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Clarification the reliability of electronic components used in nuclear industry

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Abstract. When calculating the reliability indicator of any device, under specified operating condition, usually reference data on the characteristics of the reliability of the elements. Data on the reliability of the groups of electrical-radiation equipment (ERE), used in the design, manufacture and operation of equipment, include information on the mathematical models to calculate (predict) values for the operational intensity of product groups, including information on the storage conditions and information on the reliability groups ERE and the coefficients of the models. This paper considers methods for the refinement of correction factors to estimate the failure rate of ERE under specified conditions. The results of the work allow us to clarify the existing coefficients for the prevention and reduction of the failure rate of ERE, as well as to prevent failures of elements and systems due to personnel errors.

1. Introduction

For the use of electrical-radiation equipment (ERE), the effects of environmental conditions have to be considered. The reliability of the equipment can be affected by a number of factors, such as, increasing or decreasing of temperature, sudden fluctuation of temperature, thermal shock, and the humidity. To predict the performance and failure of the component, it is necessary to clarify the reliability of each group of ERE. To do this, experiments and information about the reliability of electrical-radiation devices used in the development, manufacturing and operation of equipment, shall be recorded in reference books.

Information about the reliability of the groups ERE and the coefficients of the models includes:

- Values of the basic failure rate of ERE groups;
- Values of the coefficients included in the model of forecasting the operational reliability of ERE, and analytical expressions showing the dependence of these coefficients on the factors taken into account.

The values of the operational failure rate of the majority of ERE groups are calculated by the mathematical model:

$$\lambda_e = \lambda_b \times \prod_{i=1}^{n} K_i$$

where $\lambda_b$ – basic failure rate of ERE groups;
K_i – coefficients that take into account the change in the operational failure rate, depending on various factors;

N – the number of factors taken into account.

The coefficients included in the mathematical models for calculating the failure rate of ERE groups can be divided into two groups:

- The first group of coefficients is common for the models of most classes and groups of equipment and characterizes the modes and conditions of their operation, the quality level of ERE manufacturing;
- The second group of coefficients is included in the models of specific classes (groups) of ERE and characterizes the dependence of the failure rate in the given operating conditions on the structural, functional and technological features of ERE.

Reference data should be constantly updated to better predict the behavior and to have an understanding of the shortcomings of the equipment used to develop the most reliable new devices [1].

Depending on the factors affecting on the equipment, the experimental methods are selected. Climatic tests are conducted according to a certain methodology. In the sequence of operations in the experiment, the mandatory steps must be a pre-exposure, an external inspection of the initial test, a final exposure, and a final external examination [2].

2. Materials and methods

The Testing of electronic components (EC) for climatic effects is carried out to test the ability of equipment to perform the required functions, to preserve parameters and / or appearance within the established standards under and after exposure. For the reproducibility of the test results, its complete and accurate description is necessary, excluding any uncertainty of interpretation. Proceeding from this, the standards and technical documentation (STD) has adopted such a sequence of operations (stages) of the EC test for climatic effects:

- Pre-exposure equipment (stabilization of their properties);
- Initial parameter measurements and external inspection;
- Installation of device in the chamber and exposure their to the test mode;
- Extraction from the chambers and exposure to restore the properties of equipment (final stabilization of properties);
- External inspection and final product measurements

Pre-exposure is carried out in order to completely or partially eliminate the effects of exposure to equipment in previous operating conditions. Equipment can withstand, as a rule, under normal climatic conditions. Exposure of equipment, whose measurement results can be significantly influenced by relative humidity, is performed These conditions provide for strict maintenance of the temperature (permissible deviation ± 1 °C) at a relative humidity of 73 ... 77%. The duration of the preliminary exposure is determined by the time sufficient to establish the thermal equilibrium of the equipment with the environment. Usually it does not exceed 2 hours. Initial and final measurement equipment recommended at the same temperature and humidity environment. When installing equipment in the chamber, it is necessary to ensure that air is freely circulating between the equipment and the walls of the chamber, as well as between the components themselves. The method of installation and position of the equipment in the test are important for the reproducibility of its results. If several variants of the position of the product are possible during operation, the option that provides the greatest test rigidity should be selected. If during the test the electric load on the EC is not amenable, the components are placed on the grids of nylon threads stretched on the supports.

