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QUALIFICATION OF ELECTRICAL EQUIPMENT - A UNITED STATES NUCLEAR STEAM SYSTEM SUPPLIER PERSPECTIVE

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INTRODUCTION

The United States Federal Regulations governing design of nuclear power facilities require that structures, systems, and components important to safety shall be designed to accommodate the effects of environmental conditions associated with normal operation, maintenance, testing and postulated accidents, including the loss of coolant accident. Additionally, those items important to safety must be designed to withstand the effects of appropriate natural phenomena (e.g. earthquakes) and a quality assurance program must be established to provide adequate assurance that the safety equipment will satisfactorily perform its safety function.(1) Demonstration of the equipment's ability to perform its safety function under adverse environmental conditions has taken the form of equipment type test and/or analytical evaluation.

At Westinghouse Pressurized Water Reactor Systems Division (PWR-SD) qualification of safety related electrical equipment can be segregated into three distinct generations: (1) the initial seismic and environmental qualification programs for electrical equipment (1969-1972); (2) the supplemental seismic and environmental qualification programs (1975-1977); and (3) the seismic and environmental qualification programs to meet IEEE-323-1974, "IEEE Standard for Qualifying Class 1E Equipment for Nuclear Power Generating Stations" (1975-?). This paper will primarily review the latter two programs (in a licensing framework), as they are most current, with emphasis on electrical equipment (e.g. transmitters, rack mounted equipment) as opposed to electro-mechanical equipment (valve operators, pump motors).

INITIAL QUALIFICATION PROGRAMS

Before discussing the more recent programs, especially the supplemental qualification program, it is necessary to briefly review the initial qualification programs performed by Westinghouse PWR-SD. These programs consisted of seismic and environmental type tests on selected equipment and were initiated prior to the issuance of IEEE-323-1971(3) and IEEE- 344-1971(4). Environmental qualification was directed toward equipment located inside containment and required to function under those postulated accident conditions which could create adverse environmental conditions. During this period of time analysis of the postulated loss of coolant accident established the test requirements with respect to temperature, pressure, humidity and radiation. The temperature/pressure envelope developed for the test programs included a ten seconds rise from ambient conditions to 286°F (saturated conditions) and maintainence of this condition for approximately two hours. The radiation conditions assumed for the testing were consistent with TID-14844, "Calculations of Distance Factors for Power and Test Reactor Sites"(5) and gamma doses of up 2×10^8 rads were applied. Equipment was tested to ensure survival under during the postulated accident conditions in order that protective functions (e.g. reactor trip, safety injection, containment isolation) would be generated. This particular series of qualification tests was documented in WCAP-7744, "Environmental Testing of Engineered Safety Features Related Equipment"(6) which was submitted in 1971 to the (then) United States Atomic Energy Commission (USAEC) to demonstrate qualification per the Regulatory requirements.

Since a postulated earthquake would affect equipment located both inside and outside the reactor containment, seismic type testing was performed on selected types of safety related electrical equipment to demonstrate the equipment's ability to survive the seismic event and perform its required protective function. Both sensors and rack mounted electrical equipment, such as the Westinghouse Nuclear Instrumentation System, the Westinghouse 7100 and 7300 Series Process Protection Equipment, the Westinghouse Solid State Protection System and the Westinghouse Static Inverter, etc., were type tested. Testing was performed using the single axis sine beat method which was adopted by IEEE 344-1971(4) as the perferred test method. The equipment was tested in each of the two horizontal directions and the vertical direction. Equipment was tested for at least two assumed horizontal ground acceleration levels, 0.2g (defined as low seismic) and 0.4g (defined as high seismic). Some equipment was tested using higher ground accelerations (high-high seismic). Results of this testing were documented in WCAPs 7817, 7821 and 8021, "Seismic Testing of Electrical and Control Equipment" (Low, High and High-High Levels, respectively)(7) and submitted in 1972 to the USAEC to demonstrate seismic qualification.

SUPPLEMENTAL QUALIFICATION PROGRAM

The supplemental qualification program(8) resulted from the USAEC request for additional information on the above mentioned qualification testing. The supplemental program was designed to provide the requested information and demonstrate compliance to IEEE-323-1971 and included environmental testing of transmitters/RTDs and seismic testing of various rack mounted equipment. Since a significant period of time had elapsed from initial qualification testing (1969-1971) to the establishment of this supplemental program (1975) a substantial effort was required to review and update, as necessary, the equipments functional requirements and the test requirements.

