ELTEK International Laboratories

EIU Course 101, Classes 1, 2, and 3: The Big Picture

Class 1: The T.E.A.M. Concept

Manufacturers of end-products are focused on the application and safety of operation. For companies that manufacture products for households, the applications are expected to be used indoors in a relatively controlled climate. Manufacturers of products for use in heavy-duty earth moving equipment know that the temperature variations and weather conditions, as well as the physical vibrations during operation, will be extreme.

These two markets need and select different groups (systems) of materials for these different applications. In simplified terms, the application determines the selection of (1) materials used, (2) the Electrical Insulation Systems, (3) the design and (4) concerns about compatibility.

The real-world applications require addressing safety and performance requirements from many factors. To evaluate the total application environment requires testing of the multiple factors, commonly referred to as multi-factor testing.

The T.E.A.M concept is related to the multi-factor requirements of the real-world application of any end-product. The concept is intended to focus on the factors which can lead to aspects, safe operation and safe failure of an E/E (Electrical/Electronic) device. End-products must perform based on the expected environment of the intended use.

By understanding this concept, the overall multi-factor safety and performance requirements can be separated into manageable, smaller tasks. After collecting the technical information as single-factor or simplified-factor testing, the results can be integrated to provide more information needed to find solutions.

The T.E.A.M concept works best with the English language because of the meaning of each letter. The word TEAM is formed by using the first letter of four individual words which describe possible sources of stress; therefore, possible areas to evaluate. The four words are:

Thermal **E**lectrical **A**mbient **M**echanical

Without separating the total multi-factor stresses into smaller more manageable areas, it is difficult to conduct any test to evaluate the total multi-faceted stresses of the real world. Applying the T.E.A.M. concept to the testing of EIMs and EISs makes the process easier because the T.E.A.M. stresses are broken down into four individual areas of testing. The results can be integrated to provide insight to the total T.E.A.M.

Let's explore the meaning of each letter:

THERMAL

One of the leading causes for loss of a property is the decomposition of the molecular structure within the EIM and/or EIS. Decomposition is a *chemical* process. Each chemistry, or molecular structure, will have a decomposition rate based on the specific chemistry. The fact that a molecular structure decomposes does not mean that the properties will be reduced.

For some molecular structures, the decomposition fragments may still have the ability to provide one property, such as electrical insulation, but not another property, such as physical strength. Hence, each key property must be evaluated for the specific application.

Since decomposition due to thermal stresses can be studied under controlled conditions, it is easy to determine this area of properties.

The most common properties evaluated for retention of performance properties of an EIM are:

- Retention of electrical insulation - measuring insulation breakdown (voltage breakdown).
- Retention of physical properties - measuring tensile strength or flexural strength.
- Retention of impact strength - measuring impact strength.

There are standardized test methods or test procedures for each of these properties. These test methods and specifications are presented separately in other EIU courses. The thermal classifications are also presented as a separate EIU course.

ELECTRICAL

"Electrical" refers to the stresses which may cause failure of the electrical insulation due to the electrical/magnetic forces applied as a result of the energy flow through the conductor or from the environment around the device. These electrical stresses are *not* the same as the electrical stress applied during a thermal aging project to determine if the insulation property has decreased due to decomposition.

These stresses or forces can be the result of:

- Electrical frequency and/or range of frequencies encountered during operation
- Voltage range
- Voltage surges or spikes
- EMI (Electromagnetic Interference)

Measurable properties include:

- Dissipation factor over a range of frequencies at various temperatures
- Dielectric constant over a range of frequencies at various temperatures
- Voltage withstand at various temperatures
- Voltage surges
- Impulse surges

It is difficult to evaluate the long-term retention of these properties since the tests are usually conducted on new material. The initial values for any material will decrease with time (aging). Short-term testing cannot determine any values for materials except for the state of the material under test.

AMBIENT

The term "Ambient" usually relates to the condition of the device due to the environment in which it operates, even when it is not in use.

For example:

- If the device is stored in an unheated warehouse for three months prior to being placed into service, will the device suffer a loss of life if stored in a freezing temperature exposure?
- Could storage in a hot and dry location affect performance?
- Will moisture accumulate within the insulation that could cause major loss of insulation performance when started?
- Can a dust or salt deposit accumulate during operation which could lead to shortening of operating life?

In order to provide answers to these questions, compatibility tests should be conducted with emphasis on duplicating the ambient environment.

MECHANICAL

The term “Mechanical” usually relates to the condition of the device when it is in use. This relates to physical vibration while operating, movement of coolant and inclusion of dust or moisture. The concern: will there be loss of properties due to exposure of the device to a specific environment?

