Report 2

Great Expectations for the Combined Environmental Reliability Test (CERT)

For high assembly level or finished products

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A large number of failures in the field are caused by conditions resulting from how the surrounding environment interacts with the internal characteristics of a product, creating the immense challenge of discovering this interaction as quickly and cheaply as possible. One means of doing so is the Combined Environmental Reliability Test (hereafter, CERT), based on combining accelerated factors. When using this test, both the environmental conditions for product use and product characteristics are considered in advance, and used to hypothesize the types of failure likely to occur. After first contemplating conditions unlikely to produce failure, a CERT profile is drawn up according to a reproducible mechanism for the test failure modes. In this report, I would like to present a brief explanation and introduction that can also serve as a guideline for inaugurating CERT. We shall take a close look at the correlation between failure modes and environmental stress factors and I shall discuss accelerated results, including new failure modes occurring under conditions of both combined and independent stress failure modes being used. We shall also consider application of stress failure modes to reliability testing under combined conditions that are as close as possible to the actual environment.

1. Introduction

Recent years have brought clear indications of changes in the demands by society as well as changes in the needs of corporate management for safety and reliability, i.e., quality, of not only electronic devices, but equipment in other fields as well. When looking at the forces behind these changes, one can see that the strongest influence comes from the mandates for safety and environmental measures. In other words, these are compulsory needs linked to the product liability law, ISO 14,000 and CE marking, as well as changes in materials and products resulting from those needs and producing increasing revision in all areas, including policies for development, design, and quality. Secondly, calls are also being made for reducing product development time as well as evaluation time for the wear-out failure phase occurring in the field. These goals cannot be attained without revising the time-consuming system for confirming reliability. Thirdly, the expanding use and scope of systems and networks has brought a corresponding risk of affecting the entire system through failures in terminals or attached equipment, and resulting in a trivial defect causing an unthinkable loss. And finally, the new age emphasis on human experience has led to the pursuit of “quality perceived by the five senses”.

These developments have generated fresh desire for progress in safety and reliability testing, and as one measure for making headway in that direction, we have great expectations for results of CERT profiles in combined stress, and so we are devoting new studies to this area.

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2. Great expectations for CERT along with some basic items

2-1 CERT effectiveness

The intensity of Environmental Stress Testing (hereafter, EST) and Environmental Stress Screening (hereafter, ESS) depends on such factors as the range of stress, the ratio of change, and the number of factors and cycles. Even in independent stress testing, increasing the complexity can accelerate the test 3 to 5 times. In CERT testing, 2 or more environmental factors are combined with the aim of accelerating each factor 3 to 5 times, producing an overall acceleration of tens or hundreds of times. Combining stress factors not only accelerates the failure mode for each stress factor, it also raises the possibility of introducing completely new failure modes.

Fig.1 shows the types of failure modes introduced by combining stress factors. In actual testing the results are not as simple as they are represented in the drawing, but you can see that X, Y, and Z are the failure modes corresponding to independent stress factors A, B, and C when applied independently. Combining two stress factors creates the new failure modes XY, XZ, and YZ, and combining all three factors results in the additional XYZ mode, while at the same time accelerating each failure mode (X, Y, and Z). The combined ABC environment more nearly recreates the environment encountered in the field than do the independent environments.

Because of this, we have great expectations that CERT will be able to achieve important results by predicting failure modes and testing according to failure mechanisms.

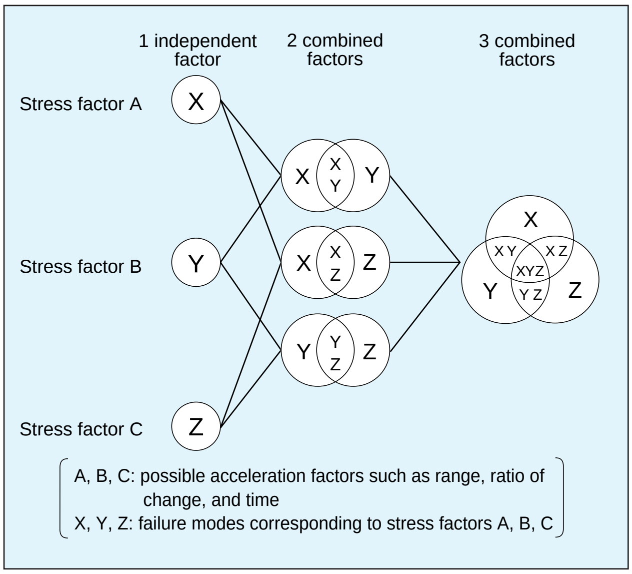


Fig. 1 Types of combined stress results

2-2 Failure and test conditions

Even in the same product one can find wide variances in safety and reliability depending on field environment conditions, manufacturing conditions, and characteristics of the product composition. Therefore, we must clearly acknowledge that failure does not occur or accelerate merely under test conditions. In other words, failure is caused by factors such as heat, current, stress, and strength of electric field characteristics concentrated at specific areas of the product, or by changes in or interruptions to those concentrations, as well as by characteristics (materials, composing parts, processing methods, and device structure) built in during the process of designing and manufacturing the product. This complex process leading to failure means that we must study test conditions from the standpoint of product characteristics and draw up a CERT profile. The test profile of any individual product is specific to that product, so if the test profile isn't reconsidered when the product changes, a mistake caused by the misapplication of MIL-STD-810C (Environmental Test Methods) produces the risk of the mistaken standards becoming incorporated into the design conditions and resulting in completely unexpected failures in the field. In other words, despite the fact that the usage environment no longer matches the characteristics of the product, the standards become part of the design conditions, so there is a danger of unexpected failures occurring in the field.

2-3 CERT as security against unexpected failure

Failure often occurs unexpectedly when we may be paying attention, but not quite closely enough. Quite frequently when considering an unexpected failure after the fact, one realizes that the failure was entirely predictable and thus usually avoidable.

Classifying failure according to physical and chemical causes produces 30 general classifications and 70 subclassifications. In spite of these groupings already being known and researched by specialists, many product designers are still unaware of them and produce designs that are tripped up by these failures. Also, extreme values can be produced by using optimum acceleration conditions rather than maximum acceleration conditions, resulting in intended improvements actually diminishing performance. As time passes, failure can also occur due to unexpected environments or conditions such as a combination of materials whose characteristics aren't suited to the environment or aren't suited to each other.

We can consider these problems using the CERT effects in item 2-1, develop an actual environment CERT profile, and use it to guard against failure in the field. This approach is based on the fact that when analyzing actual failures in the field quite a few serious problems are caused by conditions with a combination of stress factors.

