RELATED CORRESPONDENCE

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UNITED STATES OF AMERICA
NUCLEAR REGULATORY COMMISSION

BEFORE THE ATOMIC SAFETY AND LICENSING BOARD

In the Matter of)
)
CAROLINA POWER & LIGHT COMPANY) Docket No. 50-400 OL
and NORTH CAROLINA EASTERN)
MUNICIPAL POWER AGENCY)
)
(Shearon Harris Nuclear Power)
Plant))

APPLICANTS' TESTIMONY OF RICHARD B. MILLER AND THOMAS W. DAKIN IN RESPONSE TO EDDLEMAN CONTENTION 9C (THERMAL AGING OF RTDS)

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Q.1 Please state your names.

A.1 Richard B. Miller and Thomas W. Dakin.

Q.2 Mr. Miller, are your address, present occupation, employer, educational background and professional work experience described elsewhere in the record of this proceeding?

A.2 (RBM) Yes. The relevant information is provided in "Applicants' Testimony of Robert W. Prunty, Peter M. Yandow and Richard B. Miller in Response to Eddleman Contention 9A (ITT-Barton Pressure Transmitters)."

Q.3 Please elaborate on your professional experience that is directly relevant to the testimony which you are presenting regarding thermal aging of RTDs at the Shearon Harris Nuclear Power Plant ("SHNPP").

A.3 (RBM) I have participated directly in the development of Westinghouse testing methodology which includes accelerated thermal aging. This involved discussions with research facilities and other industry sources to determine which method of accelerated thermal aging would be most appropriate for our programs.

Q.4 Dr. Dakin, please state your address, present occupation, educational background, and professional experience, including that directly relevant to the testimony which you are presenting regarding thermal aging of RTDs at the SHNPP.

A.4 (TWD) My business address is Westinghouse Research and Development Center, Pittsburgh, Pa. 15235. I am retired, but still serve as a consultant to Westinghouse. My advanced education led to an A.B., summa cum laude, in Chemistry at the

University of Minnesota in 1935, an M.S. in Physical Chemistry from Michigan State University in 1938, and a Ph.D. in Physical Chemistry in 1941 at Harvard University. I started as a research fellow in the field of electrical insulation at the Westinghouse Research Laboratory in 1941, advancing to a group leader in 1946, section manager about 1950, and Department Manager about 1965.

My research activities and the research activities of those reporting to me at Westinghouse concentrated on the electrical behavior and electrical and thermal aging of insulation both in service and in laboratory tests simulating service environment conditions.

My first important paper relating to insulation aging was published in 1948 in the Transactions of the American Institute of Electrical Engineers ("AIEE") under the title "Electrical Insulation Deterioration Treated as a Chemical Rate Process." That particular paper has been very widely referenced in the electrical journals. Starting about 1950 I participated in a variety of working groups and committees in the AIEE - (later to become the IEEE), to formulate accelerated aging test standards. I also presented and published papers relating to accelerated aging tests. Most if not all of the precautions regarding application of accelerated aging mentioned in the Sandia Report referenced in Contention 9C (NUREG/CR-1466, SAND 79-1561) and other precautions also were discussed in my papers. A partial listing of my publications, including papers dealing with thermal aging and accelerated life testing, is attached hereto as Attachment A.

I was elected a Fellow of the IEEE in 1968, received the Westinghouse Order of Merit in 1979, was awarded the first distinguished Technical Achievement Award of the IEEE Electrical Insulation Society in about 1980, and this year received an IEEE Centennial Medal of the Society. From 1968 to 1980 I was the principal U.S. representative in electrical insulation to CIGRE, the Conference International Grand Reseaux Electrique.

Q.5 What is the purpose of this testimony?

A.5 (RBM, TWD) The purpose of this testimony is to respond to Eddleman Contention 9C, which states:

> It has not been demonstrated that the RTDs have been qualified in that the Arrhenius thermal aging methodology employed is not adequate to reflect the actual effects of exposures to temperatures of normal operation and accidents over the times the RTDs could be exposed to those temperatures. (Ref. NUREG/CR-1466, SAND 79-1561, Predicting Life Expectancy of Complex Equipment Using Accelerated Aging Techniques.)

Q.6 Mr. Miller and Dr. Dakin, how is your testimony organized?