Testing for environmental factors must be conducted in the appropriate environment in order to relate the information to the application. This means that a wide range of tests may need to be conducted on a single EIM and/or EIS. For this area of concern, it is usually assumed that the device is energized when exposed to the specific environment.

All of the tests evaluating ambient and environmental conditions are commonly identified as “Compatibility Tests”. The EIM or EIS is exposed to a specific environment, and the retention of the specific property is measured.

EIM TESTING VS. EIS TESTING

Generally, the thermal classification assigned to an end-product from an EIS level of testing is more reliable at predicting the end-product life because EIS testing includes the materials in direct contact with each other. The EIS conditioning includes thermal exposure, some ambient exposures to cold and moisture, mechanical stress during the vibration cycle and electrical stresses during testing.

The EIM level of testing involves only one material or a simple combination of materials. EIM stress is usually limited to only one type of stress or exposure at a time, such as thermal.

Photos showing decomposition due to heat exposure of EIS test specimens.

Benefit of Utilizing the T.E.A.M. Concept

When the T.E.A.M. approach is understood and utilized, test programs can provide the needed information to solve many problems. One aspect of T.E.A.M. is to also be able to decide when to focus efforts on improvement by redesign and when to focus on selection of new (different) materials.

The table below illustrates the separation of when to redesign and when to search for new materials.

Thermal stresses – long-term performance and some aspects of electrical stresses	Dominated by the material(s) or chemistry, related or limited	The performance cannot exceed the potential of the chemistry. Decomposition is not reversible. To improve performance, select a new EIS or new EIM.
Ambient (Environmental) Mechanical	Design and application related	If the actual performance is not near the potential performance, improvement is within the ability of the existing EIM or EIS. Redesign may provide the improvement needed.

How to determine which to do:

1. Evaluate the end-product using some level of multi-factor stress to find end-of-life under the multi-factor stress level.
2. Compare the actual end-of-life to that projected based on the single-factor evaluations of EIS-level projections.
3. If the actual and projected lives are similar, the solution to improved performance will only be achieved by selecting a new EIM or EIS. A simple guideline: if the life under the real-world stress level is within 85% of the projected life based on the EIS level of testing, significant improvement may need to be by selection of a new EIS or EIM.
4. If the actual and projected lives are not similar, redesign is certainly a possible solution. A simple guideline: if the life under the real-world stress level is less than 85% of the projected life based on the EIS level of testing, significant improvement may need to be by redesign since the capability is within the EIS or EIM involved.

Class 2: Spectrum of Testing

Section 1 – General

1.1 In line with the T.E.A.M. concept of the multifactor aspect of the real world application requirements, the testing aspect also covers a wide range of performance properties. There are tests for exposure to elevated temperatures over short periods of time and for extended periods of time. There are tests for evaluation to salt spray, humidity, UV, and oils; tests for physical strength or electrical strength; and for retention of property over time at elevated temperatures. There are tests for almost every property and exposure anyone can think of. When viewed without a pattern, the testing and the results of tests can appear to be random or chaotic.

The total range of testing can be presented from a few different points of view. One point is to approach the “big picture” as a Spectrum of Testing. A different approach is to view the big picture from the T.E.A.M. concept in which the various types of real-world stresses are separated into four main categories which can be tested and then merge the results. The T.E.A.M. concept is presented in a separate course.

1.2 This course is focused on the view of testing as a range from the end-product to the testing of individual materials. Because the various tests can be related to different levels of the overall scheme, this approach is referred to as the Spectrum of Testing (as in spectrum of light).

In the spectrum of light, when viewed in a general way, the separate colors are easy to identify. However, the closer one looks to find exactly where one color ends and the next begins, the more difficult it becomes to actually separate the colors. The same is true for testing.

Many properties of performance are the result of more than one material used in manufacturing the end-product. Many aspects of overall performance cannot be properly defined from the values of a material or from the results of a material being tested under one set of conditions. There is a connection to overall performance and the interaction of each material, each design, and each set of application conditions.

1.3 As presented in a separate EIU course titled the Flow of Standard, the concept of the Flow of Testing begins with the end-product and application. The total extends from the long-term performance and continues to the performance of individual materials. This is summarized in the flow of the Spectrum of Testing below:

Spectrum level	Summary of the Level
1	End-Product testing based on application
2	Build and test a prototype
3	Design – including determination of the thermal class
4	Compatibility of the EIS to the application
5	Test the Electrical Insulation System (EIS)
6	Compatibility of the Materials for the application
7	Long-term testing of the Electrical Insulating Material (EIM)
8	Material Property (Short-term) testing of the EIM

Section 2 – Details

2.1 The spectrum of testing starts with the end-product. All of the safety and performance requirements are based on the safety and performance of the end-product. No testing of an EIS or of any individual material or component can totally replace evaluation of the end-product.