1. Environmental Testing(A)

With respect to the environmental testing of transmitters/RTDs the review led to the establishment of revised functional requirements and a modification in the environmental test conditions. Regarding the functional requirements, one of the most important new aspects was the establishment of post accident long-term monitoring requirements for certain in-containment instrument functions (Table 1). Requirements of this nature had not been included in the initial instrument qualification tests.

TABLE 1

LONG TERM MONITORING REQUIREMENTS

In-Containment Instrument	Post Accident Time Duration
Wide Range Reactor Coolant System Temperature	2 weeks
Pressurizer Water Level	2 weeks
Wide Range Reactor Coolant System Pressure	2 weeks
Narrow Range Steam Generator Water Level	4 months

It should be noted that the required time durations identified in Table 1 are under continuing scrutiny relative to the IEEE 323-1974 program with the objective to minimize the time requirements. In order to optimize equipment performance in environmental qualification. Along with the establishment of the long-term monitoring requirements, instrument accuracy requirements were established for those instrument functions required for short-term reactor protection in the event of a postulated accident as well as those needed for long-term monitoring.

In parallel with the establishment of these instrument functional requirements, a task force was set up within Westinghouse to review and define the environmental test conditions. The first consideration in the development of the test conditions was establishment of a temperature test envelop. Recent containment analysis for steamline breaks inside containment had resulted in higher temperatures than analysis performed for postulated loss of coolant accidents. This represented a change from the original temperature profile which was based on the postulated loss of coolant accident analysis. To arrive at the temperature/pressure qualification profile various plant designs, to which the program was applicable, were reviewed and bounding-type analyses performed. These analyses included the double-ended steamline break as well as consideration of smaller break sizes.

Results of these analyses led to a revised environmental qualification test profile for equipment required to function under hostile environmental conditions. This test profile specified a ramp from ambient conditions to 320°F in three seconds, maintenance of 320°F for twenty minutes and then a ramping down to 220°F by the end of the first twenty- four hour period. From this point on the long-term monitoring portion of the test was continued using 220°F for up to 2 weeks to simulate the post accident monitoring period. As an additional conservatism, the profile specified that testing be performed at saturated conditions (∿75 psia) which represents a pressure condition more severe than most containment design pressures (∿60 psia).

In conjunction with the development of the temperature/pressure profile, radiation dose requirements were developed. While these requirements were derived in a manner similar to those specified in the original qualification test program two additional factors were included in the formulation of radiation dose requirements for supplemental program testing. These two factors were credit for shielding and required time of operation. Credit for shielding arises from the location of transmitters, i.e. outside the reactor building crane wall, which would reduce the dose received by the transmitter. Additionally, most instruments need only be available for short periods of time following an accident (to provide reactor trip/safety injection signals) and thus need not be exposed to radiation doses larger than that assumed for normal operation. For those instruments required for long-term post accident availability dose requirements were established consistent with their operational requirements. The radiation test requirements thus ranged from $4x10^4$ rads to 10^8 rads depending on the instrument, its particular functional requirement and its location.

For the actual test program various pressure and differential pressure transmitters and RTDs were selected which had widespread use on customer plants applicable to the program and were likely to perform well under the revised conditions. Three identical models of each instrument simultaneously underwent type testing. The instruments were initially calibrated and shipped to a radiation test facility. After radiation testing and calibration the instruments were shipped to the Westinghouse Environmental Test Facility located at Forest Hills, Pennsylvania for temperature/pressure/humidity/caustic spray testing. Results of the environmental testing of the RTDs proved to be completely successful for both short-term reactor protection initiation functions and the longer term post accident monitoring functions. The results of the transmitter tests were mixed; testing on the one hand demonstrated the availability of the transmitters for short-term reactor protection function initiation but on the other hand long-term availability of most transmitters tested could not be demonstrated.