A.6 (RBM, TWD) Our testimony describes RTDs and their functions at SHNPP, and the Westinghouse RTD qualification program. It includes a discussion of the Arrhenius thermal aging methodology as applied in the environmental qualification of SHNPP RTDs. Our testimony also reviews the Sandia Report referenced in Contention 9C, NUREG/CR-1466, and presents our conclusions as to the applicability of that Report to the SHNPP RTDs.

Q.7 Mr. Miller, what is an RTD?

A.7 (RBM) An RTD, a resistance temperature detector, is an instrument used to measure temperature in which the primary element, a resistance wire, has a well-defined resistance-temperature relationship. The primary element in the RTDs used at SHNPP is a platinum wire. Signal conditioning equipment is used to detect and amplify changes in the resistance of the platinum element which correspond to changes in temperature. These RTD signals are used in plant instrumentation systems.

Q.8 What types of RTDs are used at SHNPP, how many of each type are used, and where are they located?

A.8 (RBM) The RTDs used at SHNPP are manufactured by the RdF Corporation. Eighteen Model 21204 RTDs are directly immersed in bypass lines to the reactor coolant system. There are three coolant loops at the SHNPP and these eighteen RTDs are used to measure the "hot leg" and "cold leg" temperature in each loop. These RTDs are directly immersed to provide rapid time response measurements for use in the reactor protection and control systems.

Six Model 21205 RTDs are installed in wells located in the reactor coolant system piping to provide measurement of the hot and cold leg temperature in each loop for use in monitoring plant conditions.

The construction of these two types of RTDs is almost identical. The primary difference is in the length of the sheath inserted into the piping system. (See Figures 1 and 2 attached hereto.)

Q.9 What safety functions do the RTDs perform?

A.9 (RBM) Six Model 21204 RTDs provide signals to the reactor protection system used for reactor shutdown functions. A setpoint based on a loop average temperature is compared to the difference in temperature between the hot and cold leg in the same loop to determine if a low Departure from Nucleate Boiling Ratio (DNBR) or overpower situation could be developing which requires corrective action. Six Model 21204 RTDs are installed spares for the reactor protection system. The remaining six RTDs are used for control functions.

The six Model 21205 RTDs provide the control room operator with information on plant conditions, such as those used in maintaining pressure-temperature relationships during plant cooldown.

Q.10 Describe briefly the construction of the RTDs, including any age-sensitive materials in the RTD assemblies.

A.10 (RBM) The complete RTD assembly, illustrated in Figures 1 and 2, consists of a platinum element contained inside the tip of a sheath, and the necessary wire and supports which allow connection to a cable system through which signals are transmitted outside the containment building. A stainless steel sheath protects the element and wire over that portion inserted in the pipe. A stainless steel bellows hose protects external wires from moisture penetration and physical damage. (A helium leak test assures the adequacy of the moisture barrier provided by the bellows hose.)

The portion of the RTD inserted in the primary system piping contains no age-sensitive materials. The organic materials in the external cable and cable interface are epoxy potting material and silicone varnish cable coating. The epoxy potting material is located to the right of the Swagelok nut in Figure 1 and to the right of the adapter and Inconel spring in Figure 2.

Q.11 Does the silicone varnish on the RTD cable lead perform a safety function?

A.11 (RBM) No. The silicone varnish is only used in the manufacturing process to prevent the fiberglass insulation on the cable from fraying during the manufacturing process. It is not required for the RTD to perform its safety function.

Q.12 Does the epoxy potting at the cable-probe interface perform a safety function?

A.12 (RBM) Yes. The safety function that the epoxy potting material at the cable-probe interface provides is that of mechanical support and insulation for the wires at this point.

Q.13 What is thermal aging?

A.13 (RBM) Thermal aging involves a temperature dependent chemical process that can lead to changes in properties of organic materials over a period of time.

Q.14 What is accelerated thermal aging, and why is it necessary?

A.14 (RBM) Since real time aging is not practical over the long time periods for which most electrical equipment must be environmentally qualified for nuclear power plant application, accelerated processes have been developed to simulate a defined life over a much shorter period of time.

Q.15 Is accelerated thermal aging addressed by current regulatory requirements?

A.15 (RBM) Yes. 10 C.F.R. 50.49(e)(5) requires that "[e]quipment qualified by test must be preconditioned by natural <u>or artifical (accelerated) aging</u> to its end-of-installed life condition." (Emphasis added.)