3. Examples with hints for drawing up a CERT profile

Table 1 (page 19) gives examples of independent stress used in CERT for high assembly level or finished products. This table can be used to study the use of CERT by focusing on actual examples which can give us some hints.

The wide variety of causes for failure, such as seen in Table 1, includes such factors as rubbing, expansion, contraction, contamination, dehumidifying, evaporation, condensing, dew condensation, moisture absorption, chemical and physical reactions to light, changes in mechanical stress, changes in the friction coefficient, or changes in the heat transmission rate. I would like to discuss the effects of actual CERT examples according to test purposes and the failure modes (mechanisms) caused by the above-mentioned factors. Please note that numbers (1) through (15) as used here will correspond to the types of independent stress shown in Table 1.

3-1 CERT using temperature, humidity, and vibration

The three factors of temperature, humidity, and vibration are basic environmental factors that are ubiquitous throughout the earth, and as such compose the core of CERT factors. Research can confirm that 80 percent of all failures in the field can be correlated to these three factors (temperature 40%, humidity 20%, and vibration 20%). In a breakdown of the products in the environmental test equipment field shipped by our company, fully 85 percent of these products currently include the ability to test these three factors independently or combined. All other environmental stress factors such as gas, sand, dust, snow, saltwater, atmospheric pressure, and exposure to sunlight are based on combinations with temperature and humidity (or vibration) and so these three environmental factors always form the basis when designing CERT.

3-1-1 Combined failure modes caused by a drop in the friction coefficient

When applying heat stress with a temperature cycle, we can confirm failure modes such as failure caused by materials from differences in material quality (thermal expansion coefficient) and mass (heat capacity) as well as other modes such as mechanical failure or failure due to changes in electrical characteristics. On the other hand, when performing CERT with temperature, humidity, and vibration combined and applying independent stress failure mode acceleration, we can confirm the occurrence of new failure modes caused by the combined stress multiplication effect.

(1) Failure mechanisms

When a product with different thermal expansion coefficients is moving (expanding and contracting) in temperature cycle (1), “peeling” and “loosening” occur. If humidity (3) is applied at that point, moisture penetrates into the cracks, and the coulomb friction coefficient drops in the joints and contact areas. Applying vibration (8) at this point will increase the overall response at a specific frequency. For example, when changing from a dry to a wet condition, the response of the joint surfaces doubles due to the drop in the friction coefficient. In this way, by repeatedly applying factors such as movement, absorption, freezing, and resonance, we are able to evaluate new failure modes produced by significantly accelerating the independent factor failure mode as well as utilizing the three-factor combined multiplication effect. Also, if we make a combination by replacing vibration (8) with vibration (10), continuing the resonance in the specific frequency leads to rupture even at the low acceleration of 0.1G.

(2) CERT program example

- (1) × (3), (1) × (8) — 10 cycle
- (1) × (3) × (8) — (8) Random (Refer to Fig. 2)
  — (8) Sine (at 5 to 200 Hz, 0.5G, 5 min. sweep)
- (1) × (3) × (10), (1) × (10) — Fixed at product resonance frequency, 1.0G
- (7) × (1) — At constant 95^{+5}_{-0} % RH, temperature cycle 30C°↔60°C
- (7) × (8), (9), (10) — According to purpose of the test

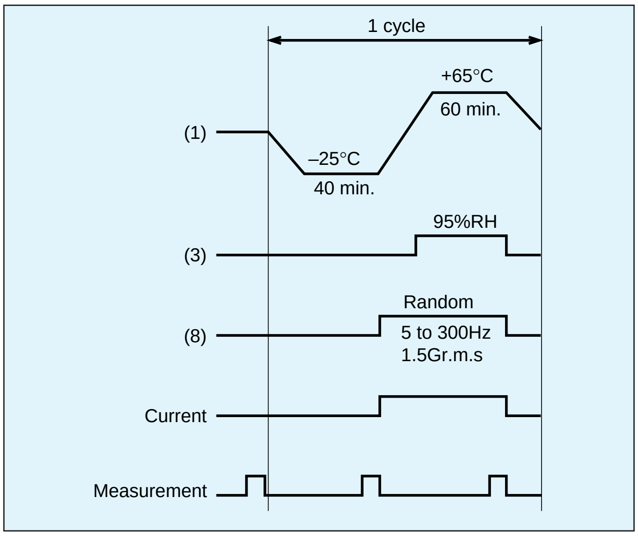
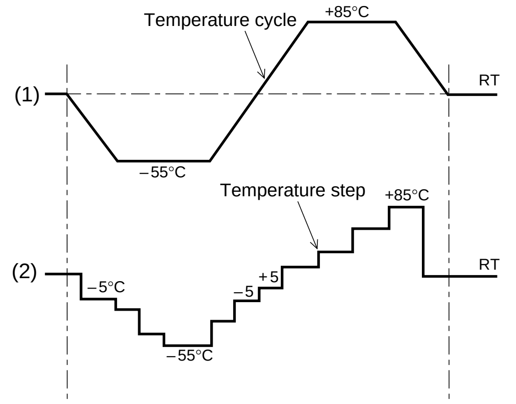
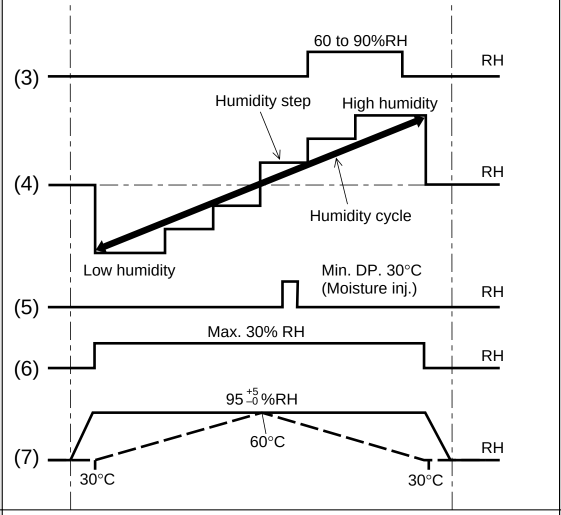
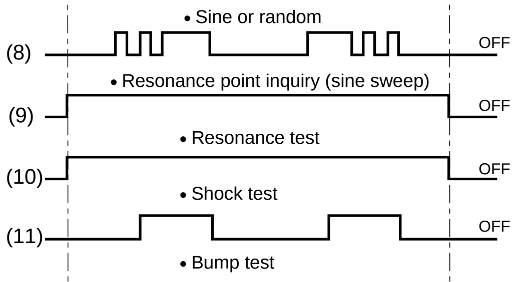
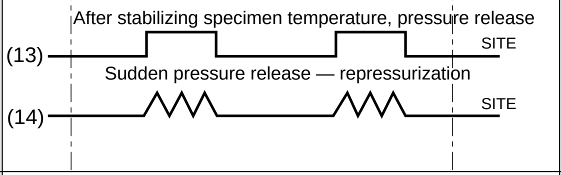
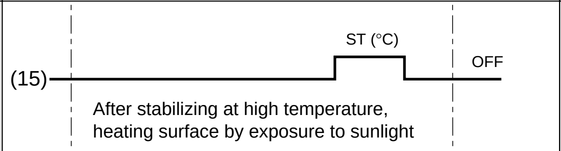
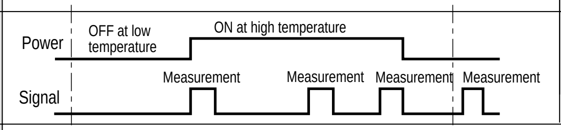
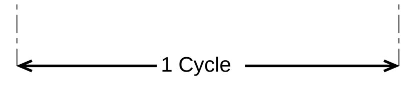


