting the product's lifespan.

Q\_2: Why is accelerated life testing necessary?

A\_2:

1. Product Lifetime Requirements: Many products are required to have lifespans of several years or over a decade.

2. Shorter Development Time and Technological Changes: Development times are getting shorter and the pace of technological change is increasing.

3. Product Liability (PL) Enforcement: With increasing product complexity, customer expectations for reliability and trust are higher.

4. Overcoming Time and Sample Size Limitations: Accelerated life testing is needed to assess the reliability and performance of products with high confidence within a short period.

Q\_3: What is the purpose of accelerated life testing?

A\_3:

1. Identifying Failure Modes and Weaknesses: Detecting failure modes and weaknesses during product design.

2. Monitoring Design and Process Changes: Assessing the impact of stress on lifespan during production process audits.

3. Improving Reliability: Evaluating and improving the reliability of materials and components.

4. Comparing Competing Products: Comparing the reliability of various products to more effectively set warranty periods.

Q\_4: What are the types of accelerated life testing?

A\_4: There are two main types: qualitative tests and quantitative tests.

1. Qualitative Tests: These tests aim to identify and improve design weaknesses. Various stresses are applied to the product to evaluate its operational limits and potential failure modes. Methods include step-stress, progressive-stress, and combined-environment tests, typically applied to subsystems, assemblies, or finished products. The focus is on identifying unexpected failure modes and developing mitigation strategies to ultimately enhance reliability.

2. Quantitative Tests: These tests aim to estimate the product’s lifespan under usage conditions. The focus is on analyzing lifespan-stress relationships to predict how long the product can endure under specific stress conditions.

Q\_5: What are the quantitative testing methods in accelerated life testing?

A\_5: Quantitative Testing Methods

1) Constant Stress Testing: Testing the product at one or more fixed stress levels and recording the failure times. This method is widely used in real environments and is relatively simple to maintain stress levels.

2) Step-Stress Testing: Periodically increasing the stress levels while observing product failures. This method allows for quick data collection but may complicate reliability estimation.

3) Progressive Stress Testing: Gradually increasing the stress levels over time.

4) Cyclic Stress Testing: Periodically varying the stress levels applied to the product.

Q\_6: What are the characteristics of quantitative testing methods in accelerated life testing?

A\_6: Characteristics of Quantitative Testing Methods

1. Failure Modes:

- In quantitative testing, the failure modes need to be predictable. The failure modes that occur during testing should align with those expected under actual usage conditions.

2. Data Analysis and Life Prediction.

- Statistical Analysis: Analyzing life data statistically to evaluate the life distribution at each stress level and estimate the life under usage conditions.

- Life-Stress Relationship Models: Modeling the relationship between life and stress to estimate life under real-world conditions.

Q\_7: Why is predicting failure modes important in accelerated life testing?

A\_7: Predicting failure modes is crucial because the test results will only be reliable in real-world environments if the failure modes observed during testing align with those expected under actual usage conditions.

Q\_8: What are the procedures for accelerated life testing?

A\_8: The procedures for accelerated life testing are as follows:

1. Define Objectives and Requirements

- Clarify product lifespan requirements: Set goals related to product lifespan and reliability that must be met.

- Identify failure modes and mechanisms: Understand the main failure modes and their causes for the product in question.

2. Develop Experimental Plan

- Select test subjects: Choose the products or components to be tested in the accelerated life test.

- Determine stress levels: Decide on the stress levels to be applied to the product, including variables such as temperature, humidity, voltage, and vibration.

- Choose test methods: Select suitable test methods for accelerated life testing, such as constant stress, step stress, or progressive stress.

- Plan sample size and test duration: Determine the number of samples required and the duration of the tests.

3. Collect Laboratory and Field Data

- Gather baseline data: Collect data from laboratory tests and actual usage environments to serve as baseline information.

4. Review Suitability of Acceleration Models

- Choose acceleration models: Select appropriate acceleration models (e.g., Arrhenius model, Weibull model) and assess their suitability.