This unsuccessful testing resulted in a series of troubleshooting tests to identify the failure mechanism and develop a design to eliminate the problem. This was performed on an expedited basis due to the licensing status of plants committed to the supplemental program. The failures were caused by entrance of steam through the seals into the electronic's housing. To eliminate this problem, Westinghouse and one of its transmitter suppliers developed a modified casing design for pressure and differential pressure transmitters. Prototype pressure and differential pressure units, using electronics identical to those which had undergone the previous series of tests, were assembled and shipped to Forest Hills for environmental tests. This series of testing was successful for both short-term and long-term functions and results were reported to the U.S. Nuclear Regulatory Commission (USNRC) in early 1977.

To ensure that the validity of the qualification tests is maintained Westinghouse has instituted, in conjunction with its supplier, a rigid quality assurance program, which includes an essentially separate transmitter production line. Upon placement of purchase orders by Westinghouse for a quantity of transmitters, the manufacturer will order materials and components from his sub-vendors from which the specified number of transmitters will be manufactured. Each design will be qualified by type test as previously described.

Additionally, basic data concerning heat transfer characteristics of transmitters, or equipment in general, exposed to superheated conditions was taken during several of the instrument tests. Thermocouples were attached to the exterior case and circuit board of certain transmitters. Due to the fast ramp requirement of the test profile the required peak test temperature of 320°F was overshot from 30 to 60°F depending on the particular test run. The autoclave temperature would slowly drift back to the required temperature over a period of several minutes. Thus for a period of time the equipment being tested would be exposed to super-heated conditions of 350°F to 380°F with a pressure of approximately 75 psia. Data from the thermocouples placed on the exterior instrument case showed that the case temperature followed the saturation temperature corresponding to the pressure inside the test autoclave. This confirmed the insensitivity of the equipment to short-term super-heated conditions which had heretofore been shown by calculations. Moreover, the thermocouples mounted at the circuit boards showed a slow increase in board temperature indicating that the initial temperature ramp in the autoclave may not be an important factor in circuit board response.

These data have important implications in the development of test profiles or justification of previous testing performed at lower temperatures. Westinghouse has performed calculations using this information to predict instrument surface temperature as a function of calculated containment environment. By using this information it can be shown that saturated temperature testing can be more conservative than superheated temperature testing for short periods of time and thus calculated containment environments should not have to be matched by test environments.

2. Seismic Testing

During the USNRC (formerly USAEC) review of the Westinghouse documentation regarding seismic qualification of electrical equipment, several questions were raised regarding operability of the equipment during the simulated seismic conditions. Furthermore, during the period of time (1972-1974) that the USNRC was reviewing the documents, IEEE 344-1971 was being revised (to what is now IEEE-344- 1975(9)). The draft revisions available placed substantially more emphasis on qualification using multifrequency multiaxis techniques rather than the single axis sine beat methods used in the original Westinghouse qualification tests. The USNRC requested information regarding the effect of multifrequency, multiaxis inputs on safety-related electrical equipment.

Following identification of USNRC concerns, Westinghouse and USNRC representatives visited several plant sites to view the various types of safety-related electrical equipment supplied by Westinghouse PWR-SD. After the site visits, additional meetings were held with USNRC representatives and agreement was reached regarding what equipment should be retested and what methods should be used.

Equipment chosen for retest to demonstrate electrical operability during the simulated seismic conditions included the Westinghouse Static Inverter and Instrument Bus Distribution Panel, Foxboro Process Control Equipment, Westinghouse 7100 Process Control Equipment, Westinghouse 7300 Process Control Equipment and the Westinghouse Nuclear Instrumentation System power range equipment. To address the USNRC concerns regarding multiaxis and multifrequency input effects Westinghouse agreed to test the Foxboro, 7100, 7300 equipment and Nuclear Instrumentation System (NIS) equipment using multifrequency biaxial methods (the Static Inverter and Instrument Bus Distribution Panel would be tested using sine beat, biaxial test inputs).(8) Since the USNRC concerns were based primarily upon electronic operability during the seismic simulation the testing, except for the NIS, was limited to testing of bistable amplifier channels.

Prior to performing any of these tests a method for developing multifrequency biaxial inputs had to be derived. Such a method was developed by S. J. Jarecki of Westinghouse(10) and submitted to the USNRC for their concurrence prior to actual testing. Concurrence by the USNRC on this method was gained and testing was performed during the first half of 1976. Results of the seismic testing demonstrated the ability of the equipment to perform its safety function during the simulated seismic event. The incorporation of the mulitfrequency biaxial inputs into the test program demonstrated the acceptability of this equipment in light of the new IEEE-344-1975 philosophy.