Fig. 2 Temperature-humidity-vibration CERT

Table 1 Examples of independent stress, failure (mode), and test equipment (for high assembly level and finished products)

<table>
<tr><th></th><th>Representative types of independent stress</th><th>Stress levels</th><th>Failure (modes)</th><th>Test equipment</th></tr>
<tr><td>[A] Temperature</td><td> </td><td>Rate of temperature change in (1)<table><tr><td>Low</td><td>0.5 to 2.5°C/min.</td></tr><tr><td>Mid</td><td>5 to 15°C/min.</td></tr><tr><td>High</td><td>30 to 90°C/min.</td></tr></table>Test temperatures in (1) and (2) (°C)<table><tr><th>Low temp.</th><th>High temp.</th></tr><tr><td>+5</td><td>(+125)</td></tr><tr><td>–5</td><td>(+105)</td></tr><tr><td>–10</td><td>(+100)</td></tr><tr><td>–25</td><td>(+95)</td></tr><tr><td>–35</td><td>+85</td></tr><tr><td>–40</td><td>+70</td></tr><tr><td>–55</td><td>+55</td></tr><tr><td>(–65)</td><td>+40</td></tr></table></td><td>***Caused by heat stress (expansion, contraction)**
Failure of material surface, mechanical failure, cracking
***Caused by extreme temperature Changes in electrical characteristics, failure of sensitive parts**
• Increased wear on moving parts due to expansion and contraction, or due to degradation of lubrication
• Surface degradation and distortion
• Increase or decrease in viscosity or flexibility
• Promoting heat aging, or oxidation or chemical reaction due to heat aging
• Changes in electrical characteristics E.g., resistance, inductance, capacitance, power factor, dielectric constant
• Sealing defect in seal or gasket</td><td>• High temperature test
• Low temperature test
• Temperature cycle test
• Thermal shock test</td></tr>
<tr><td>[B] Humidity</td><td> </td><td>***As a rule, test conditions follow standards, actual examples, and actual environments**
One example of humidity conditions**<table><tr><th>%RH</th><th>0°C</th></tr><tr><td>95^{+5}_{-0}</td><td>30↔60</td></tr><tr><td>95</td><td>20 to 85</td></tr><tr><td>90</td><td>50 to 70</td></tr><tr><td>85</td><td>85 (45–)</td></tr><tr><td>20 to 95</td><td>85</td></tr><tr><td>60</td><td>20 to 65</td></tr><tr><td>50</td><td>25 to 60</td></tr><tr><td>30 to 90</td><td>5 to 15</td></tr><tr><td>20</td><td>71, 85</td></tr><tr><td>5 to 20</td><td>10 to 35</td></tr><tr><td>2-5 max</td><td>–35 to +55</td></tr><tr><td>45 to 98</td><td>–35 to +70</td></tr><tr><td>30</td><td>40 to 60</td></tr></table></td><td>Changes in humidity and temperature cause condensing and moisture absorption in parts and devices, and lead to corrosion, insulation degradation, and other problems.**
***Caused by extreme humidity**
Degradation of mechanical strength, distortion, and embrittlement
• Absorption of moisture content, adsorption (high humidity), increase in conductivity, corrosion, and expansion in electrolytic materials
• Evaporation of moisture content, drying (low humidity), contraction, static electricity, increased wear of moving parts
• Loss of plasticity
• Short circuit caused by dew condensation
• Sticking due to corrosion and contamination of lubrication</td><td>• Temperature and humidity test
• Try test
• Temperature and humidity cycle test
• Moisture resistance test
• Dew condensation test
5°C 60%RH ↔ 25°C 90%RH
–30°C Free ↔ 25°C 90%RH
• Humidity absorption test</td></tr>
<tr><td>[C] Vibration</td><td> </td><td>***Transfer test**
5 to 200 Hz, 1 to 5G, sine, random, shock
***Resonance point inquiry**
10 to 2000 Hz, 0.4G max., sine sweep
***Resonance test**
From fixed to ±3 Hz sine sweep, 5G max.
***Screening**
10 to 2000 Hz, 1 to 5G, sine, random</td><td>***Caused by mechanical stress**
Mechanical failure due to resonance, fatigue, loading stress, and other
***Caused by looseness and wear**
Increase in wear of moving parts
• Wires rubbing together
• Loose clamps, fasteners, and other
• Broken insulation at contact point, short circuiting, and
• Defective contact
• Cracking and breaking
• Electrical noise, optical misconfiguration</td><td>• Vibration test
Sine
random
shock
• Combined multi-axial test
Multiaxial, multi-dimensional vibration test that is near actual environment and that can be done in two or three directions at the same time</td></tr>
<tr><td>[D] Altitude</td><td> </td><td>***Examples of altitude conditions**<table><tr><th>kPa</th><th>mmHg</th><th>kPa</th><th>mmHg</th></tr><tr><td>84.2</td><td>633</td><td>11.6</td><td>87</td></tr><tr><td>59.9</td><td>450</td><td>4.4</td><td>33</td></tr><tr><td>29.9</td><td>225</td><td>0.13</td><td>1</td></tr></table></td><td>***Reduced thermal transfer coefficient of the air, reduced electrical strength, boiling at low temperature, and other**
• Sparks, corona, ozone, air bubbles
• Reduction of crystal oscillator load
• Breakage of sealed parts and structure</td><td>• Altitude test</td></tr>
<tr><td>[E] Exposure to sunlight</td><td> </td><td><table><tr><th>Atomosphere (°C)</th><th>ST (°C)</th></tr><tr><td>45 to 85</td><td>80 to 125</td></tr><tr><td>25 to 35</td><td>60 to 80</td></tr></table></td><td>***Extreme thermal stress distribution**
• Surface degradation, distortion, embrittlement weakening, color fading
• Reduced elasticity, heat aging, heat warping
• Internal heat rise, physical and chemical changes</td><td>• Exposure to sunlight (surface heating) test
• Sunlight equivalence test</td></tr>
<tr><td>[F] Power, signal</td><td> </td><td>***One example of source voltage**
Rated +5 to +10%
Rated –2 to –10%</td><td></td><td></td></tr>
<tr><td>[G] Time</td><td> </td><td colspan="3">(1) Number of cycles: 5 to 200 (to 1000, to 2000) cycles
(2) Test time: 12 to 500 (to 1000) hours
(3) Soak time: 10 to 60 minutes (until specimens stabilize)</td></tr>
</table>