5. Execute Tests and Collect Data

- Perform tests: Conduct the accelerated life tests as planned and collect data.

- Monitor and record: Accurately record and monitor all data collected during the tests.

6. Analyze Data and Interpret Results

- Statistical analysis: Analyze the collected data statistically to develop lifespan prediction models.

- Failure data analysis: Analyze failure times and conditions to understand failure mechanisms and identify areas for design improvement.

7. Report Results and Implement Improvements

- Report results: Summarize and report the analysis results to relevant departments or stakeholders.

- Improve design and processes: Use the test results to make improvements to product design or manufacturing processes.

8. Validate and Confirm Results

Q\_9: How is the acceleration factor calculated?

A\_9: 𝐴𝐹= Lifespan under normal conditions/ Lifespan under accelerated conditions ,

Using the Arrhenius model ->$AF = \exp \left( \frac{E\_a}{k} \left( \frac{1}{T\_{\text{emp1}}} - \frac{1}{T\_{\text{emp2}}} \right) \right)$

Q\_10: What are the conditions for the validity of acceleration in accelerated life testing?

A\_10: The validity of acceleration is established when the life data from two different acceleration conditions, when plotted on a probability plot, align such that the lines fitted to each condition are parallel to each other.

Q\_11: How is accelerated life data analysis performed?

A\_11: Accelerated life data analysis is performed using probability plots. This involves plotting the life data, assessing distribution fits, fitting lines for different stress levels, ensuring that the lines are parallel, and estimating the life and parameters under normal usage conditions.

Q\_12: What is a probability plot?

A\_12: A probability plot is a graph where data points are scaled to fit a vertical line if they follow the assumed lifetime distribution.

Q\_13: What are the types of accelerated life tests?

A\_13:

1. Arrhenius Model

- Scope of Application: Used when chemical reaction rates or material degradation are of primary interest.

- Basic Principle: Explains the effect of temperature on reaction rates. The reaction rate constant increases exponentially with temperature.

- Formula: $\text{Rate} = A \times e^{-\frac{E\_a}{RT}}$

A: Frequency factor, $E\_a$: Activation energy, R: Gas constant, T: Absolute temperature

2. Inverse Power Law Model

- Scope of Application: Mainly used for modeling failures related to electrical stress in electronic components.

- Basic Principle: Predicts the lifespan response to stress levels.

- Formula: $\text{Life} \propto \frac{1}{\text{Stress}^n}\propto \text{Stress}^{\frac{1}{n}}$

- n: Stress index, indicating the effect of stress on lifespan

Q\_14: What are the limitations and cautions for accelerated life testing?

A\_14:

1. Model Fit: Inappropriate accelerated life testing models can lead to incorrect conclusions.

2. Stress Levels: Shorten the testing period but set stress levels as close as possible to the product's operational range.

3. Measurement and Monitoring: Establish a better model through as many measurements and monitoring as possible during the test.

4. Failure Mode Consistency: The failure modes and mechanisms under use conditions and accelerated conditions must be the same.

5. Product Consistency: The test products should be identical to the final development or mass production products.

Q\_15: What is the Arrhenius model?

A\_15:

1. Basic Principle: A model based on the Arrhenius law for chemical reaction rates.

2. Application: Electrical insulators, dielectrics, lubricants, grease, semiconductor devices, plastics, capacitors, incandescent lamp filaments, etc.

3. Key Equation: $\nu\_r = \gamma \cdot \exp \left( -\frac{E\_a}{k \cdot T\_{\text{emp}}} \right)$

$\nu\_r$: the reaction rate, $\gamma$: a constant , $E\_a$: the activation energy (eV) , 𝑘: the Boltzmann constant (8.6171 \times 10^{-5} eV/K)

𝑇𝑒𝑚𝑝: the absolute temperature (K), 𝑇𝑒𝑚𝑝=$^\circ\text{C} $+273.16

4. Arrhenius Equation:

The relationship between the reaction rate constant k and temperature T is given by: $k = A \cdot e^{-\frac{E\_a}{RT}}$