Q.16 Dr. Dakin, what is the Arrhenius methodology of thermal aging?

A.16 (TWD) The Arrhenius methodology is based on the premise that deterioration of materials in service is due to chemical reactions. These reactions occur internally, sometimes between components of the material and sometimes with compounds in the environment such as oxygen or water vapor. It is widely-known that chemical reactions occur more rapidly at increased temperature. Arrhenius in the last century showed theoretically that the temperature dependence of chemical reactions followed an exponential equation:

$$\text{rate} \sim \exp(-E/kT) \sim \text{a constant/time}$$

where T is the Kelvin temperature (degrees C +273);

E is the activation energy of the chemical reaction (electron volts); and

k is the Boltzmann gas constant (electron volts/degrees Kelvin).

The activation energy is characteristic of the material and the significant chemical change. This equation provides the theoretical basis for accelerated aging tests.

It is postulated that there is a consistent correlation between the amount of physical change and the amount of chemical reaction. Therefore the time to reach a selected amount of physical change will vary according to the Arrhenius equation, rearranged as follows:

$$\text{time to reach a specified change} \sim \exp(-E/kT)$$

Usually this equation is changed to the logarithmic form:

$$\mathrm{Ln}(\text{time}) \sim (-E/kT) = (-E/k)/T$$

and the logarithms of times to change are graphed versus reciprocal Kelvin temperature, as illustrated by Figure 3 (attached hereto), which is based on electrical tests of an epoxy resin laminate after aging. The quantity, E/k, is the slope of the graph. The value of E, the activation energy, ranges between about 0.5 to 1.5 electron volts depending on the material and the significant chemical reaction of interest. The times to reach a specified level of deterioration (in this example 50% of the original dielectric strength) are graphed. Such data are extrapolated down to expected continuous service temperatures to predict the time to reach the specified level of deterioration.

Other than actually testing materials and systems for the expected years of actual service, this is the most logical scientific way of predicting that they will be reliable. Usually accelerated type tests of materials are made extending up to one or two years. After the linearity of the Arrhenius graph is confirmed for a material, then short time more accelerated tests are acceptable to evaluate small changes in materials or application condition.

The electrical power industry has been very diligent in pursuing this type of testing to ensure reliability of new or improved materials and systems, and generally the experience has been excellent in confirming the predictions.

Q.17 Mr. Miller, has the NRC Staff approved the Arrhenius method for environmental qualification of electrical equipment in nuclear power plant applications?

A.17 (RBM) Yes. The NRC Staff, in Section 4(4) of NUREG-0588, "Interim Staff Position on Environmental Qualification of Safety Related Electrical Equipment," states: "The Arrhenius methodology is considered an acceptable method of addressing accelerated aging." Most recently, in Regulatory Guide 1.89 (Rev. 1), "Environmental Qualification of Certain Electric Equipment Important to Safety for Nuclear Power Plants" (June 1984), the Staff endorsed the use of this method. In addition, the Westinghouse qualification methodology described in WCAP-8587, "Methodology for Qualifying Westinghouse WRD Supplied NSSS Safety Related Electrical Equipment," has been accepted by the NRC. "Safety Evaluaton Report of Westinghouse Equipment Qualification Documentation WCAP 8587, WCAP 8587 Supplement 1, WCAP 8687 Supplement 2, and WCAP 9714: Seismic and Environmental Qualification of Safety Related Electrical Equipment" (November 10, 1983). The accelerated thermal aging techniques discussed in WCAP-8587 are based on Arrhenius methodology.

Q.18 Describe briefly how and for what period of time the RTDs for SHNPP were environmentally qualified.

A.18 (RBM) The overall RTD qualification program includes thermal aging, thermal cycling, irradiation aging, and vibration aging, as part of the preconditioning process. In addition to and following the normal thermal aging, the RTDs are temperature cycled to account for the effects of expected plant heatup and cooldown cycles. They are also exposed to radiation simulating normal operation and accident conditions as well as vibration simulating the effects of pipe and flow vibration. This generic preconditioning process simulates a minimum 20 year life for the RTDs installed in the bypass lines and a minimum 10 years for the RTDs installed in the wells. After this preconditioning the RTDs are subjected to the effects of a seismic event and a high energy line break environment.