(3) Combined failure mode and acceleration

(a) Independent failure mode acceleration series (failure mode with independent temperature, humidity, and vibration)

- Defective contact, open, short, defective insulation, battery corrosion
- Defects in fixed tools and fixed methods, part mounting defects, neighboring parts rubbing
- Gear engagement, chemical contamination, seal defects
- Materials and methods of attaching and joining, surface roughness of materials

(b) Combined failure mode series (failure mode with combined temperature, humidity, and vibration)

- Solder defect, broken lead, relay contamination, defective part determination
- Hardware looseness, peeling of coating from metal-resin group
- Characteristic defect of parts with no acceptance inspection, or inspection difficult to perform
- Continuous cracks in conductor pattern, through holes, or interior of multilayer substrate board
- Defects caused by cracks in parts due to soldering of Surface Mount Device (SMD) and cracks in solder
- Open or short circuits, at connectors or contact parts
- Defects caused by peeling or cracking of adhesion, filling, or coating
- Combined acceleration of independent failure mode in (a)

3-1-2 Cracking, corrosion, and fatigue related to the combined failure mode

(1) Fatigue and stress corrosion

It is well known that fatigue and stress corrosion are accelerated in the combined environment of temperature, humidity, and vibration, and that these two failure modes can appear independently or simultaneously. Failure such as embrittlement destruction of metals and stress corrosion cracking are accelerated by stress stemming from temperature change (1), and vibration (8) in a corrosive atmosphere (e.g., gas) and humidity conditions (3) and (7). In general, vibration causes fatigue through mechanical stress, but temperature and humidity also influence this process. Therefore, as the temperature rises there is a tendency toward shorter fatigue life.

(a) CERT program example

- (1) × (3) × (8) ┐ Refer to Fig. 3 (fatigue, corrosion, and stress corrosion)
- (7) × (8) ┘
- (2) high temperature × (10), (2) × (8) × (15), (2) × (4) × gas (corrosive gas)

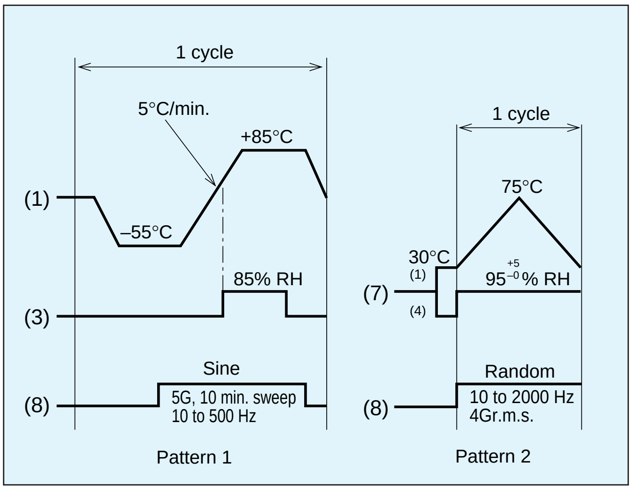


Fig. 3 CERT temperature, humidity, and vibration

(b) Combined failure mode and acceleration

- Extreme acceleration of corrosion and stress corrosion cracking
- Changes in strength and elasticity, and determination of structure, materials, and parts composing product
- Degradation of solder and adhesive

(2) Surface coating destruction and corrosion

Humidity causes surface corrosion, but does not strongly stimulate the interior of the substance. Therefore, in normal humidity tests (3) and (4), it is difficult to evaluate such areas as surface coating, sealing method (gasket, sealant), undercoating, and adhesion and joining methods.

Repeated expansion and contraction using temperature cycle (1) produces cracking in the surface coating and sealed sections. Applying humidity (3) and (4) at this point causes the moisture content to penetrate the interior. As the moisture diffuses through the interior it causes chemical reactions (oxidation, reduction, and neutralization) that take ionic substances from the periphery and from other components, and induce hydrolysis and electron movement.

Next, as a new interface is created, it produces precipitation of new substances, it causes corrosion, and accelerates under combined conditions. If vibration (8) is also applied at that point, the stress system response increases within the mechanism and accelerates corrosion and breakage of the corroded section. Results can include such problems as changes occurring in electrical resistance and PCB capacity, which can cause functional loss.

(3) Electrolytic corrosion

We know that when humidity is present in a direct current electrical field, electrolytic corrosion occurs in the presence of Cl (chlorine) and F (fluorine) ions. In particular, Al (aluminum) produces hydrochloric acid in the presence of chlorine ions, causing it to corrode. In condition (2) of this failure mode also, we can greatly accelerate the time leading to failure.

3-2 CERT using temperature, humidity, vibration, altitude (changes or drops in air pressure), and exposure to sunlight

Along with the demands for reducing product development time and evaluation time of the wear-out failure phase occurring in the field, I have presented a summary of the fact that when we analyze failure occurring in the field we often find that failure based on conditions combining various stress factors constitutes a major problem. As one approach to solve this problem, we find that in reproducing, independently and/or simultaneously, such conditions as temperature (A), humidity (B), vibration (C), altitude (D), and exposure to sunlight (E), chiefly in developing steps, performing EST and ESS, there is a CERT for confirming safety and reliability for all phases of the Bathtub curve (endurance life: initial failure, random failure, and wear-out failure), as well as for evaluating influences occurring under field conditions.