𝑘: the reaction rate constant, 𝑅: gas constant, 𝑇: absolute temperature (Kelvin), 𝐴: pre-exponential factor (a constant that adjusts the reaction rate constant with temperature), $E\_a$: activation energy , which is the energy barrier that must be overcome for the reaction to occur

5. Lifetime Prediction:

The nominal lifetime L is given by: $L = C \cdot e^{\frac{E\_a}{kT}} $

( 𝐶: model constant, 𝑇 : absolute temperature , $E\_a$ : activation energy, 𝑘 : the Boltzmann constant)

Q\_16: Utilization of the Arrhenius Model in Accelerated Life Testing

A\_16: The purpose is to predict the product's lifespan under various environmental conditions. It is based on the relationship between temperature and reaction rate. The principle is that as temperature increases, the reaction rate increases, and as temperature decreases, the reaction rate decreases, following an inverse proportional relationship. The equation is:

$k = A \cdot e^{-\frac{E\_a}{RT}}$

**[Reliability validation test]**

Q\_1: What is a reliability validation test?

A\_1: It is a method for testing how long a product can operate without issues. The main purpose is to confirm whether the product maintains the expected level of performance and reliability as anticipated during the design and manufacturing processes. In simple terms, it is the process of demonstrating through experimentation that the product can be used as expected without failure.

Q\_2: What is the purpose of reliability validation testing?

A\_2:

1. Design Verification: To ensure that the product operates as designed before it is fully manufactured. This involves testing prototypes to verify environmental conditions, legal requirements, reliability, etc. If no issues are found, the design is considered to be validated.

2. Process Validity Confirmation: After passing design verification, it confirms that the production process in the factory meets design requirements without issues during mass production. This ensures that quality does not deteriorate as the product is produced in large quantities.

Q\_3: What are the reliability criteria in a reliability validation test?

A\_3:

1. Parameters: Numbers that represent the product's performance or lifespan.

2. Reliability: The probability that the product will operate without failure for a specified period.

3. Percentile (B-life): The point in time at which a certain percentage of the total products are expected to fail.

Q\_4: What are the main elements of a reliability validation test?

A\_4:

1. Reliability (R): Reliability at a specific point in time (B-life)

- 90% (B10)

- 95% (B5)

- 97% (B3)

- 99% (B1)

2. Confidence Level (C)

- 50%

- 60%

- 70%

- 80%

- 90%

- 95%

3. Test Conditions

- Definition of Failure: Definition of what constitutes a product failure

- Failure Mechanism: The principle behind how failures occur

- Applied Stress: Various stresses applied to the product

- Thermal stress

- Vibration, voltage, etc.

4. Test Time ($t\_{c}$) or Sample Size

- Sample size and test time are determined after setting R and C

- $t\_{0}$ (Validation Lifetime): The target lifetime to be validated through testing

- 1 year

- 5 years

- 10 years

Q\_5: What is the zero-failure test method?

A\_5: The zero-failure test method (referred to as "bogey test" in the automotive industry) is the most commonly used method in reliability validation testing. It is considered successful if the product does not experience any failures over a specified period.

Q\_6: Why is the zero-failure test preferred?

A\_6: It is mainly suitable for high-cost products where testing is expensive and time-consuming. For components like automotive parts or heavy equipment parts, where testing itself is costly and takes a long time, this method is used to quickly obtain results in a short period. Additionally, this method is relatively easy and straightforward because it only requires verification of whether any failures occur.

Q\_7: What is the N-failure test method?

A\_7: It is a test method used to determine how long it takes for a product to fail. For example, testing continues until a certain number of products fail, and the results are then used to evaluate the reliability of the product.

Q\_8: What is the percentile (B-life) in reliability validation testing?

A\_8: Percentile (B-life): $B\_{10}$ life refers to the point in time at which 10% of the products are expected to fail. For example, if the $B\_{10}$ life of an automotive part is 1,000 hours, it means that after 1,000 hours, 10% of that part's units are expected to have failed.

Q\_9: What is the reliability criterion in reliability validation testing?