Q.19 Please describe how the Arrhenius method was applied in the environmental qualification of the RTDs for SHNPP.

A.19 (RBM) Since the epoxy is the only safety-related age sensitive material used in the RTDs, the activation energy for this material was selected. Using the Arrhenius equations and the ambient temperature at the cable interface, an aging temperature was calculated which would simulate the desired life at an accelerated rate and not inadvertently degrade the material due to the high temperature alone.

Q.20 What is the ambient temperature at the cable interface to which the RTDs will be exposed during normal operating conditions, and how was it determined?

A.20 (RBM) The ambient temperature at the cable interface is equal to the normal ambient temperature in this region plus the expected temperature rise associated with heat transfer to this interface from the reactor coolant system. The normal ambient temperature surrounding the cable interface portion of the RTD assembly was determined by Carolina Power & Light Company to be 120°F (approximately 50°C). FSAR § 3.11.4.4. In addition, Westinghouse performed heat transfer calculations to determine the temperature rise expected at this interface which accounts for heat transfer from the reactor coolant system. The temperature rise will be limited to 50°C as long as a minimum air velocity is maintained. Therefore, using a normal ambient temperature of 50°C and the expected temperature rise of 50°C, the temperature to which the RTDs will be exposed is 100°C.

Q.21 What was the activation energy used to calculate the temperature to which the equipment was exposed during qualification testing and to calculate the time duration of the test?

A.21 (TWD) Since the epoxy performs structural and insulating functions, an activation energy of 0.98 electron volts was selected, which is consistent with these parameters. This selection of 0.98 electron volts was a conservative choice based on an examination of a large amount of test data on epoxy resin systems.

Q.22 Was the Arrhenius method used to simulate accident conditions as well as normal operating conditions?

A.22 (RBM) Yes, but only in the post-accident period. The first day following a high energy line break is simulated in real time and temperature. Following the first day of testing the remaining post-accident period is simulated by accelerated thermal aging. Westinghouse employs a standard accident profile which uses a conservative 0.5 electron volt activation energy to calculate the time/temperature relationship during this period. The RTDs were subjected to this generic profile.

Q.23 What were the results of the accelerated thermal aging portion of the qualification testing for SHNPP RTDs?

A.23 (RBM) After the accelerated thermal aging portion of the qualification test was completed, certain tests were performed. These tests were calibration checks at 32°F, 525°F and 625°F as well as insulation resistance measurements. No degradation of the RTDs was detected during these tests.

Q.24 Has the NRC Staff accepted Westinghouse's qualification testing of the RTDs used at SHNPP?

A.24 (RBM) Yes. As I indicated in response to Q.17, the Westinghouse qualification programs for electrical equipment, including safety-related RTDs, have been accepted by the NRC Staff on a generic basis. The NRC Staff specifically approved the qualification of RTDs. This generic testing envelopes the environmental conditions, including temperatures, for which the SHNPP RTDs must be qualified.

Q.25 Dr. Dakin, are you familiar with NUREG/CR-1466, entitled "Predicting Life Expectancy and Simulating Age of Complex Equipment using Accelerated Aging Techniques," first published by Sandia National Laboratories as a consultant's report to the NRC ("Sandia Report")?

A.25 (TWD) Yes.

Q.26 Please briefly summarize the Sandia Report.

A.26 (TWD) The Sandia Report discusses the application of the Arrhenius relation of temperature to aging much as I have outlined in answering Q.16. This report discusses the usefulness of the Arrhenius relation in accelerated aging tests but also discusses possible conditions which would invalidate the use of this relation for extrapolation from accelerated aging tests. The report points out the need for a single chemical reaction to control the aging of the material over the whole temperature range from accelerated test temperatures down to service temperatures. If, for example, moisture diffusion were controlling at lower temperatures, this would change the slope of the Arrhenius type graph to a lower slope and predict a shorter failure time than predicted by extrapolating high temperature tests. I have cautioned against such effects in several of my own papers from the first one on this subject in 1948 and later ones up to about 1960.

Q.27 Which type of testing does the Sandia Report primarily address, qualification testing or materials testing?

A.27 (TWD) This Sandia Report discusses primarily materials testing.

Q.28 In the materials testing of the epoxy used in the SHNPP RTDs, did the epoxy exhibit an Arrhenius dependence on temperature?