Below are presented some aims for CERT and their anticipated results.

- Establish external stress that reproduces as closely as possible the environmental conditions that the product encounters from the time of shipping from the factory until it is discarded, and aim for measures and/or development to obtain reliability under conditions of those kinds of stress.
- Aim for measures and/or development to find a truer correlation between the reliability values in testing and the reliability values in the field.
- In spite of the problems in failure analysis and measurement evaluation technology, aim to develop measures that can perform accelerated testing under more severe stress for the various factors than found in the field environment, and at the same time to reduce test time by combining factors.
- Think of roughly the same conditions as the product is exposed to in actual use, and be able to evaluate the influence occurring in the actual environment. Also, be able to promote the combined failure mode occurring from a combination of stress factors, and be able to take corrective measures in advance.

Current CERT testing is extremely close to these aims as it can independently and/or simultaneously test stress factors A, B, C, D, and E in these ways and is now able to reproduce a combined environment almost identical to that actually occurring.

Looking at shipping trends at TABAI ESPEC, there is almost no actual equipment that can simultaneously combine the five factors ABCDE, with most equipment able to handle ABCD and ABCE (i.e., using ABC as a base, add D (altitude) and E (exposure to sunlight) but not simultaneously). The major trends in testing are ABCDE for space equipment, ABCD for aircraft and space equipment, and ABCE for automobiles, cellular, and portable equipment.

Fig. 4 gives the TABAI ESPEC "Combined Environment Reliability Test Equipment: CERT Series" as a reference example of equipment.

Specifications

- Temperature: Air temperature, –70 to +150°C, 5°C/min.
  Wall surface temperature, –60 to +180°C (radiant heating and cooling walls)
- Humidity: 20% RH to 98% RH
- Altitude: Atmospheric pressure to 0.14kPa (1 mm Hg)
- Vibration: 5 Hz to 2000 Hz, random or sine
- Options: Dry air, moisture inj., ECA (External Cooling Air)
- Test area inside dimensions/capacity:
  CERT-22 W1500 × H1000 × D1500 mm/2.25 m^3
  CERT-33 W1500 × H1500 × D1500 mm/3.375 m^3

Fig. 4 TABAI ESPEC's Combined Environment Reliability Test Equipment: CERT Series

3-2-1 CERT using temperature, humidity, vibration, and altitude

(1) Trends in equipment and testing

To control the temperature of the chamber and the temperature of the specimens in this type of CERT equipment, the chamber has not only general ventilation, but also radiant heating and cooling inner walls as standard equipment to cover atmospheric pressure regions where there is less or no heat transmission from convection currents. (Refer to Fig. 4.) In addition, we can provide systems tailored to special needs, such as the dry air system to control low air pressure, low humidity (max. 10% RH) and no dew condensation, or the moisture injection system to cause dew condensation when atmospheric pressure and temperature rise, or the ECA (External Cooled Air supply) system programmed to heat and cool specific areas of the specimen.

Tests that have used this equipment have mainly been applications for one section of equipment mounted on aircraft or equipment mounted on automobiles (e.g., engine and ECU systems, sealed equipment systems), to identify failure that can occur under combined conditions resembling the actual environment, and to evaluate device characteristics occurring in storage and during transportation. However, in the present day and age, we have seen the miniaturization and increasingly mobile use of communications equipment, instrumentation equipment, AV equipment, computers and other equipment, along with their use in an ever-expanding range of environments, which has brought increasing opportunities for such stress as altitude and exposure to sunlight. Accordingly, the range of CERT use has expanded in step with these, to identify failure occurring in use at high altitudes and during air shipping and to take corrective measures in advance.

(2) Example of altitude CERT program

- (2) × (4) × (8) × (13) —— Refer to Fig. 5.
- (2) × (13) —— Abnormal heating
- (2) × (6) × (10) × (13) —— Wear
- (2) × (13) —— Limited region overheating
- (2) × (3) × (8) × (14) —— Coating breaking
- (1) × (4) × (10) × (14) —— Defective seal
- (2) × (6) × (8) × (13) —— Corona, electrical discharge
- (2) × (13)

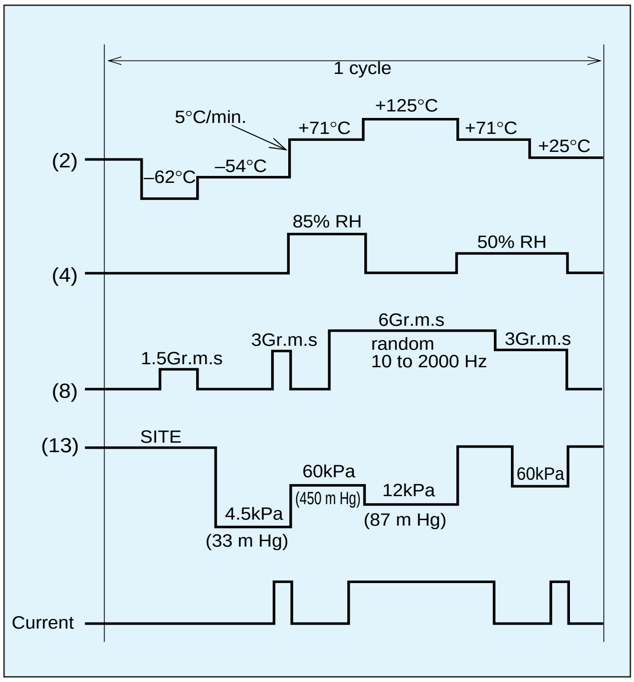


Fig. 5 Example of CERT with temperature, humidity, vibration, and altitude

(3) Test items for acceleration and combined failure modes

(a) Acceleration array of independent failure (modes occurring with independent atmospheric pressure testing)

- Use changes in atmospheric pressure to accelerate such items as action and leakage of respiration and promote failure modes such as an insulation drop, electrical breakdown, leakage from sealed containers, breakage and explosion of containers, and defective seals.
- Failures occur such as unstable operation of device due to corona and electrical discharge, drop in the life of electrical contact points, reduced load of liquid crystal oscillator.
- Temperature of device rises due to reduced thermal transfer coefficient with localized overheating of parts generating heat and emitting light.
- Degradation of functions due to physical and chemical deterioration of low density materials, degradation of elasticity, or penetration of low temperature section, contact section, or rotating section by generated gas.
- Low temperature boiling, evaporation of lubrication, or overloading, overheating, or wear of the rotating section.