End-product evaluations can be reduced by using information about the EIS or EIM. The thermal classification of the end-product can be assigned based on the EIS selected. Characteristics of the other products may be obtainable from the characteristics of individual EIMs.

2.2 **Spectrum Level 1 – End-product**

In earlier times of the electrical industry, all safety and performance testing was conducted only on end-products. Motors, generators, and transformers were designed and prototypes were built and then tested for perhaps years, to determine the long-term life or long-term performance of the end-product.

The ability to afford such commitments of time and money are rare in today's business world. To remain competitive it is essential to be aware of, and to use (when appropriate), any options which can provide information about performance and safe operations.

Technical information about individual materials or insulation systems may, in some cases, reduce or eliminate certain levels of the evaluation of the end-product. Materials can function as Electrical Insulating Materials (EIM) or as physical support or some other benefit that could add to the product. Since safe operation and long-term performance are related to the total application environment (T.E.A.M.), a review of end-product certification programs will always be expected to start with the end-product.

2.3 **Spectrum Level 2 – Prototype**

Building a prototype unit implies that the design of the end-product with the selection of all materials to be used has been completed. The prototype unit is intended to be a pre-production unit used to evaluate production procedures and processes. A prototype of the final product can be evaluated for actual safe performance.

However, due to cost of time and money, prototypes are usually evaluated without long-term aging. As stated above, the time and cost of long-term evaluations of a prototype unit in today's business world can be cost prohibitive.

2.4 **Spectrum Level 3 – Design**

Design of any end-product requires knowledge of the application, performance requirements, safety requirements, operating temperature limits, material capabilities and other aspects of mechanical stresses during operation and ambient conditions (operating environment conditions).

If the design is to replace materials from different vendors, the design process may be simple because details about the original material and the alternate material can be requested and supplied.

When the design project is to develop a new end-product or to expand the operating range of an existing version of the end-product, the amount of information needed may be much greater.

What options are available to obtain the needed long-term and safety performance? One approach is to build prototype units and test them under application conditions. Another approach is to utilize programs where EIS or EIM information is available. When the EIS or EIM data is not available, it may be necessary to conduct testing at the EIS or EIM level before moving to the prototype level of expense.

For the Design level of activity, most manufacturers require significant information from vendors. Testing conducted by vendors can be provided to any number of manufacturers which can add to cost effectiveness.

2.5 **Spectrum Level 4 – Compatibility at the EIS Level**

Compatibility relates to the evaluation of the end-product in application environments. When an EIS is evaluated for compatibility in the application environment, the information can greatly reduce the testing and evaluation needed of the end-product.

Compatibility testing of an EIS can be conducted in environments related to oils, refrigerants, soaps, detergents, bleaches, or almost any potential environment.

The combination of Compatibility and EIS testing provides the evaluation of the electrical insulation portion of the end-product. This may be sufficient for many end-products.

2.6 **Spectrum Level 5 – Electrical Insulation System (EIS)**

The entire EIS concept was developed and implemented as the result of a major research and development program initiated by the United States military and a small group of commercial manufacturing companies. The program began around 1950 and continued throughout that decade. The results of this program can be found in a report available from:

U.S. Department of Commerce
National Technical Information Services
ADA-044156
Title: *Reliability Prediction Studies on Electrical Insulation: Navy Summary Report*
Issued by: Naval Research Laboratories, Washington D.C.
Issue date: July 1977
Key researchers: E. Brancato / L. Johnson / F. Campbell / H. Walker

The research summarized in this publication was the original background testing conducted on actual end-products (motors) and the laboratory models which lead to a major part of the IEEE series of test methods for evaluation of EIS.

This research program became the source for most EIS-level programs in our industry today.

An EIS is defined in International Standards such as the International Electrotechnical Commission (IEC) 61857 series as two or more materials, one of which is a conductor and one of which is an insulator. In UL 1446, an EIS is defined as “a unique, intimate combination of two or more insulating materials used in electrical equipment.” The common aspect is as follows: an EIS evaluates the interaction between two or more materials in contact with each other.

EIS testing can be viewed as a long-term compatibility program. The rating of the EIS is based on the performance of the combined group (system) of materials composing the EIS. EIS testing is a Relative Thermal Index (RTI) level of test. RTI testing is covered in a separate course.

EIS testing can provide the thermal rating of the end-product because of the level of conditioning and electrical stresses involved.