A.28 (TWD) Yes.

Q.29 What implications does this have for qualification testing of the RTDs?

A.29 (TWD) It indicates that the qualification test is a satisfactory confirmation of the long-term useful life of the epoxy resin.

Q.30 Do any of the "predictive difficulties" discussed in the Sandia Report apply to the epoxy used in the SHNPP RTDs?

A.30 (TWD) None of the predictive difficulties discussed in the Sandia Report applies because the insulation system of the RTD connector and cable is sealed against moisture, so that diffusion of moisture is prevented. Moisture diffusion is the only potentially invalidating condition, referred to in the

Sandia Report, that could apply to the accelerated thermal aging of RTDs. Further, epoxy resins are not known to be sensitive to moisture effects as was the polyurethane cited in the Sandia Report.

Q.31 Dr. Dakin, in your opinion, does the Sandia Report support in any way the allegation in Eddleman Contention 9C that the "Arrhenius thermal aging methodology is not adequate to reflect the actual effects of exposure to temperatures of normal operation and accidents over the times the RTDs could be exposed to those temperatures"?

A.31 (TWD) No. Indeed, the Sandia Report (at page 47) concludes that "[a]ccelerated aging techniques offer the best opportunity for predicting lifetimes or simulating life of complex equipment."

Q.32 What is your conclusion concerning the application of the Arrhenius method to the qualfication of the SHNPP RTDs?

A.32 (TWD) My conclusion is that the Arrhenius method is satisfactory for simulating the thermal aging of the organic materials in the qualification of the SHNPP RTDs.

Attachment A

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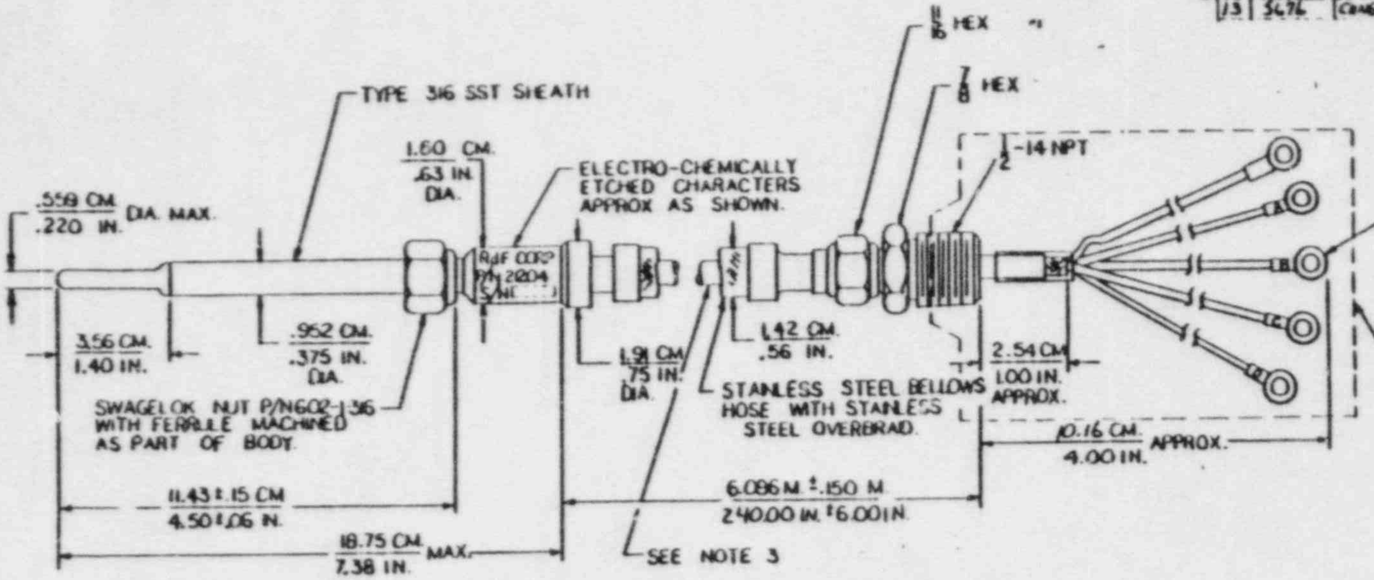
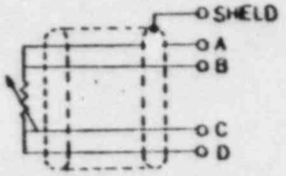
*Papers dealing with thermal aging and accelerated life testing.