(b) Array of combined failure mode (modes occurring with combined temperature, humidity, vibration, and altitude testing)

- (a) In addition, in a temperature, humidity, and vibration CERT failure mode, combined acceleration is possible in a mode with significant environmental effects from atmospheric pressure.
- Instability in engine start-up and combustion.
- Moving parts and system lock or looseness, structural parts coming loose or coming off.
- Electrical machinery systems failure due to frosting, dew condensation, or freezing
- Failure based on respiration, evaporation, or expanding and contracting of sections joining different types of materials. (Adhesion, molding, coating)
- Distortion and breakage of structural parts
- Breakage or failure of glass or optical system equipment
- Cracking of solid fuel
- A CERT profile can be drawn up with exposure under actual usage conditions, so it is possible to evaluate environmental effects using the actual environment.

3-2-2 CERT using temperature, humidity, vibration, and exposure to sunlight

(1) Trends in equipment and testing

In addition to the CERT systems with chambers that control temperature, humidity, and vibration, we also provide systems with lamps and irradiation intensity control for exposure to sunlight testing. The type of lamp differs according to the purpose of the test.

For example, when conditions of sunlight equivalency are required, xenon and halogen lamps are used either independently or in combination using wavelengths closely resembling sunlight to control “total amount of sunlight” in test conditions. On the other hand, when specimen surface temperature alone is important, inexpensive infrared lamps can be used to heat the surface, using “temperature” control in this case.

I shall deal with sunlight exposure testing with the infrared method in this item, but it is roughly the same as the testing trends and information in part (1) of item 3-2-1.

Temperature, humidity, vibration, and exposure to sunlight: CERT profile and environmental effects (exposure to sunlight test)

Evaluating the characteristics and endurance of equipment suffering surface heating under exposure to sunlight in addition to temperature, humidity, and vibration

<Accelerated evaluation of development>

Environmental effects of exposure to sunlight

<Accelerated evaluation of quality>

Effects of extreme heat stress on part surface

Strength is evaluated in regard to distortion and breaking due to heat stress from surface exposure to sunlight.

(1) Distortion, breaking, softening, and degradation of elasticity in such items as glass, resin, adhesives, case housings, and surface-mounted parts

(2) Sticking, looseness, or overheating of rotating or sliding parts

Effects of radiant heating on interior and periphery

Evaluating changes in the characteristics due to radiant heating from surfaces exposed to sunlight

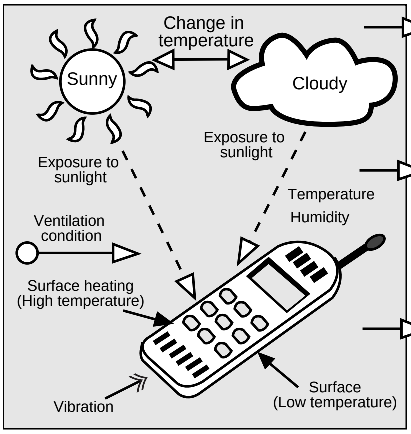
(1) Electrical characteristics, malfunctioning, softening, and degradation of elasticity of sealants, adhesives, substrate board, peripheral parts, and anti-moisture coating

(2) Overheating and changes in characteristics of parts generating heat and emitting light

Accelerated failure modes caused by temperature, humidity, and vibration

Example of exposure to sunlight and example of equipment subject to testing

<Example of conditions on cellular phones>

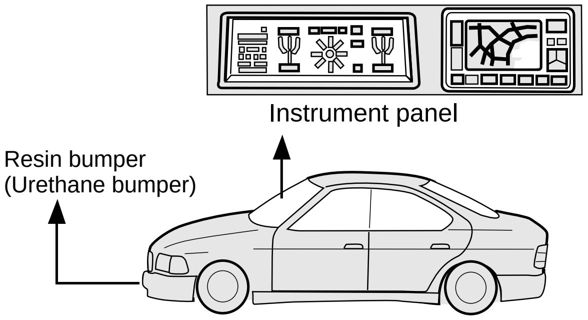


Left outdoors (sea, mountains, four seasons), or inside a sunroom or automobile

Conditions causing other stress (gas, dust, salt, dew condensation)

Sunlight energy (Max. 1000 W/m^2)

<Example of automobile conditions>



<Compact mobile equipment that can be used outdoors>

- Communications equipment
- AV equipment
- Instrumentation equipment
- Medical equipment
- Military mobile equipment
- Cameras, personal computers, and others

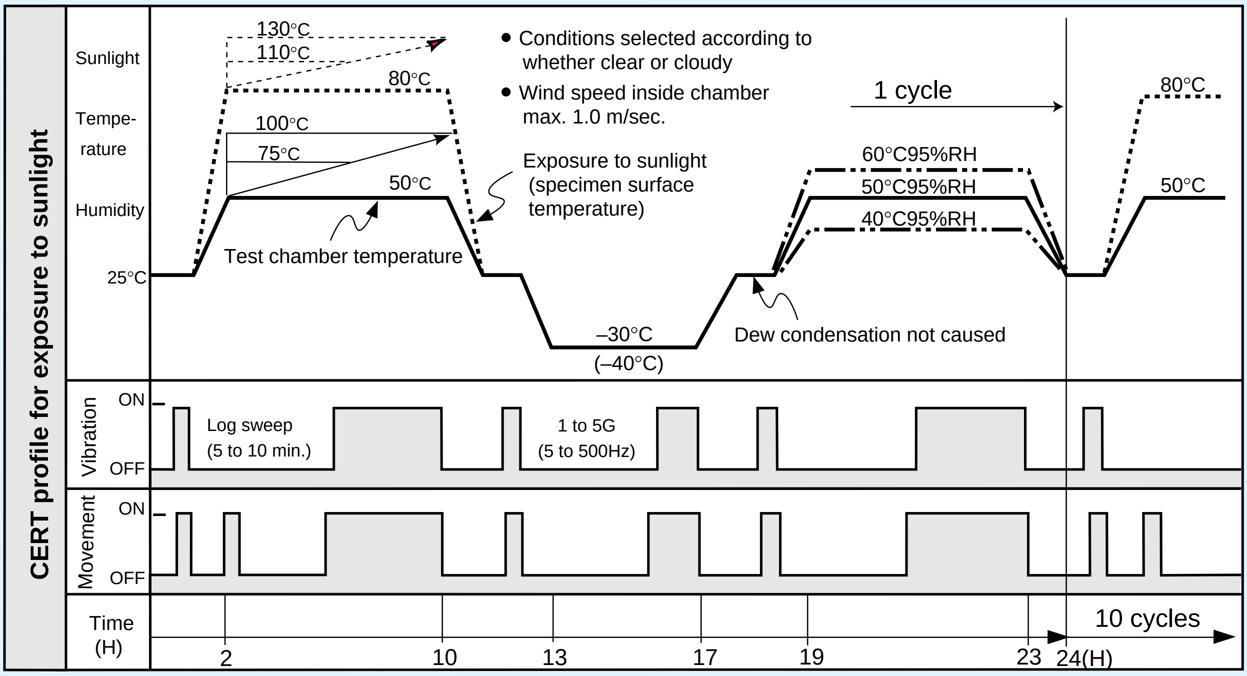


Fig. 6 Example of test conditions and effects (concrete examples of temperature, humidity, vibration, and exposure to sunlight)