When tested with an electric load, the product is installed on special boards, devices (cassettes, holders, contacting devices). Metal parts of devices must have anti-corrosion coatings. The time of exposure in the test mode is counted from the moment the mode is set in the chamber. This time at high / low temperature should be sufficient for heating / cooling equipment throughout. External inspection of equipment should be carried out in accordance with the STD.
Climatic tests are carried out not only at the design stage of FEC, but also in mass production for the rejection of potentially unreliable equipment (acceptance tests) and to control the stability of production (periodic tests). Modes and conditions of testing FEC set depending on the degree of stiffness, which, in turn, is determined by the conditions of further operation of the FEC as part of the system. The equipment are considered to have passed the test, if they during and after it meet the requirements specified in technical specification (TS) for this type of test.

To increase the informativeness and effectiveness of climate testing during the development and manufacture of equipment, it is advisable to conduct them in such a sequence in which each subsequent test increases the impact of the previous one, which could go unnoticed. It is recommended that the so-called normalized sequence of climatic tests, including a test at elevated temperature, a short-term test for moisture resistance in a cyclic mode (the first cycle), tests for the effects of low temperature and atmospheric pressure, the test for moisture resistance in a cyclic mode (the rest of the cycles). In this case, between any of these tests may be a break of no more than 3 days, except for the interval between the tests for moisture resistance and the effect of low temperature, which should not exceed 2 hours. Parameters of equipment are usually measured at the beginning and end of the normalized sequence [3].

3. Results and Discussion
Testing the climatic effects of high temperature of the medium are carried out to check the performance of FEC and/or to preserve their appearance under the influence of high temperature and after it. There are two methods of testing for elevated temperature: thermal and combined load (thermal and electrical). According to the first method, non-heat-releasing FEC are tested, the temperature of which during operation depends only on the ambient temperature; on the second - the heat-generating FEC, which are heated in the operating state due to the power released under the action of an electric load.

When tested under combined load, the equipment are placed in a chamber and tested under normal or maximum permissible electrical load corresponding to the upper value of the ambient temperature and set depending on the degree of stiffness specified in table 1.

| Degree of stiffness | I  | IV | VI | VII | VIII | IX  | X  | XI | XII | XIII |
|--------------------|----|----|----|-----|------|-----|----|----|-----|------|
| Temperature, °C    | 40 | 50 | 70 | 85  | 100  | 125 | 155| 200| 250 | 315  |

Heat chambers are used to test for elevated temperatures.

Tests for the effect of a reduced temperature of the surrounding environment are carried out to check the performance of the FEC and to preserve their appearance under the influence of a reduced temperature and after it. During the test, the same parameters are measured as during the test for high temperatures. At the same time, to check the efficiency of the FEC, it is provided to withstand them under an electric load at a given temperature. First, the FEC parameters are measured under normal conditions, then the equipment are placed in a cold chamber, set the temperature limit according to the data specified in the TS and presented in table 2.

| Degree of stiffness | III | IV | VII | VIII |
|--------------------|-----|----|-----|------|
| Temperature, °C    | -10 | -25| -4  | -60  |
Withstand EC at a given temperature for a time, which is selected depending on the degree of test rigidity from the time series of values given in TS, but not less than 24 hours;

- raise the temperature in the chamber to the operating low (in accordance with the TS for the tested EC) temperature and withstand them under electric load for a time sufficient to equalize the temperature throughout the volume;
- include EC, conduct measurement specified in the PI and the parameters and verify the operation of the setting elements and switching devices;
- raise the temperature in the chamber to normal and withstand EC for the time required for heating them throughout the volume;
- open the camera, perform external inspection and measurement of EC [4].