A\_9: Reliability criterion: In reliability validation testing, customers may require that the product's lifespan exceeds a specified time ($t\_{0}$). The criterion is demonstrated through testing to prove that the product meets this requirement.

Q\_10: What is the binomial distribution?

A\_10: The binomial distribution is used to calculate the number of times an event occurs within a fixed period. In reliability validation testing, the binomial distribution is used to calculate the probability that a product will not fail within a specified time.

Q\_11: How is a validation test using the binomial distribution conducted?

A\_11: It is a method to determine the probability (reliability) that a product will not fail within a specified time ($t\_{0}$). This test verifies whether the product meets the expected reliability ($R\_{0}$) at a given confidence level (C).

Q\_12: How are the null hypothesis and alternative hypothesis set up in a validation test using the binomial distribution?

A\_12:

- Null Hypothesis $H\_{0}$ : $R\left(t\_{0}\right)\geq R\_{0}$ (The product's reliability is as high as expected.)

- Alternative Hypothesis $H\_{1}$ : $R\left(t\_{0}\right) < R\_{0}$ (The product's reliability is below expectations.)

Q\_13: Why are the null hypothesis and alternative hypothesis set up?

A\_13: In statistics, the null hypothesis ($H\_{0}$) is initially established to test whether it is correct. If the null hypothesis is concluded to be false, then the alternative hypothesis ($H\_{1}$) is considered to be true. In reliability testing, the null hypothesis typically assumes that the product's reliability is sufficiently high.

Q\_14: Is it okay to assume in the alternative hypothesis that the product's reliability is as expected, instead of the null hypothesis?

A\_14: Theoretically, it's possible, but typically, the null hypothesis assumes that the product works as expected. If you set the alternative hypothesis first, it assumes that the product lacks reliability. Therefore, the more common approach is to start with the null hypothesis, test it, and if it is rejected, then adopt the alternative hypothesis.

Q\_15: What is the validation test method using the binomial distribution?

A\_15:

- Sample size (n): Test n randomly selected products.

- Critical number of failures (c): During the test period ($t\_{0}$), the null hypothesis ($H\_{0}$) is accepted if no more than c products fail.

- Number of failures (r): The actual number of failed products during the test.

- If the number of failures (r) exceeds the critical number of failures (c), the null hypothesis ($H\_{0}$) is rejected, and the product is deemed to not meet reliability expectations.

Q\_16: What is the critical number of failures?

A\_16: The critical number of failures is the maximum allowable number of failures during the test. If the number of failures does not exceed this limit, the product is considered reliable; if it does exceed the limit, the test is deemed a failure.

Q\_17: Why is a larger sample size needed as the confidence level (C) increases?

A\_17: A higher confidence level (C) increases the trustworthiness of the test results. To achieve greater confidence, more data needs to be collected, which requires a larger sample size.

Q\_18: What is a threshold?

A\_18: A threshold is the value that, if exceeded, results in a failure in the test. For example, in reliability testing, if the number of failures exceeds the threshold, the product is considered to have failed to meet the reliability criteria.

Q\_19: How is the threshold calculated?

A\_19: The threshold is calculated based on the set confidence level (C) and reliability (R). It varies depending on the sample size and test duration and is determined in advance during the test design phase.

Q\_20: What is a zero-failure test (c=0) in validation testing using the binomial distribution?

A\_20: A zero-failure test is a method where no failures are allowed for the product to be considered reliable. To meet the required reliability $R\_{0}$ and confidence level C, a "minimum sample size (n)" is needed.

Q\_21: How do you calculate the sample size in a validation test using the binomial distribution?

A\_21: In a zero-failure test, the minimum sample size is calculated using the following formula:

$n\geq\frac{\ln\left(1-C\right)}{\ln \left(R\_{0}\right)}$

- $R\_{0}$: Required reliability (e.g., if 90% reliability is needed, $R\_{0} = 0.90$)

- C: Confidence level (e.g., for a 95% confidence level, C = 0.95)

Q\_22: Explain validation testing using the exponential distribution.