(2) An example of a CERT exposure to sunlight program

- (2) × (4) × (8) × (15) —— Refer to Fig. 7 Distortion and breaking
- (1) × (8) × (15) ——— Surface coating

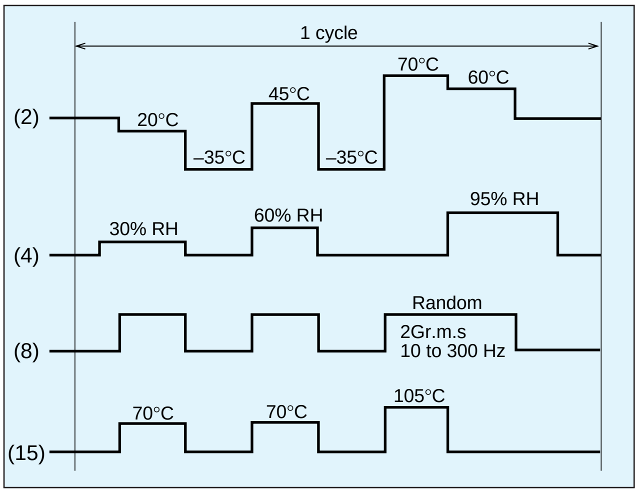


Fig. 7 A CERT example with temperature, humidity, vibration, and exposure to sunlight

(3) Test subjects for effects of acceleration effectiveness and environmental stress

Characteristics and endurance of a device are evaluated when the surface is heated in a sunlight exposure environment.

- Strength is evaluated for such conditions as warping and breaking under heat stress caused when a single side or a single surface is exposed to surface heating.
- Case housings, parts installed on the surface
- Glass, resin, coating
- Internally installed parts and machinery are evaluated for effects of surface heating.
- Softening and loss of elasticity of adhesive and sealant
- Sticking or looseness of rotating or sliding parts
- Malfunctioning or defective contact at electrical contact points
- Overheating of structure and parts generating heat and emitting light
- Acceleration of failure mode produced by temperature, humidity, and vibration

3-3 Key points in performing CERT

(1) In the resonance test (10), the test method must be selected according to the resonance mode shown in Fig. 8. In particular, when the resonance characteristics are sharp, normally a ±3 Hz sine sweep is desired to cause exposure at the peak.

(2) The effects of the vibration test generally depend on the axis of applied vibration (XYZ directions), so a test with triaxial capacity is planned.
In addition, one axis may have a stronger effect. (This tendency is strong in random vibration.)

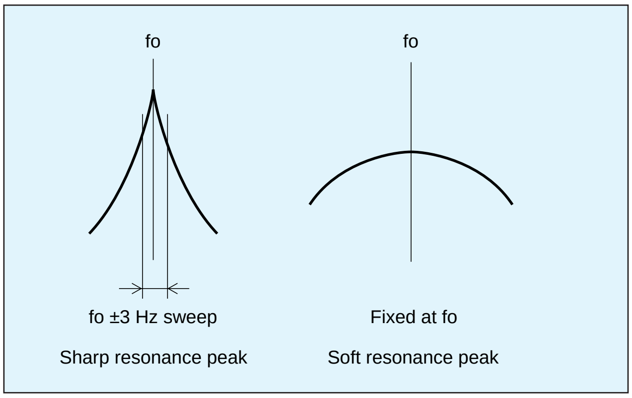


Fig. 8 Selecting test method according to resonance mode

(3) Due to miniaturization, surface-mounted substrate boards usually have few parts connected by soldered leads, and independent vibration stress produces almost no effect. CERT is also effective in this type of case.

(4) The test effectiveness is higher when the temperature range of temperature cycle (1) is at least Δ = 80°C.

(5) As a rule, the specimen power supply is OFF from the beginning of the temperature drop to the end of the low temperature period. The purpose is to achieve the target temperature quickly.

(6) When there is a change in the rate of temperature change, the soak time must be reconfirmed. Particular care is needed when the rate of change has increased, as the intended strengthening of stress becomes the opposite, a weakening.

(7) It depends as well on the atmospheric pressure of the test day, but as a rule it is better to avoid a 100°C (boiling) test and a 0°C (freezing) test. This is because erratic heat conditions may result when the specimen contains moisture in the test chamber with its precision settings and precision adjustments. However, it may sometimes be a bold idea to perform tests under these conditions.

(8) Humidity absorption (humidity resistance) tests and dew condensation tests have different objectives, so conditions are not set to produce dew condensation during a moisture absorption/ moisture resistance test.

(9) When including altitude stress in a combined test, the temperature of the specimen must always be monitored because the air density drops and the thermal transfer coefficient worsens. This makes it difficult for the specimen to reach the temperature target. In this type of situation, radiant heat and cooling equipment can be used together in the equipment provided in the test chamber. By the way, heat exchange using general ventilation equipment reaches its limits at 11.6kPa (87 mm Hg) and completely ceases to function below 4.4kPa (33 mm Hg), so radiant heating and cooling equipment are essential.

(10) I mentioned in item 2-2 that failure occurs based on the combination of conditions of the test and the product characteristics (materials, composing parts, processing methods, and device structure), but in the complex environment profile of CERT, if a hypothesis of the failure mechanism based on the internal characteristics of the product is not reflected in the test profile, it becomes difficult to specify the cause when failure occurs, and when drawing up a revised failure mechanism profile it becomes necessary to retest.

(11) In vibration testing, the multiaxial, multidimensional test equipment can be used to avoid the complex set-up and changeover work in reproducing the vibration environment close to the actual environment, and in the XYZ triaxial test.