Westinghouse is currently reviewing the severity of multifrequency biaxial test method as compared to the single axis sine beat method previously used by Westinghouse PWR-SD. These tests, and test performed more recently on other equipment, have created concern regarding the requirements of IEEE-344-1975. This standard states that five Operating Basis Earthquakes should be simulated and the Safe Shutdown Earthquake simulation is to be applied a total of four times if single frequency testing is performed or two times if random inputs are used.(9) Thus this qualification series requires a minimum of seven or nine separate strong motion tests. Consequently, the potential for failure is enhanced due to the increased number of required tests. In the context of the true spirit of qualification, it appears that this test method may be overly severe. Westinghouse will suggest that these test requirements be reviewed by the appropriate IEEE Committee.

IEEE-323-1974 QUALIFICATION PROGRAM

1. Background

Upon the issuance of IEEE-323-1974(2), Westinghouse PWR-SD formulated an internal steering committee to review the standard and determine potential methods of implementing the new factors (e.g. aging, margins, qualified life) contained in the standard. Shortly after the publication of IEEE-323-1974 the USNRC issued Regulatory Guide 1.89(11) which stated that plants receiving the USNRC Safety Evaluation Report for a construction permit after July 1, 1974 or for electrical equipment purchased after November 15, 1974, the safety-related electrical equipment should be qualified in accordance with IEEE-323-1974.

Although Regulatory Guides are legally not USNRC requirements, the incorporation of this standard into a Regulatory Guide made it virtually impossible for the affected plants to have acceptable qualification programs unless they compiled with IEEE-323-1974. This action by the USNRC was felt by the industry to be premature in that certain aspects of the standard were (and still are) beyond the state of the art; however commitments to the standard were required in order to avoid delays in plant licensing.

On the Westinghouse RESAR-41 (the Reference Safety Analysis Report describing the 3800 Mwt design), Westinghouse was required by the USNRC to submit a program providing the methods that Westinghouse intended to employ to meet IEEE-323-1974. The internal steering committee, mentioned above, developed a program(12) which was submitted to the USNRC in September, 1975 for their review and approval. Following submission of this report Westinghouse PWR-SD management determined that USNRC agreement on the qualification methods would be required prior to Westinghouse initiating any of the testing or analysis programs. This was, and is, viewed as imperative due to the large financial exposure involved and the Westinghouse experience on changes in requirements with time, as discussed above.

Westinghouse PWR-SD is determined to avoid a position similar to that which resulted after the original tests; that is, perform the qualification testing, submit the results and have them later rejected by the USNRC thereby necessitating a supplemental program.

As was mentioned above, the program to qualify safety-related electrical equipment to IEEE-323-1974 was submitted to the U.S. Regulatory Authorities in September, 1975 for their review and approval. Since that time Westinghouse PWR-SD efforts have been primarily de-voted to gaining approval of this program involving numerous interactions with the NRC. Recently Westinghouse received an interim evaluation from the Regulatory Authorities that agrees for the most part with the qualification approaches proposed by Westinghouse. As a result of this interim evaluation Westinghouse recently submitted Revision 1 to the topical report(13) which represents a substantial update to the original version and provides further program definition.

Westinghouse experience in attempting to define such a program and gain regulatory acceptance has demonstrated that caution is called for in both the setting forth and in the implementing of new regulatory requirements in order that licensing and eventual operation of plants are not delayed. The case of IEEE-323-1974 represents a vague requirement to which utility applicants are committed, while at the same time the industry is struggling to develop acceptable methods to meet the requirements and the regulatory authority appears undecided as to what constitutes "acceptable" methods.

2. Important Aspects in the Westinghouse Program for Complying with IEEE-323-1974

The Westinghouse program for complying with IEEE-323-1974 is based on sound and practical techniques. Additionally, realistic programs introduced to address the aging phenomena of complex electronic equipment are also aimed at enhancing the reliability of equipment. The very roots of the program are the functional requirements of the equipment within the plant.