2.7 **Spectrum Level 6 – Compatibility at the Material Level**

Compatibility of materials can reduce, or in some cases, eliminate the need for compatibility testing of end-products. Compatibility testing at the material level is of the same nature as the EIS level: to evaluate ambient conditions and performance of the individual material.

If a material cannot show performance in an environment, it is assumed that it cannot perform when used as an EIS or in an end-product.

Manufacturers often need or require material compatibility test results before considering the material for use. The more common applications are oil-filled transformers, refrigerant units, clothes or dish-washing machines, home appliances and similar applications.

2.8 **Spectrum Level 7 – Long-term Performance of Materials**

Long-term performance refers to the concept of evaluating the potential life of a material in an application. The best approach to this type of testing is to compare a potential alternate material's performance to the performance of the original material.

Most of the long-term evaluations are limited to thermal stresses because heat is more controllable making the ratings more reliable. For thermal ratings, the values are called Relative Thermal Index ratings (RTI) when compared to another material's performance, or Thermal Index (TI), when the rating is established by projecting life to a pre-selected time, but the rating is not established by comparison to another material.

2.9 **Spectrum Level 8 – Material Properties**

This level of the spectrum refers to the performance and safety requirements of a material as manufactured or "new". This is the type of information commonly found on material information sheets. This is the material that the vendor wishes to sell and the user is interested in purchasing.

This level of testing is not focused on long-term performance, only the as-received performance.

2.10 The above spectrum of tests is intended to show that there is a relationship between the wide range of tests and the connection between material, systems and production.

Class 3: The Structure of Standards

Section 1 – General

1.1 The Structure of Standards refers to the flow or arrangement of the safety and performance requirements. All safety and performance requirements start with the end-product.

The Flow of Standards

1. Always states here → Safety and Performance of the End-product
2. Construction of and evaluation of the Prototype
3. Design
4. When the application requires, Compatibility of the EIS for the environment
5. For thermal classes requiring, selection of an established EIS
6. Pre-selection of materials, Compatibility of the EIM and minor materials
7. Long term retention of properties of materials
8. Material properties as received

Many of the end-product requirements can be satisfied by selection and usage of materials having documented performance as a material. Many of the end-product performance requirements such as thermal classification or long term compatibility can be satisfied when an established EIS is selected and the information used.

However, using either EIM or EIS with established performance or thermal rating does not always resolve all of the safety or performance requirements of the end-product. The process of evaluating the end-product is based on the application and the specific combination of the T.E.A.M. factors. Using documented EIM and EIS can satisfy and simplify many situations and applications by using Electrical Insulation Systems (EIS) and Electrical Insulation Materials (EIM) Standards.

1.2 One example of safety requirements being met by using information about the individual materials is for flame ratings (Safety). When the safety of the end-product application requires a flame rating of V-0 (refer to flame testing in a separate course), one solution is to test the end-product.

However, another approach is to select individual materials each of which have a V-0 rating. If all materials are flame resistant, the collective would be expected to retain that flame-resistant characteristic.

In addition to the individual materials being flame resistant, the end-product usually contains other non-combustible materials such as the metal core or stack. Selection of documented V-0 materials can remove the need for evaluation of the end-product without the need to conduct flame testing on the end-product itself.

With reference to flame ratings, the flow of information on satisfying requirements began with the end-product but was resolved by the material selection. The requirement for safety (flame ratings) did not originate with the materials but with the end-product.

The fact that individual materials can be tested and rated makes the selection of the materials easier. The testing and rating of the individual materials reduces, or in some cases eliminates, the need to test the end-product because the performance has been established.

1.3 Another aspect of end-product performance is the operating temperature of the end-product in the application. The operating temperature should be determined by the application. For example, the operating temperature of an electric motor is influenced by air flow through the windings, the amount of metal to act as a heat sink, as well as by other aspects of design and operating environment.

The operating temperature of a specific electric motor cannot be predetermined by the design of the motor itself without the application being included. For many motor applications the thermal classification evaluation can be resolved by use of an established EIS with the thermal classification equal to or higher than the operating temperature of the motor in application.

The Standards related to the evaluation of an electric motor are the starting point, but the thermal capabilities can be resolved by the selection of an established EIS which exceeds the thermal requirements. As presented in the T.E.A.M. course, thermal is only one aspect of the total stresses of the real world. Also as presented in the T.E.A.M. course, the total stresses can be separated and addressed in part and the results of the individual parts can be merged to address the total.

The flow of standards starts with the end-product and moves to the individual material for resolution of some, or in some cases all, of the performance and safety requirements.