REVISIONS				
SYM	ECR	DESCRIPTION	DATE	APPROVED
10	5276	REDRAWN & REV. .220 DIA MAX.	2-3-82	[illegible]
11	5517	18.00 WAS 4.00, 240.00 IN WAS 20 FT	[illegible]	
12	5624	CHG. SEALED ENCLOSURE WAS VAPORTIGHT	[illegible]	[illegible]
13	5676	CHG. LEAD LENGTH 4.00 WAS 18.00	[illegible]	[illegible]





SCHEMATIC DIAGRAM

RdF Corp.
23 Elm Ave.
Hudson, N.H.
DATA SUBMITTAL
Date DEC 8 1982

NOTES:

1) ELEMENT: REF. GRADE PLATINUM.

2) RESISTANCE: 200.15 ± 1.50 Ω AT 32°F.

3) 4 CONDUCTOR, #22 STRANDED NICKEL PLATED COPPER, MICA TAPE, INSULATED WITH GLASS BRAID. 304 SST OVERBRAID, MICA TAPE GLASS BRAID, SILICONE VARNISH IMPREGNATED OVERJACKET. CABLE IS PROTECTED BY A STAINLESS STEEL BELLOWS HOSE WITH OVERBRAID.

4) ACCEPTANCE TEST PER T-10350.

CONTROLLED DRAWING
Change only with
customer approval

3	2	1	PART OR IDENTIFYING NO	NOMENCLATURE OR DESCRIPTION	REF DESIG	MATERIAL OR NOTE	SPECIFICATION	ITEM NO
REQ'D PER ASSY								

LIST OF MATERIALS

UNLESS OTHERWISE SPECIFIED
ALL DIMENSIONS ARE IN INCHES
DO NOT SCALE DRAWING
REMOVE ALL BURRS AND BREAK ALL SHARP EDGES
TOLERANCES ON DIMENSIONS
XX ± .03 ANGLES ± [illegible]
XXX ± .010 FRACTIONAL ± [illegible]