Heat and cold chambers are used to test for elevated temperatures. The test for the effect of changes in the temperature of the surrounding environment is carried out to check the performance and maintain the appearance of the EC after the specified impact. Depending on the purpose and operating conditions, as well as on the design features of the EC, the test is carried out by the method of either two chambers (for EC, which under operating conditions are subjected to a rapid change in the temperature of the surrounding environment) or one chamber (with a slow change in the temperature of the medium). For the test, three cycles shall be established, unless otherwise specified in the TS. Each cycle consists of two stages - tests: at low and high temperature of the surrounding.

Thermal Cycling — one of the toughest types of climatic tests-allows to identify hidden design defects and violations of technology.

The test for a thermal shock (on the stability of an ES to the effect of sharp temperature changes) is sometimes carried out along with a test for the effect of a change in the temperature of the surrounding environment.

This test is very rigid and is used to establish the limit strength properties of the EC; its results can be relatively quickly obtaining data on the weakest parts of the structure of the EC. The test is carried out using the method of two liquid baths. In this case, the EC is usually exposed to 10 cycles, unless another number is specified in the TS. The test for one cycle is carried out in two baths: in one, the water has a lowered temperature, in the other, it is elevated. The temperature values correspond to the test modes.

Tests for exposure to high humidity are conducted to establish the moisture resistance of the EC. There are two types of test for moisture resistance: prolonged and accelerated. Long-term testing is carried out to determine the ability of products to maintain their parameters during long-term exposure to humidity and after its end; accelerated testing - with the purpose of prompt detection of gross technological defects in batch production and defects that could arise in previous tests. Both types of tests can be carried out in cyclic (with condensation of moisture) and continuous (without condensation of moisture) modes.

The cyclic mode of the test is characterized by the effect of high humidity in a cyclic change in the air temperature in the chamber. Usually it is used for equipment that do not have compacted casings of all classes, which must remain operational in conditions of dew.

The EC test at electrical load is provided if exposure to humidity in the operating conditions of the equipment under voltage can lead to electrochemical corrosion. As a load in this test is the voltage that provides minimal heat in the test equipment. In most cases, the moisture resistance test is carried out without electrical load.

Product parameters are usually measured at the end of the test (in the last cycle at the end of the last hour of exposure at the upper temperature), without removing them from the humidity chamber.

Heat and humidity chambers are used to test for the effect of elevated temperature [5].

The specific test mode is set depending on the purpose and operating conditions of the EC in accordance with table 3.
Table 3. The degree of rigidity of the moisture resistance test, depending on the operating conditions of the equipment during the year.

| Degree of stiffness | Test moods | Operating conditions |
|---------------------|------------|----------------------|
|                     | Relative humidity (high value) (%) | Test temperature (°C) | Presence of moisture condensation | Relative humidity (average monthly value) (%) | Ambient temperature (°C) | Duration of exposure during the year (months) |
| I                   | 80         | 25                   | -                                | 65                     | 20                   | 12                                      |
| II, III             | 98         | 25                   | -                                | 80                     | 20                   | 2                                       |
| IV                  | 100        | 25                   | -                                | 80                     | 20                   | 6                                       |
| V                   | 100        | 25                   | +                                | 90                     | 20                   | 12                                      |
| VI, VII             | 98         | 35                   | -                                | 80                     | 27                   | 3                                       |
| VI, II              | 100        | 35                   | +                                | 90                     | 27                   | 12                                      |

4. Conclusion
To clarify the validity coefficients for the electronic components used at the facilities of nuclear technology, it is necessary to periodically test the climate impacts.

The results of these tests will help to reduce the number of failures of ERE, to assume the time of failure of already used equipment, as well as to bring to zero the number of failures for newly created equipment and to improve the reliability of equipment, which contributes to better safety and economic benefits.

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