3-4 The acceleration test and the acceleration factor

To understand the basic philosophy, refer to “Guidance for acceleration testing and reliability” in issue No.4 of the Japanese edition of Technology Report. The section on environmental test standards and environmental test methods is almost completely devoted to accelerated testing. Here, we shall consider the common problem of the acceleration factor, for which a solution has not been forthcoming. Research is being carried out on devices and special failure modes reporting many examples, but when a high assembly level beyond the PCB is reached, the situation becomes too complex to serve as the subject of debate and research. Rather, when the temperature is raised by 30°C in a test of completed products, just how much acceleration is achieved depends on the individual product and its characteristics, and the subject becomes even more difficult. At present we can only compare results with past test data and experience, and the problem presents no quick solutions.

Further, concerning item (4), let me note that the values specified are the greatest common denominator from a variety of irregular data.

(1) How to determine acceleration

Because this is a relative problem, we must base it on something such as past data.

1) With the same specimen, set two or more different stress levels, and using the same failure mode as the judgment standard, perform a “life test”. In this case, we must carry out prior screening and remove initial failure.
2) When data from actual test results has been plotted onto a graph of “test time — cumulative failure rate”, if the curve of stress parameters has the same distribution, this can be determined as related to acceleration.

(2) How to consider acceleration tests

These tests are carried out in accordance with failure mechanisms, but at present this process cannot easily be accelerated uniformly.

Therefore, acceleration test planning must be done to reduce the reaction process that requires so much time. Because of that, the deciding factor is knowing how the product breaks down, and knowing the mechanism leading to failure.

(3) IC acceleration factor

This example was reported more than 10 years ago, but it is included here for reference.

Table 2 Acceleration factors for moisture absorption time in every type of environment (for ICs)

No.	Moisture absorption conditions	Acceleration factor	
1	Interior storage	1	• Measuring changes in weight after storing for 1 year yields an acceleration factor of 1 for interior storage. • The acceleration factor of the pressure cooker test is ten times the factor for the humidity absorption test.
2	Soaking in distilled water	11	
3	High temperature, high humidity (65°C, 95% RH)	125	
4	High temperature, high humidity (85°C, 85% RH)	310	
5	Boiling	1240	
6	Pressure cooker (134°C, 100% RH, 3 atm)	3100	

Table 3 Acceleration factors from actual testing of cumulative failure rate from test time (for dual high-powered ICs)

No.	Test conditions	50% life	Acceleration factor	
1	30°C, 81% RH	(2,780,000Hr)	(1.8×10^{-3})	• The values for condition No.1 are hypothetical • There is temperature dependency in the acceleration factor.
2	85°C, 81% RH	3,300Hr	1	
3	115°C, 81% RH	446Hr	7.4	
4	130°C, 81% RH	85Hr	38.8	
5	150°C, 81% RH	10.4Hr	266	

(J.E.Gunn model)

(4) Acceleration trends with high assembly level specimens

Table 4 When changing temperature Ta in the constant temperature storage test

No.	Constant temperature storage temperature Ta	Effects and acceleration factor
1	Ta < 50˚C	Up to 50˚C, no major differences in effects are anticipated from changing Ta.
2	60˚C < Ta < 120˚C	Increases 80 to 100% for every 10˚C rise (with 60˚C as 1).
3	Ta > 120˚C	Increases 40 to 60% for every 10˚C rise (with 60˚C as 1). However, damage to the specimen is highly probable.

Table 5 When changing temperature change rate Tr in the temperature cycle test

No.	Temperature change rate Tr	Effects and acceleration factor
1	Air: Tr < 2°C/min.	Up to 2°C/min. no major differences in effects are anticipated from changing Tr.
2	Air: 5°C/min. <Tr < 10°C/min.	Factor increases 10 to 20% for every 1°C/min. increase (with 5°C/min. as 1)
3	Air: 10°C/min. < Tr < 30°C/min.	Factor increases 15 to 30% for every 1°C/min. increase (with 5°C/min. as 1)
4	Liquid: Tr > 40°C/min.	Increases 4 to 6 times with an inactive liquid (with air as 1)

Table 6 When changing temperature range ΔT of the temperature cycle test (When Tr = 5 to 15°C/min.)

No.	Temperature range Δ	Effects and acceleration factor
1	ΔT < 80˚C	Up to a temperature range width of 80°C, no major differences are anticipated from changing the ΔT.
2	ΔT > 80˚C	Increases 10 to 20% for every 10°C increase in width of ΔT.

Table 7 When changing the degree of acceleration of sine wave vibration (20°C<Ta<100°C)

Vibration is not essentially an accelerated test. It is meant to be done at actual environment frequencies and G characteristics and does not fundamentally belong in this item.

No.	Degree of acceleration St	Effects and acceleration factor
1	St < 1G	Even low-level vibration can produce dramatic results depending on the purpose.
2	2G < St < 10G	Factor increases 40 to 60% for every 1G increase (with 2G as 1)
3	St > 8G	Fatigue occurs readily, making it difficult to confirm failure.
• The higher the exposure temperature, the greater the effects, and at 100°C the effect increases 2 to 3 times over the effect at 20°C.		

4. In conclusion

I have discussed expectations for CERT, aims and hints for introducing this type of testing, key points for performing the tests, and guidelines for acceleration factors, but there are difficulties associated with adjusting failure modes and accelerated effects in a combined stress environment for high assembly level specimens. However, accelerated effects of failure modes occurring in a combined environment or failure modes in independent environments and actual failures occurring in the field are actually produced by a combination of stress factors in a combined environment. I believe there are great expectations for CERT concerning how to confirm such matters as the fact that safety and reliability differ even in the same product depending on the production conditions and the life cycle environment conditions, and whether such problems can be corrected in advance. Also, since the enactment of the product liability law, the manufacturer bears responsibility for safe use even for products that have reached the wear-out stage, and so CERT can be used to ensure safe use in the field throughout the life of the product. In addition, we have great expectations for CERT as a means of reviewing system safety and reliability evaluations to counterbalance the “production while developing and improvement while producing” stance to shorten the time it takes to get products to market.

[Reference Bibliography]

1) MIL-STD-810E

2) MIL-STD-781D/MIL-HDBK-781

3) “Bibliographical Investigative report on Combined Environmental Testing”, Kansai Electronic Industry Development Center (1986)

4) Which Environmental Stress Screens Should Be Used D Karam (1981)

5) Guidelines and Tailoring for Improved Process Control and Product Performance IES (1990)

6) “Reliability Testing: Outline and Equipment Parts”, Union of Japanese Scientists and Engineers (1985)

7) Toshio Yamamoto: “Guidance for acceleration testing and reliability”, Technology Report (Japanese edition) No.4 (1995)