DRAWN	[illegible]	4/3/82
CHECK		
ENGR	D.S.J.	[illegible]
APPROVED		

SURFACE ROUGHNESS PER MIL STD 10
MATERIAL
FINISH

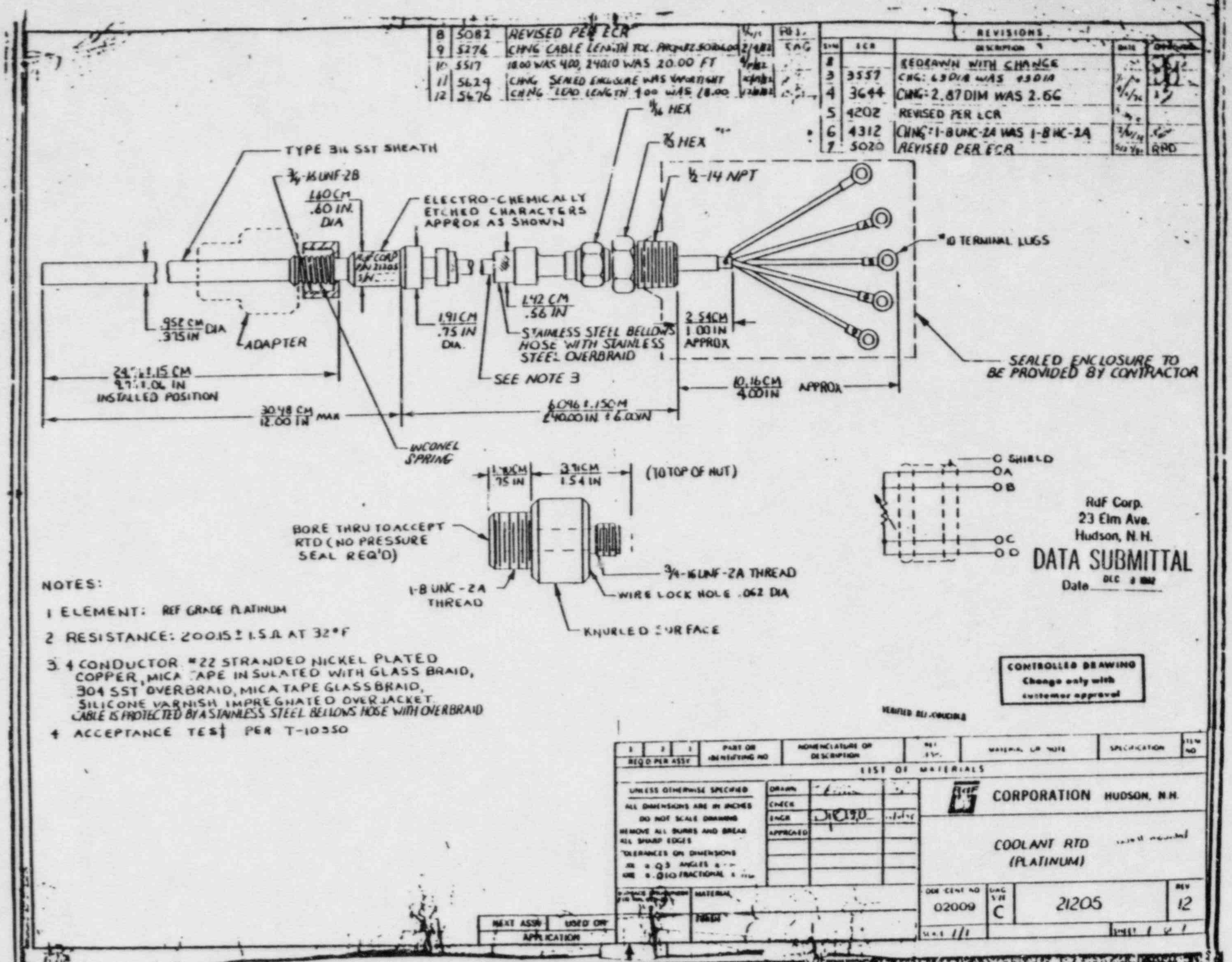
NEXT ASSY	USED ON
APPLICATION	

RdF Corporation HUDSON, N.H.

COOLANT BYPASS RTD
(PLATINUM) [illegible]

CODE IDENT NO	DWG SIZE		REV
02009	C	21204	13
SCALE 1/1		SHEET 1 OF 1	

Figure 1



SYM	ECR	DESCRIPTION	DATE	APPROVAL
8	5082	REVISED PER ECR		RBL
9	5276	CHNG CABLE LENGTH TOL. FROM ±2.50 FT TO ±.50 FT	2/1/82	SAG
10	5517	18.00 WAS 4.00, 240.00 WAS 20.00 FT		
11	5629	CHNG SEALED ENCLOSURE WAS VAPORTIGHT		
12	5676	CHNG LEAD LENGTH 4.00 WAS 18.00		

REVISIONS

SYM	ECR	DESCRIPTION	DATE	APPROVAL
1		REDRAWN WITH CHANGE		
3	3557	CHG: .63 DIA WAS .43 DIA		
4	3644	CHNG: 2.87 DIM WAS 2.66		
5	4202	REVISED PER ECR		
6	4312	CHNG: 1-8UNC-2A WAS 1-8 NC-2A		
7	5020	REVISED PER ECR		RPD

RdF Corp.
23 Elm Ave.
Hudson, N.H.

DATA SUBMITTAL
Date DEC 8 1982

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4 ACCEPTANCE TEST PER T-10350

CONTROLLED DRAWING
Change only with customer approval

VERIFIED RELIABILITY

REQ'D PER ASSY	PART OR IDENTIFYING NO	NOMENCLATURE OR DESCRIPTION	REF DES	MATERIAL OR NOTE	SPECIFICATION	ITEM NO

LIST OF MATERIALS

UNLESS OTHERWISE SPECIFIED
ALL DIMENSIONS ARE IN INCHES
DO NOT SCALE DRAWING
REMOVE ALL BURRS AND BREAK ALL SHARP EDGES
TOLERANCES ON DIMENSIONS
.XX ±.03 ANGLES ±
.XXX ±.010 FRACTIONAL ±

DRAWN
CHECK
ENGR
APPROVED

MATERIAL
FINISH

NEXT ASSY | USED ON
APPLICATION

RdF CORPORATION HUDSON, N.H.