A\_22: Reliability validation testing using the exponential distribution is a method that verifies a product's reliability through its "mean time to failure (MTTF)" or "failure rate ($\lambda$)." This approach is commonly used in reliability testing because it assumes a constant failure rate and is mathematically less complex compared to other distributions.

Q\_23: What information is needed before starting a validation test using the exponential distribution?

A\_23:

1. Mean Time to Failure (MTTF) or Failure Rate ($\lambda$): The average time the product operates before failing, or how frequently it fails. For example, if MTTF is 100 hours, it means the product fails on average every 100 hours.

2. Confidence Level (C): The probability that the test will be successful.

3. Test Time ($t\_{0}$): The duration for which the product will be tested.

4. Allowable Number of Failures (c): The maximum number of failures permitted during the test.

Q\_24: What needs to be determined in a validation test using the exponential distribution?

A\_24: Sample Size (n): The number of products to be tested needs to be decided. This value is calculated based on the confidence level (C), mean time to failure (MTTF), and allowable number of failures (c).

Q\_25: What are the types of validation testing methods using the exponential distribution?

A\_25:

- Replacement Test: This method involves replacing failed products and continuing the test. It allows for accurate calculation of reliability.

- Formula for calculating sample size (n) in a replacement test: $n\geq\frac{\theta\_{0}\chi\_{1-C}^{2}\left(2c+2\right)}{2t\_{c}}$

- Non-Replacement Test: This method continues the test without replacing failed products. It provides an approximate calculation.

Q\_26: What is the zero-failure test method for the exponential distribution?

A\_26: In the zero-failure test method, the test is considered a failure if any failures occur, and it cannot validate the MTTF.

- Sample Size: $n=\frac{\theta\_{0}\chi\_{1-C}^{2}\left(2\right)}{2t\_{c}}=\frac{-\theta\_{0}\ln\left(1-C\right)}{t\_{c}}$

- Test Time: $t\_{c}=\frac{-\theta\_{0}\ln\left(1-C\right)}{n}$

Q\_27: What is the validation test plan when following the Weibull distribution?

A\_27: The Weibull distribution is a statistical model used to predict product lifetimes. This model is used to verify the product's reliability.

Q\_28: What is the purpose of validation testing when following the Weibull distribution?

A\_28: To demonstrate how reliably the product operates up to a specific time.

Q\_29: What is the percentile life in validation testing when following the Weibull distribution?

A\_29: It indicates the probability of the product failing at a specific time. For example, $B\_{10}$ represents the time at which 10% of the products are expected to fail.

Q\_30: What is the basic assumption in validation testing when following the Weibull distribution?

A\_30: It is assumed that the product's lifetime follows a Weibull distribution.

Q\_31: What is the shape parameter ($\beta$) in validation testing when following the Weibull distribution?

A\_31: The shape parameter ($\beta$) describes the failure pattern of the product. For example, if $\beta$ is greater than 1, the probability of failure increases over time.

Q\_32: What is the scale parameter ($\eta$) in validation testing when following the Weibull distribution?

A\_32: The scale parameter ($\eta$) affects the average lifetime of the product.

Q\_33: What is the reliability function in validation testing when following the Weibull distribution?

A\_33: The reliability function calculates the probability that the product will not fail up to a specific time. $R\left(t\_{c}\right)=\exp\left[-\left(t\_{c}/\eta\right)^{\beta}\right]$

Q\_34: What is the validation test plan when following the Weibull distribution?

A\_34: In the validation test plan for the Weibull distribution:

- Test Time ($t\_{0}$): If no failures occur during the specified time, the product is considered to meet the required reliability.

- Minimum Sample Size (n): To ensure a high probability of no failures, the necessary number of test units is determined.

Q\_35: What is the accelerated life testing when following the Weibull distribution?

A\_35: Accelerated life testing involves applying higher stress to the product to complete the test within a realistic time frame.

- Acceleration Factor (AF): A value that indicates how much the lifetime is reduced due to the increased stress level.