Functional Requirements and Location

The functional requirements of the equipment being considered will dictate the modes of operation under which the equipment must function (e.g. normal, abnormal, accident, post accident), when the equipment must be able to function (e.g. during normal operation only, accident only, post accident only, etc.), what the equipment must do (e.g. trip the plant, isolate the containment, actuate pumps and valves, monitor conditions), how well the equipment must perform its function (e.g. generate signals with ± 10% accuracy, close valves within 10 seconds of receipt of signal, etc.) and how long the equipment must function. The general location of the equipment within the nuclear plant will provide knowledge of the potential environments to which the equipment can be exposed. For example, equipment located inside containment or in cubicles around steam and feedwater lines located outside containment could be exposed to high temperatures resulting from ruptures in those lines while equipment located in control room areas would be exposed to less several environments and environmental variations.

Aging(13)

For electronic equipment the functional requirements and location of the equipment are also used to determine the approach to be followed for aging considerations. For such equipment which could be exposed to hostile environmental conditions in the event of a postulated high energy line break (i.e., postulated reactor coolant system pipe break, steam line break or feedwater line break), Westinghouse will simulate aging using known thermal techniques; that is, the use of the temperature half-life technique (Arrehenius Plots). In adopting this approach, Westinghouse has assumed that equipment assemblies are combinations of insulating systems. Aging half-life temperatures will be drawn from knowledge of insulation system characteristics. Since it is desirable to establish a single value of temperature half-life for an individual piece of equipment that is to be aged, the approach currently contemplated calls for the half-life selected to be the largest value applicable to the system determined by research of available data. A simulated aging test performed using this temperature would establish the projected qualified life of the equipment being tested. It is recognized that such a test procedure may be overly severe in that some components will be overaged and will not have failed and will therefore be subjected to the accident testing in the overaged condition. Also, failures of more rapidly aging components can be expected while performing the test. These failures also occur randomly in real time operation and the system is maintained by replacing the failed component. The same will hold true for a simulated aging test. The failed components will be replaced and the test continued.

The effects of age on electronic equipment not subjected to a high energy line break will be accounted for by analysis via the Westinghouse aging evaluation program. The analysis will be performed to discover materials that could affect the proper functional operation of a system if subjected to mechanical or electrical stresses after operating in its normal environment for a length of time and to discover components whose failure rate predictions could lead to design modifications or periodic replacement.

The aging of a system is evaluated by consideration of the aging factors of non-metallic materials and the environmental conditions at the plant location. Temperature is considered the most important aging factor and Arrhenius plots relating life to temperature exist for many materials and components. These curves are developed by aging specimens at several different temperatures and proof testing at intervals for properties of interest such as dielectric strength or change in capacitance.

At this time, two areas remain of concern when adapting existing Arrhenius plots to Westinghouse equipment designs. First it must be demonstrated that the failure criteria used to obtain the plots apply to the designs. In some cases, these criteria may be very restrictive and conservatism can be claimed based on the actual tests. In other cases, where representative but not exact data is available, conservatism can be obtained by decreasing the projected qualified life. It may be necessary to conduct more tests with different failure criteria and obtain a plot for the actual application. Secondly, indefinite extrapolation of Arrhenius plots is not permissible and will be somewhat limited by the actual data points of the various plots. The limiting factor will be determined as part of the program and if it is felt that the projected life should be extended for economic reasons, tests on aged materials to extend the credibility of the Arrhenius plots will be considered.

As noted above, the projected qualified life will be determined by a conservative projection of Arrhenius plots and other available data. The results will be to recommend replacement of material to extend the projected qualified life of the system, recommend design changes to extend projected qualified life and to recommend component replacement as part of a maintenance program. Random component failures will be replaced as detected or as part of a normal maintenance schedule. The projected qualified life of a system will be the point in time when it is no longer practical or economical to maintain the system.

Seismic Qualification

Electronic equipment which is to undergo thermal aging simulation Westinghouse will seismically qualify the equipment in accordance with IEEE-344-1975(9). Methods used to derive multiaxis, multifrequency inputs will follow the latest versions of those outlined in Reference 10. As mentioned above, these methods were developed for the bistable tests performed as part of the supplementary qualifications program.