COOLANT RTD
(PLATINUM)

CODE IDENT NO 02009
DWG SIZE C
21205
REV 12
SCALE 1/1
SHEET 1 OF 1

Figure 2

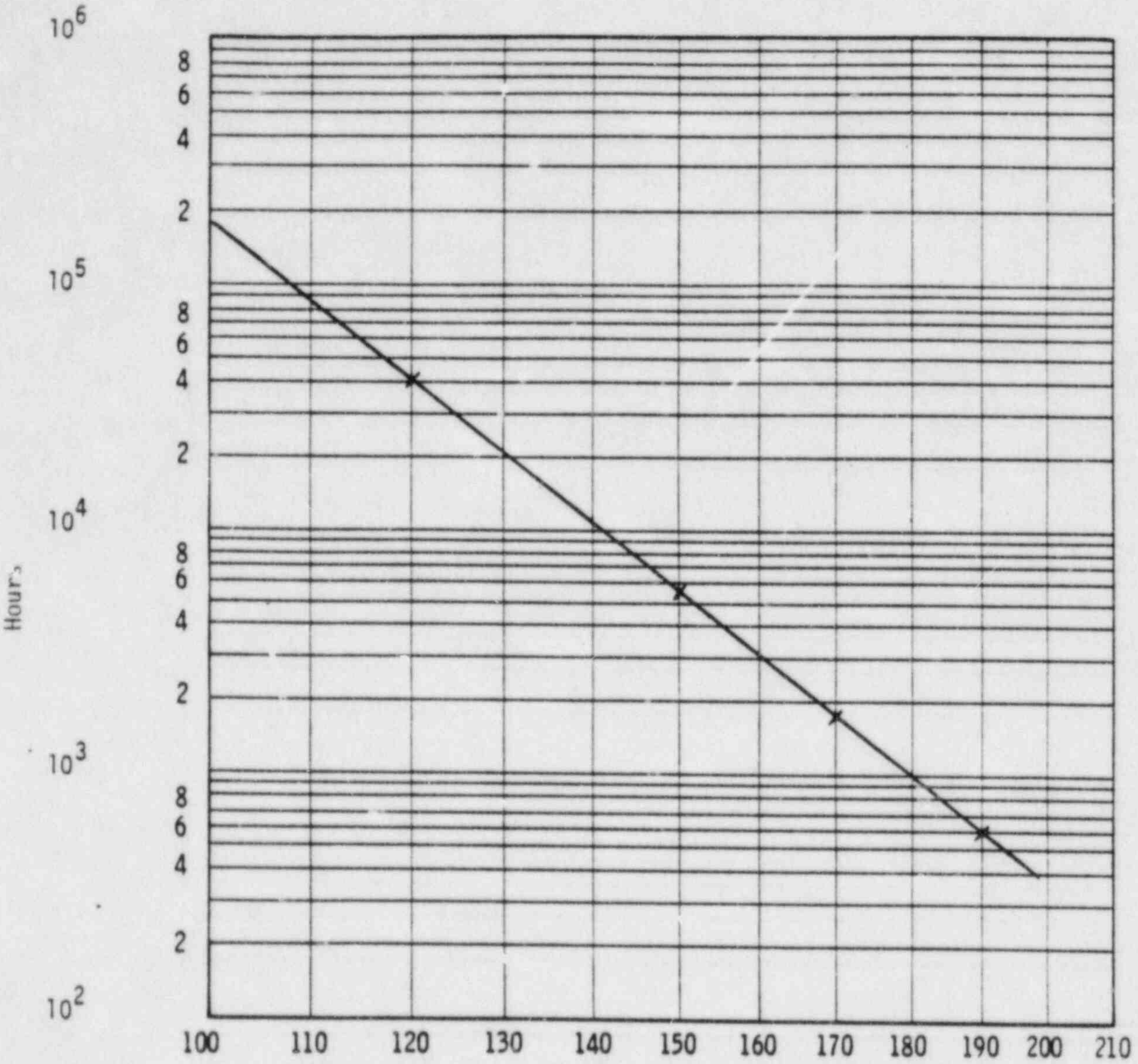

Figure 3. Time to Reach 50% Dielectric Strength of an Epoxy Laminate (Grade FR4, 1/16")

Data from UD-NEMA Report 821