- Actual Test Time ($t\_{a}$): The time tested under accelerated conditions, which is converted to the equivalent time under normal use conditions. $t\_{a}=t\_{1}/AF$

Q\_36: What are the confidence level and test duration in validation testing when following the Weibull distribution?

A\_36:

Confidence Level (CL): The probability that the test will be successful. As the confidence level increases, the test duration becomes longer.

Q\_37: What are the hypotheses in validation testing when following the Weibull distribution?

A\_37:

- Null Hypothesis ($H\_{0}$): The product's percentile life is equal to the target life.

- Alternative Hypothesis ($H\_{1}$): The product's percentile life is greater than the target life.

Q\_38: What is the practical application of validation testing when following the Weibull distribution?

A\_38:

Process Validation: To verify the stability of the production process, a lower confidence level, such as 60%, may be used.

Q\_39: What is the one-failure test plan in Weibull distribution testing?

A\_39: It allows for up to one failure during the test. In other words, if a single failure occurs during the test, the entire test can still be considered successful.

Q\_40: Why is the one-failure test plan used in Weibull distribution testing?

A\_40:

1. Reliability Information: It is used to verify if a new product design is an improvement over an existing design. If the new product provides better reliability than the existing one, this test can demonstrate that fact.

2. Reduced Failure Probability: Since the test is considered successful even if one failure occurs, the probability of failing the validation test is reduced in cases where the product has a low failure rate.

Q\_41: Why are different distributions used in binomial, exponential, and Weibull reliability testing?

A\_41: Each distribution is used based on the failure pattern of the product:

- Binomial Distribution: Used to check for failures within a specific time period.

- Exponential Distribution: Used to evaluate the mean time to failure (MTTF) under the assumption of a constant failure rate.

- Weibull Distribution: Used when the failure rate changes over time.

Q\_42: What does 'stress' mean in reliability testing?

A\_42: Stress refers to the various external pressures that a product is subjected to during operation. For example, thermal stress examines how well a product functions when exposed to high temperatures, while vibration stress tests the product's ability to withstand shaking. These stresses are used to assess how well the product can endure under actual use conditions.

Q\_43: How are test time ($t\_{c}$) and demonstrated life ($t\_{0}$) different?

A\_43: Test time ($t\_{c}$) is the actual duration during which the product is tested, while demonstrated life ($t\_{0}$) is the target lifespan of the product. For example, if the target lifespan ($t\_{0}$) is 1 year, the test evaluates whether the product can operate without failure for 1 year. The test time ($t\_{c}$) is the period over which the actual testing is conducted to validate this target.

Q\_44: Why can the definition of failure vary between tests?

A\_44: The definition of failure can vary because different products have different criteria for what constitutes a failure. For example, for a computer, a failure might be defined as the system not powering on, while for a smartphone, a failure might be defined as a cracked screen or non-functional buttons. The specific conditions that are considered a failure must be defined based on the characteristics of each product before the test.

Q\_45: In an N-failure test, if the number of failures (r) exceeds the critical failure number (c), does that always mean failure?

A\_45: Yes, the critical failure number (c) represents the maximum number of failures allowed. If the number of failures (r) exceeds this threshold, the test is considered a failure. This means the product has not met the expected reliability.

Q\_46: What is the difference between reliability and confidence level?

A\_46: Reliability (R) is the probability that a product will operate without failure for a specified period, while the confidence level (C) indicates how confident we are that this reliability estimate is accurate. In simpler terms, reliability is "the chance that the product won't fail," and the confidence level is "how much we trust that this chance is accurate."

Q\_47: What is the difference between replacement testing and comparison testing?

A\_47: Replacement testing involves replacing a product as soon as it fails and continuing the test, which provides more accurate data. In contrast, comparison testing does not replace failed products and continues with the remaining units. This method is simpler but may introduce some error.

Q\_48: Why is one failure allowed during testing?

A\_48: Allowing one failure during testing can indicate that the product has high reliability. If the product is highly reliable, a single failure may not significantly affect the overall reliability of the product line. This approach is used to test whether improvements in reliability have been made, and it reflects that the product's reliability is already high.