For electronic equipment whose aging characteristics will be reviewed by the Westinghouse Aging Evaluation Program and have been previously qualified, the results from single axis sine beat testing and the supplemental seismic testing discussed above will be used demonstrate acceptability to

IEEE-344-1975. For new equipment seismic qualification will be performed in accordance with IEEE-344- 1975.

Equipment Qualification Data Package

The Equipment Qualification Data Package (EQDP) provides a consistent format for documenting the performance requirements of individual equipment and the results of its qualification. Contents of the Data Package have been made to coincide with the documentation requirements of IEEE-323-1974. For each piece of safety-related electrical equipment Westinghouse will document the qualification results in the EQDP. Criteria and results documented in the Data Packages will also constitute interface requirements between Westinghouse and its customer. The requirements not only include those to insure that the environmental qualification conditions are not exceeded but also any periodic maintenance, component replacement, etc. required to maintain the qualification status of the equipment.

CONCLUSIONS

Westinghouse PWR-SD initiated qualification of safety-related electrical equipment prior to the issuance of the 1971 vintage IEEE qualification standards. This early testing combined with the supplemental testing programs performed in 1975 and 1976 have provided a sound technical basis for qualification upon which experience and state of art advances can be added. The issuance of IEEE-323-1974 and subsequent adoption of the standard by the Regulatory Authorities has required nuclear vendors and utilities to formulate plans for implementing this standard in order to avoid licensing delays. Although Westinghouse believes that adoption of this standard as a licensing requirement to be inappropriate due to the industry uncertainty on addressment of specific phenomena, Westinghouse has developed a program for implementing this standard. This program (Reference 13) is based on known qualification techniques and practical programs to evaluate known data as it is applicable and to generate data where it is required. However, the uncertainty associated with this standard and its ramifications should be remembered in guiding the development and implementation of new standards.

FOOTNOTES:

A. For a more complete discussion regarding the Demonstration Program Environmental Testing the reader is directed to "Qualification of Class 1E Transmitters" by I. Garber and R. B. Miller of Westinghouse, presented at the October 21, 1976 IEEE Nuclear Power Symposium in New Orleans, Louisiana, USA.

REFERENCES:

1. Title 10, Code of Federal Regulations; Appendix A to Part 50, "General Design Criteria for Nuclear Power Plants", Criterion 1 (Quality Standards and Records), Criterion 2 (Design Bases for Protection Against Natural Phenomena) and Criterion 4 (Environmental and Missile Design Bases), 1971.

2. IEEE-323-1974, IEEE Standard for Qualifying Class 1E Equipment for Nuclear Power Generating Stations, 1974.

3. IEEE-323-1971, IEEE Guide for Qualifying Class 1E Equipment for Nuclear Power Generating Stations, 1971.

4. IEEE-344-1971, IEEE Guide for Seismic Qualification of Class 1 Electric Equipment for Nuclear Power Generating Stations, 1971.

5. Nunno, J. J. et al; Calculation of Distance Factors for Power and Test Reactor Sites, TID-14844 March, 1962.

6. WCAP 7744, "Topical Report: Environmental Testing of Engineered Safety Features Related Equipment (NSSS-Scope)", J. Locante and E. G. Inge, August, 1971.

7. WCAP 7817, 7821, 8021, "Seismic Testing of Electrical and Control Equipment" (Low, High and High-High respectively), E. L. Vogeding et al, December 1971.

8. Westinghouse letter to U. S. Nuclear Regulatory Commission; NS-CE- 692 (C. Eicheldinger to D. B. Vassallo; July 10, 1975).

9. IEEE-344-1975, IEEE Recommended Practices for Seismic Qualification of Class 1E Equipment for Nuclear Power Generating Stations, 1975.

10. WCAP 8695, "General Method of Developing Multifrequency Biaxial Test Inputs for Bistables", S. J. Jarecki, September 1975.

11. Regulatory Guide 1.89, "Qualification of Class 1E Equipment for Nuclear Power Plants"; USNRC; November, 1974.

12. WCAP 8587, "Environmental Qualification of Westinghouse NSSS Class 1E Equipment", Westinghouse Staff, August, 1975.

13. WCAP 8587, Revision 1; "Methodology for Qualifying Westinghouse Supplied NSSS Safety Related Electrical Equipment"; W. G. Jordan, D. G. Lorentz, and R. B. Miller, September 1977.